Experimental Investigation and Optimization of Welding Process Parameters of Mild Steel Plate during Metal Inert Gas Welding

Takela kumela Debere

A Thesis Submitted to the Department of Mechanical Engineering

School of Mechanical, Chemical, and Materials Engineering

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

Office of Graduate Studies

Adama Science and Technology University

July , 2023

Adama, Ethiopia

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DECLARATION

I declare that this thesis entitled "experimental investigation and optimization of welding process parameters of mild steel plate during metal inert gas welding" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

<u>Takela Kumela Debere</u>	______________	______________
Name of Student	Signature	Date

RECOMMENDATION

I, the main advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "experimental investigation and optimization of welding process parameters of mild steel plate during metal inert gas welding" prepared under my guidance by **Takela Kumela Debere** Submitted in partial fulfillment of the requirements for the degree of Masters of Science in Manufacturing Engineering.

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

______________	______________	__________________
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APPROVAL SHEET

I, the advisor of the thesis entitled "experimental investigation and optimization of welding process parameters of mild steel plate during metal inert gas welding" developed by **Takela Kumela Debere**. Hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

____________________	________________	______________
Main Advisor	**Signature**	**Date**

We, the undersigned, members of the Board of Examiners of the thesis by T**akela Kumela Debere** have read and evaluated the thesis entitled "experimental investigation and optimization of welding process parameters of mild steel plate during metal inert gas welding" and examined the candidate during the open Defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering.

________________________ Chairperson	_____________ Signature	______________ Date
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________________________ External Examiner	_____________ Signature	______________ Date

Finally, approval and acceptance of the thesis is contingent upon the submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department by Graduate Council (DGC) and School Graduate Committee (SGC).

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___________________________ School Dean	_____________ Signature	______________ Date
___________________________ Office of Postgraduate Studies, Dean	_____________ Signature	______________ Date

ACKNOWLEDGMENT

I've had a lot of ups and downs in the process of finishing this thesis. I've met a variety of generous people, battled a lot, and triumphed in the face of adversity. And it was only because of GOD that I was able to have this experience and learn these life lessons. So, first and foremost, I'd like to express my gratitude to the almighty GOD for his unending blessings and lessons in my life. Dr. Moera Gutu my thesis advisor, deserve special thanks for his advice, support, and understanding throughout the thesis.

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Acronyms

AC	alternative current
AISI	America iron and steel institute
ANOVA	analysis variance
ASTM	American society for testing and materials
ASTM	America society for testing material
AWS	American welding society
CDI	composite desirability index
DC	Direct current
DOE	design of experiment
GMAW	Gas Metal Arc Welding
GTAW	Gas tungsten arc welding
HAZ	Heat affected zone
HRB	Rockwell hardness
HV	Vickers Hardness
MAG	Metal Active gas
MIG	Metal Inert gas
MMA	Manual Metal Arc
MS	Mild steel
MSS	Mean Sum of Square
OA	Orthogonal Array
S/N	Signal to Noise Ratio
SEM	Scanning electron microscopy
SST	Total sum of squares
SSTR	Treatment sum of squares
TIG	Tungsten Inert Gas
TS	Tensile strength
UTM	Universal testing machine
UTS	Ultimate tensile strength

ABBRIVATION

A	Ampere
b	width
D	diameter
Dg	composite desirability
di	individual desirability
et.al.	And others
L	length
t	Thickness
PT	penetrant test

ABSTRACT

Metal inert gas welding (MIG) is an arc welding process uses a consumable electrode covered with a coated wire to lay the weld. This welding process can be used for different material types. It was often used for light to heavy duty work involving iron and steel, like carbon steel, cast iron and nickel alloys. This study, has focused on the effect of MIG welding quality on tensile strength and hardness has investigated a design of experiment has low carbon steel in the case of Ethiopia. High dependability all position capability, the convenience of use of cheap cost and high productivity are the main benefit of employing metal inert gas (MIG) for surface among all methods. This process is extensively used procedure for joining mild steel, alloy steel and other metal. The parameters like welding current, welding voltage, welding speed and welding angle) affected mechanical properties (tensile and hardness test, bead geometry, and microstructural properties of mild steel AISI4130welded metal using Taguchi methods. for each case sixteen welded test sample were generated using Taguchi orthogonal array design and variety welding condition. These AISI4130 materials were commonly used in industrial application such as roller sprocket, gear shaft, machine component and general engineering products. As a result, the above MIG welding parameters for weld quality of welded were optimized in the study using Taguchi based desirability function analysis and other tools like analysis of variance (ANOVA)technique by Minitab 17 software. Those test was used to evaluate the welding defect of both welded sample and the same specimen are defect free for both welded samples employing AISI 4130 respectively, the microstructure of weld metal produced consists of a skeleton e-ferrite in an austenite matrix from the result of optical microscopy. The tensile strength experimental results revealed that welding current, followed by welding speed, was a highly significant parameter for tensile strength. Weld metals had higher hardness than base metals, this was supported by the fact that the Vickers's hardness tests in both cases had hardness greater than a base for fusion zone and heat affect zone respectively and that no crack was observed in the weld metal. Vernier calipers can be used to measure the dimensions of the beads. The quality of the welded junction is determined by the bead dimensions. With all combination of welding process parameters, the butt joint was selected. Based on conducted experiment the most significant control parameter was welding current with maximum contribution of 44% whereas welding speed was the second parameter with 35% contribution. At optimized welding parameters; the maximum tensile strength was 761Mpa. The maximum optimal hardness value of welded joint was 409HV and weld beads joint was 7.1mm from desirability function analysis result. As conducted by liquid penetrant test; the welding defects (porosity, under cut, lack of penetration and others) were observed on sample number 1 and 7 whereas samples numbers are relatively defect free which was welded with optimum welding parameters. Percentage of tensile improvement of welded metals was 63% with a parametric setting of (A1B4C2D3) and percentage of hardness improvement 33.7% confirmation test results in agreement with the predictive optimum setting result this was in agreement with predictive optimum setting value.

Keywords: *Multi-response optimization, MIG welding, mild steel, welding quality, Taguchi methods.*

CHAPTER-1

INTRODUCTION

1. 1. Background

Welding is a system in which two similar or dissimilar metals or nonmetals are joined by applying pressure or non-pressure, it is exceptionally utilized for becoming a member of metal Components in manufacturing processes, when there are wishes to be part of portions together or more substantial lengths of trendy sections are required to fabricate the preferred structure Generally, welding is the technique of joining a member of metals and plastics besides using adhesives or fasteners. Welding is the method of applying heat and pressure to the surface unique substances such as polymers, metals, and alloys to manipulate the everlasting joining of the process. Metal inert gas welding (MIG), also known as Gas Metal arc welding (GMAW), is an arc welding process that creates an electric arc using a consumable electrode, it was created for the duration of WWII, Welding of difficult-to-weld materials like AISI 4130, Mild steel, alloy steel and black steel became possible because of this discovery The heat affected zone is within the bottom metal itself and it's a microstructure different from that of the bottom metal before welding because it's been temporary subjected to elevated temperature during welding the portions of the bottom metal don't undergo any microstructure changes during welding as they're far enough off from the warmth source and much lower temperature to which they're subjected. During the welding process some portion of the metal achieves the liquid state while the encompassing material suffers from the influence of the diffused heat. As result, three main regions are distinguished within the weld microstructure: the bottom metal, the weld metal and also the heat affected zone. is mostly some millimeters in width, possesses an inhomogeneous microstructure accompanied with a steep gradient on mechanical properties as result a study of weld metallurgy is extremely important because the mechanical properties, of weldment are determined by the characteristic properties of individual microstructure present within the weld deposit and also the weld heat affected zone (Yadav et al. 2016).

Nowadays, it is typically used for welding hard-to-weld metals such as Mild steel and black sheet metal. MIG welding is most, in many instances, used to weld thick sections. Rakesh Kumar and Satish Kumar discussed the influence of various welding parameters like current, arc voltage, welding speed and welding angle on the mechanical properties during the MIG welding of steel grade 4130.The microstructure, hardness and sturdiness of the welded specimens are investigated during this study.

MIG Welding: - is a system in which two similar or dissimilar metals or nonmetals are joined by applying pressure or non-pressure, it is exceptionally utilized for becoming a member of metal

Components in manufacturing processes, when there are wishes to be part of portions together or more substantial lengths of trendy sections are required to fabricate the preferred structure. Metal inert gas welding (MIG) is an arc welding process in which a continuous solid wire electrode is fed through a welding gun and in to the weld pool, joining the two base materials together. Shielding gas is also sent through the welding gun and protect the weld pool from contamination.MIG welding gives high quality welding with the coalescence of heat generated by an electric arc established between a filler wire and the base metal, that Welded area is protected by shielding gases like carbon dioxide Narrow weld joint can be used on MIG welding and steel secure around weldment. Metal inert gas welding was smallest heat affect zone , less grain growth ,less distortion and less temper .MIG are less smoke and fumes so operator environment improve MIG was welded all position of welding, little slag and low spatters Generally, welding is the technique of joining a member of metals and plastics besides using adhesives or fasteners AISI 4130 mild steel plate used for all industrial applications requiring more wear resistant and strength Welding is the method of applying heat and pressure to the surface unique substances such as polymers, metals, and alloys to manipulate the everlasting joining of the process It was excellent weld ability and ductility making ideal project such as bridges, body of car and manufacturing structures . It was observed that the HAZ was more prone to corrosion showing severe pitting corrosion as compared there to of the underside metal. AISI 4130 mild steel was good atmospheric corrosion resistance and reasonable strength .it is good overall combination of strength, toughness and fatigue strength. the most implementation area was structural steel, some are notable application such as manufacturing equipment, bearing, pulley, gears, vehicle parts and crushing machinery. Mild steel widely used in manufacturing industry, it was cheeps and applicable and suitable for cutting coating methods and good weld ability while provide good enough for properties. AISI4130 mild steel is commonly applicable high quality structure material machine components like shaft, pulley, sprocket, gear, pipe, tankers and rollers, pins, structural steel and automobiles, machine body, tankers, and fencing processing equipment parts are some examples of typical applications.

Weld ability: mild steel plate offers very good weld ability, and the additional alloying elements in mild steel also makes strengthening them a cost-effective option for many welding applications is used for somewhat greater strength will still having a good ductility. machinability of 4130 steel is quite good, rating against the standard steel of 100 % machinability 4130 steel has good ductility and it is readily formed by standard methods

M.A.Bodude which i.Momohjimoh used OAW and SMAW techniques to influence of the amount of heat which was supplied to measure the mechanical properties of low carbon steels. Hardness, impact energy and enduringness of the welding portion are calculated (Haragopal et al. 2011). Constructed a replacement design for input process parameters to optimize the varied mechanical properties of mild steel, Aluminum alloy, used for construction of aerospace wings. Pressure, current, groove angle and pre-heat temperature are considered as process parameters. Process parameters were assigned for each experiment. Investigated employing a series of electrochemical and mechanical tests to grasp the behavior of MIG welded and un welded. It was observed that the HAZ was more prone to corrosion showing severe pitting corrosion as compared there to of the underside metal. When the welded specimen went off from the weld center the hardness also increased and torsion welded specimens were broken at the HAZ suggesting softness of this area due to the impact of MIG welding.(Sapakal and M.T.Telsang et al. 2016) investigated the influence of welding parameters like welding currents, welding voltage, welding speed on the penetration depth of mild steel during welding by using Taguchi design method. Result showed that the welding current had large impact on the penetration depth. discuss the micro structural development during MIG welding of copper with iron filler Metal Inert Gas Welding of mild steel plate such as carbon steel is attainable to keep appropriate mechanical and metallurgical properties, MIG welding is handy to control, fumeless, and spatter less clean method wants minimal finishing or now and again no finishing, MIG welding gives outstanding welding with the coalescence of heat generated through an electric arc between a tungsten wire and the steel (Journal et al. 2016)(Surjeet Singh et al., (2016) Shielding gases like carbon dioxide protect the weld area, MIG welding process is used to weld material with a consumable tungsten wire. The wire is either made of pure tungsten or alloy blended with small amounts of oxides (copper or alloy) to enhance the arc's steadiness and make it less complicated to strike, the wire is linked to an imperative energy source, and shielding fuel is also employed via a welding gun (Chakrabarty et al. 2021)(Nadu and Nadu 2020).

The work pieces to be joined are melted at the faying surfaces during welding, and a permanent joint can be formed after Solidification. In some circumstances, a wire material Creates a liquid weld pool that solidifies to establish a strong link between the components. The weld ability of a material is influenced by metallurgical changes during welding, such as variations in hardness in the weld zone due to rapid solidification, the degree of oxidation induced by materials reacting with atmospheric oxygen, and the tendency of crack formation at the joint position. Carbon dioxide are employed as shielding gases since they do not react chemically, and the purpose of inert gas is to keep the welding area free of contaminants (Kumar et al. 2016).

MIG welding can also be used for welding with manually and automatic applied wire, like gas welding. MIG welding mechanical tools are used in applications such as connecting tubes and welding tubes to final plates of heat exchangers. These automatic welding tools can incorporate many advanced features, including the mechanical supply of filler wires. Melting the edges of the components to be soldered is used to apply welding, which is done without the use of external pressure. This group includes various traditional fusion welding methods such as gas tungsten arc welding (GTAW), shielded metal arc welding (SMAW), gas metal arc welding (GMAW)(Hameed Majeed, Esmaeel Radhi, and J. Abid 2021).

Submerged arc welding (SAW), and flux-cored arc welding (FCAW), all of which can be used to Weld dissimilar metal combinations. However, fusion welding of various metals comes with a slew of challenges (Serindağ et al. 2022) (dos Santos Paes et al. 2022). These issues stem from metallurgical incompatibility issues, such as the production of brittle phases, the separation of high and low melting phases due they studied the effect of process parameters like welding speed and heat input on the penetration depth. They revealed that the penetration depth increased with an increase in speed up to an optimum value of 1450 mm/min. Shape factor also increased with an increase in welding speed up to 1450mm/min. Depth of penetration also increased with an increase in input up to an optimum value so decreased with an additional increase in heat input. Investigated the mechanical properties and microstructures of the welding joints by optical Microscopy, Rafael Garcia applied the metallurgical characterization of APIx65 steel joint welded by MIG welding process with axial field. APLx65 was heat treated in nonconventional due to improve the resistance produced mechanically. It absolutely was discovered that with the applying of an external axial flux during welding, the defects that were normally produced without the applying of flux were eliminated. These defects include porosity and lack of lateral fusion to call some. The mechanical properties of joints within the presence of magnetic fields were improved. The toughness of the welded joints in presence of magnetic fields was also improved. They grain refinement zone with within the microstructure within the weld bead and significant reduction of porosity because the explanations for these kinds of observations. k. Srinivasan and V. Balasubramanian studied the effect of hat input on fume generation and joint properties of Gas metal arc welded Austenitic stainless steel (AISI 4130) plates. They also studied the mechanical properties (strength, hardness and toughness) and applied the micro structural analysis of the weld deposits. They finally concluded that the FGR and fume percentage show a directly proportional relationship with the feed rate of GMAW. Shekhar Srivastava and R.K Garg] tried to test the effect of various process parameters on welding of IS 2062 plate using GMAW with a copper coated mild steel wire of 0.8mm diameter. They obtained various results like bead width, bead height and depth of penetration using Response surface methodology.to chemical mismatch, and potentially others.

1.2. Overview of MIG welding

Welding is a type of arc welding where a consumable wire electrode and an inert gas, also called shielding gas as feed through the welding gun an arc is struck between the end of the wire electrode and work piece MIG welding. An electric arc can be created between a tungsten wire electrode and a work piece using this power, as shown in Fig 1.

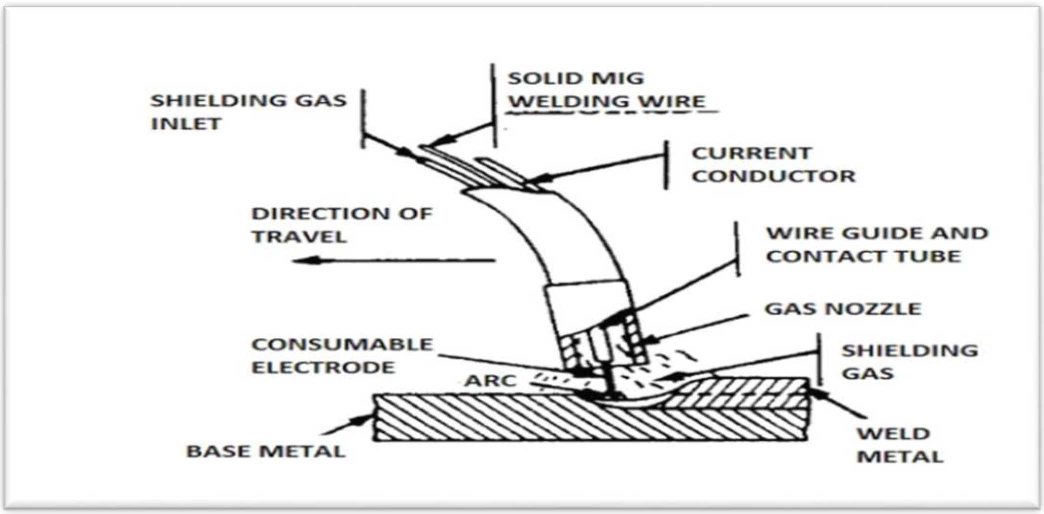


Figure 1. 1. Principle of MIG Welding

AISI 4130 mild steel plate used for all industrial applications requiring more wear resistant and strength. Carbon steels are category of steel with 0.25 to .30 carbon content, AISI 4130 is mild steel designed to be able to function in areas requiring greater strength and hardness. This steel possesses excellent size accuracy, concentricity, and straightness which together enable to minimize wear in highly applications. AISI 4130 can be formed into turned, ground and polished bar that can be machined unsymmetrically with limited distortion (Tlbo-anfis 2021). According to the researcher the process is used primarily to weld iron and steels (including stainless steel) but aluminum, nickel and copper alloys can also be welded with this method. The base-metal thicknesses that can be welded using the SMAW process generally range from 1.6 mm to a large unlimited thickness. The thinner materials require a skill welder, tight fit-up, and the proper small-diameter welding electrode.

MIG welding are used on applications such as industrial sheet metal welding, deep groove welding and welding tubes to final plates of heat exchangers. The main uses of MIG welding are tick metal welding such as plate and low carbon steel plate welding, and high carbon welding. It is also suitable for welding connections and different positions, are capable those are, good bead, lower spatters and easy to learn except for alloy of aluminum. Additionally, MIG welding is more suitable for thick materials from about 0.5 mm to about 5 nm. In contrast, MIG welding cannot compete with methods such as short arc welding in terms of productivity.

1.3. Equipment of MIG welding

The main required types of equipment comprised for MIG welding are as follows:

- Power source
- Wire feeder
- Grounding cable
- Welding gun
- Optional liquid cooling unit
- Shielding gas

1.4. Joining method of metals

The intricate functionality of many current industrial applications necessitates the use of different metals for connecting. Multiple material combinations are being employed for various goods as the maker seeks to maximize production and operational costs, improve mechanical and thermal qualities, and create lightweight solutions for sectors such as shipbuilding, aviation, and automotive industries, construction industry, machinery industry and materials industry can be joined using a variety of approaches.

The following are the key approaches employed in industrial applications and in creating the research topic:

A. Fusion,

B. Pressure welding

A. Pressure Welding Methods

Welding takes place at a temperature lower than the melting point off the metal being welded. External pressure can be used to solid-weld the two components together, as long as the pressures are high enough to generate spindle reactions in the surfaces of the two parts to be linked (Lu etal., 2010).

For welding, of different metals, friction welding, gas welding, pressing, explosion welding, ultrasonic welding, and other methods are utilized.

b. Fusion Welding methods

Melting the edges of the components to be soldered is used to apply welding, which is done without the use of external pressure (Trailer, 2016; Walak et al.,2012). this group includes various traditional fusion welding methods such as gas metal arc welding (GMAW), shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), submerged arc welding (SAW), and flux-cored arc welding (FCAW), all of which can be used to weld different types of metal combinations. However, fusion welding of various metals comes with a slew of challenges (Chaudhari ct al., 2020; Kah and Jukka Martikainen, 2013), These issues Stem from metallurgical incompatibility issues, such as the production of brittle phases, the separation of high and low melting phases due to chemical mismatch, and potentially other

1.5. Research motivation

In today's production industry, quality is the most important factor. According to some sources, quality is defined as customer satisfaction when delivering a purchased product. Product quality in various application areas is determined by the requirements attained in the product that meet your functional needs. In the welding area, welding quality has a significant impact on welded metals' mechanical and microstructural properties. On the other hand, the weld's quality is determined by the welding process parameters. Many process parameters can control the mechanical characteristics, weld bead shape, weld chemistry, and metallurgical aspects of the generated weld in a complicated way, resulting in direct or indirect impacts (Greyjevo & Metodo, 2019). Welding process factors, in general, have a significant impact on mechanical and microstructural qualities, as well as weld bead shape. Various researchers experimented by considering some common process parameters such as welding current, welding voltage, and welding speed. Other process variables, such as welding current and welding speed, however, have a considerable impact on mechanical and microstructural qualities. Because the chemical and physical properties of materials differed when the base metals to be welded were welded metals, the filler metals utilized compromised this difference. The gap between the roots was also a key determinant in weld penetration, which has an impact on mechanical properties. So, design and production flexibility is substantially needed by the possibility to design new products utilizing various metal and alloy combinations (filler wires). And optimizing the finished properties of a product, such as mechanical, microstructural, and corrosion and beat resistance, while managing its cost, ate a motivation for similar and dissimilar metal welding.

1.6. Statement of the Problem

Controlling welded product quality is challenge due to selection of appropriate welding process parameters such as welding current, welding voltage. Welding speed and welding angle and etc. In this project MIG welding has popular application in many industries for which it is mandatory to get good welded quality. The most significant challenge for using mild steel as structural material is low strength after welding is involved. Since high-temperature fusion process causes microstructural changes which in adverse effects mechanical properties of the welded protect. Manufacturing companies like Ethio-industry have most common problems faced by manufacturer was to control welding process input parameters to obtain a good welded joint with required quality such as high strength, low porosity. However; there were problems welded qualities such as undercut, slag inclusions, lack of penetration and spatters are several times found during quality inspections of finished products. Hence; the process requires sufficient control parameter to provide the required welding quality by controlling welding current to describe the electricity that jumps across the arc gap between end off wire electrode with work piece, the wire speed and voltage. In this thesis research problems were addressed by conducting experiments and optimizing process parameters and their effects on mechanical strengths in mild steel welding using MIG process in Ethiopia.

1.7. Research Questions

a) What are the optimum welding parameter setting for welding mild steel metals and what are the most significant MIG welding parameters?

b) In what conditions was the best welding quality achieved for both parameters?

c) How to Investigating microstructure of weld heat affected zone and compare with parent metal?

1.8. The objective of the study

1.8.1. General objective

The main objective of this study is to get high quality welded mild steel by controlling welding process parameters and investigation welding defects during metal inert gas welding on mild steel plate.

1.8.2. Specific objective

The following specific objectives were formulated to get the stated general aim of the study:

1. Determination of the regulating welding parameters has the most significant impact on weld quality.
2. Analysis of welding metallography using optical microscopy to study microstructure.
3. Investigation of welded joint mechanical properties like tensile strength and micro- hardness
4. Investigation of welding quality and welding defects using fluid penetrant methods.
5. Weld bead geometry determination like weld width.
6. Response Optimization in a Multi-Response Parametric Setting for welding process parameters.

1.9. Significance of the Study

MIG welding investigation to determine the effect of welding parameters on mechanical properties in a welding operation of metals plates with quality welded joint results in the product having excellent mechanical properties (tensile strength and hardness), resulting in increased product lifetime and profit.

The thesis has the following significance:

- ❖ This study proposes a method for conducting an experimental analysis and Parametric optimization of metal inert gas welding parameters while welding of AISI 4130 mild steel metals.
- ❖ The thesis focuses on bits that can assist preserve greater mechanical qualities in but weld joints, increase product lifetime, improve weld quality, and eliminate welding defect in welded joints.

Finally, the thesis can be used as an input for defect-free weld, resulting in improved weld quality in strength, hardness and good bead welds.

1.10. Scope and limitation of the Study

The thesis was focused on investigation MIG welding quality on mild steel using design of experiment and its associated welding parameters that effect of welding current, welding voltage, welding speed, and welding angle type during the welding of mild steel plates. Mechanical properties such as tensile strength (UTS), hardness strength (HV) were utilized to analyze the MIG welded metals. Finally, this thesis examines and optimizes the effect of welding parameters on the welding quality.

- By identifying the most significant welding parameters and optimizing which parametric
- Set best welding quality was achieved during welding of mild steel plate metals.
- Metallographic analysis using OM to study microstructures of mild steel
- This study focused on the experimental investigation of MIG welding parameters for
- Welding quality and welding defects were determined using visual inspection and fluid penetrant technique (PT).

1.11. Structure of the Thesis

The thesis consists of five chapters:

Chapter One: Begins with an intention to introduce the overall background of the study, an overview of MIG welding, mild steel plates welding techniques, thesis questions, objectives, the problem statement, the significance of the study, and scopes of the study.

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

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

Chapter Four: The results and discussion of the experimental values are covered in this chapter. It investigates the impact of process parameters on the quality of MIG welded parameters metals. And keeping the parameters settings in optimum condition.

Chapter Five: It is the final chapter that summarizes the thesis done and proposed the recommendation and future work for further studies.

CHAPTER - 2

LITERATURE REVIEW

2.1. Introduction

The effect of process factors on weld quality is explained in a massive volume of material available in journals and books. This chapter examines the research works by addressing weld, mild steel plate pasteurization of weld, parameter optimization, mechanical characteristics, welding bead, hardness test, tensile strength welding and, and welding procedures to know and get the work direction. During 0ptimizing, the difference in welding parameters between the base metals creates tensile stress in one and stress in the other. The metal deposited under tensile stress may experience hot cracking during welding or porosity cracking during service if the stress is not released. This is critical in recirculation applications where the seal must operate at high temperatures. Many weld-related problems are associated with junctions despite the numerous metals joining applications. As a result, extra attention must be paid to welds to reduce or eliminate faults throughout the welding process. The composition and characteristics of the weld metal are the most important factors to consider when MIG welding mild steel metals. They are determined by the compositions of the base and wire metals, as well as their relative dilution and mutual solubility. The relative dilutions and compositional gradients close to each base metal affect the solidification characteristics of similar junctions. When it comes to the warm crackling of the joint during solidification, the solidification attribute is the most important (Chaudhari et al., 2020; Kah & Jukka Martikainen, 2013).

To determine the existence of mutual solubility in MIG welding of dissimilar metals, it is necessary to examine and understand the phase diagrams of the metals involved. Combinations with mutual solubility can be successfully mated if the two base metals are not mutually soluble, and filler metal soluble with both similar base metals can be added. Mutual solubility between the several metals that define the joint's characteristics, such as crack sensitivity, ductility, and corrosion, is used to create the intermetallic compound (IMC) of the final weld metal's microstructural composition (Chaudhari, Loharkar, and Ingle 2020). Melting temperature is an important consideration when MIG welding different metals. There is a lot of heat involved, and one of the base metals' melts faster than the other at the same temperature. Significant variations in melting temperatures between the base metals or the filler metal can cause the metal with a lower melting temperature to rupture. Because the base metal is weak and partially solidified, the solidification and contraction of the metal with a higher melting temperature causes strains in the metal with a lower melting temperature.

Buttering the filler metal with an intermediate melting temperature can be employed to solve the problems caused by discrepancies in the melting temperatures of the base metals (Kah and Jukka Martikainen 2013).

2.2. Thermal Conductivity

When welding metals with significantly different thermal conductivity, the heat source must provide a thermal differential for proper thermal equilibrium. The heat conduction rapidly from the molten weld pool to the base metal, base metal with higher thermal conductivity takes away the thermal energy and affects the energy input required to melt the base metal locally. Thus, the heat source is always directed towards the metal with higher thermal conductivity to balance the heat. Preheating the base metal with a higher thermal conductivity can control heat loss to the base metal and reduce the cooling rate of the weld metal zone (WZ) and the heat-affected zone (HAZ) (Chaudhari et al., 2020; Kah & Jukka Martikainen, 2013). A heat affected zone (HAZ) of a weld is that a part of the welded joint which has been heated to a temperature up to solids of the parent material leading to varying degree of influence on micro structure which may lead to change in mechanical properties as a consequence of heating and cooling cycle. The temperature distribution around a metallic arc butt the vanguard of the temperature pattern is compressed, because the arc is continually moving cold metal and edge becomes extended because the leaves preheated metal in its wake.

A part of HAZ which is heated to beyond the critical temperature of grain growth and extend up to the fusion boundary zone is named grain coarsened heat affected zone (HAZ). During this region, adjacent to the fusion boundary, the first microstructure has been reaustenitised at temperatures and retention times sufficient for marked grain growth to occur. The austenitic grain size attained will vary per variety of things like distance from the fusion boundary, being greatest immediately adjacent thereto. Weld energy input, as a function of peak temperature and relative retention time. Original grain size: under the non-equilibrium conditions, finer austenite grain sizes may result from finer microstructures. Steel compositions, particularly with relation to the presence of refractory carbides or nitrides which are difficult to dissolve within the available times scale at heat have also effect during this region. Finer austenite grain sizes may result from finer original microstructures. Steel compositions, particularly with relevancy the presence of refractory carbides or nitrides which are difficult to dissolve within the available timescale at extreme temperature have also effect during this region.

2.2.1. Coefficient of Thermal Expansion

During cooling, the difference in thermal expansion coefficients between the base metals creates tensile stress in one and compressive stress in the other. The metal deposited under tensile stress may experience hot cracking during welding or cold cracking during service if the stress is not released. This is critical in recirculation applications where the seal must operate at high temperatures (Chaudhari et al., 2020; Kah & Jukka Martikainen, 2013).

Under are some of the studies that focus on Welding dissimilar metals**.** Using DOE Taguchi and ANOVA methodologies (Kausar 2019) analyzed and studied the weld quality parameters of tungsten inert gas welding on different metal plates IS 4130. Process parameters such as current, voltage, and speed and angle are chosen, and weld quality is determined by tensile strength, hardness, and microstructure. The findings demonstrate that voltage has the most significant impact on stiffness, followed by the gas flow and current. And the most important parameter is tensile current, followed by voltage and speed. The optimum parameters for hardness are 130 (Amp) current ,(80) speed (24Volts) voltage, and (30) degree angle, while the optimum parameters for tensile strength are 130 (Amp), 24 (Volts), and 80 (min/sec). Good flow indicates that the connection is vital when it comes to microstructures.

The Analysis and Experimental Investigation of Weld Characteristics for MIG Welding on Metals on MS4130 was examined by (Vennimalai Rajan et al. 2020). Tensile strength, hardness, and bend tests inspected the weld quality. The results showed that the tensile strength was 507.902 N/mm2 at a peak load of 49.880 KN, the bending strength was 31.213 N/mm2 at a peak load of 3.140 KN the Rockwell hardness was 78kgf.

Satputaley et al., (2021) evaluated the influence of MIG welding on maximum tensile strength for 4130 Chromoly and 7075T6 aluminum in an experimental investigation. The results demonstrate that Chromoly 4130 has a weld strength of 396.69 MPa, the same as Al 7075T6, resulting in poor weld mechanical properties and poor welding performance. Al 7075T6 has low weld penetration when used for high-strength applications. MIG welding on Chromoly 4130 produces great weld penetration without compromising the material's characteristics.

Anbarasu et al., (2020) used mild steel (IS 2062) as the base material and super Duplex ER70-3 as the filler material to investigate the effect of filler material on the hardness of MIG welds. Materials can be created by selecting current, welding speed, and gas flow as process parameters. The Taguchi method of the L9 orthogonal network was used to conduct the test. Micro-hardness and microstructure are two of the weld quality metrics. Finally, their inquiry came to this conclusion. As the welding speed increases, the hardness improves with good surface morphology. A welding current of 130 A, a welding speed of 80 mm/min, and an voltage of 24 liters/min should increase hardness.

Using the MIG welding process**,** (Sayed et al. 2019) conducted a review paper on different metal welds in stainless steel and mild steel. They concluded that to optimize welding output such as strength, tensile strength, hardness of welds, etc., by different input parameters like welding current, voltage, gas flow, welding speed, etc. Hazari et al., (2019) performed an experimental investigation on MIG welding on ms 4130 by selecting welding current, electrode diameter, and speed. The weld's final quality was validated by ultimate strength and hardness. The maximum tensile strength increased dramatically as the amperage was raised, but the yield strength improved significantly. By increasing the effectiveness of the shielding gas, the ultimate tensile strength increases according to the gas flow rate. (The diameter of the filling material changes little; nevertheless, material soldered with a 2.5 mm diameter filler shows a significant difference.)

Sewa Singh et al., (2019) Select process factors such as welding lines and airflow in different heating circumstances to develop similar and dissimilar welding efficiency in towing gravity loads experimental surveys. To ensure maximum pull resistance, the materials utilized in the study are ASME SA 213 GR. T11 and BS 3059: 1987 PT 1 ERW 320. The results reveal that a similar ASME SA 213 Gr. T11 weld produces a maximum tensile strength of 601.63 MPa when welded at 110 A with a 10 L/min inert gas flow and no preheating. When warmed to 150 °C before welding, BS 3059:1987 PT1 ERW 320 showed a maximum tensile strength of 544.17 MPa at 110 A current and 10 l/min inert gas flow. The tensile strength of the material is at its highest.

Kumar et al.,(2017) used the Taguchi technique to investigate the experimental investigation of MIG welding of stainless steel 4130 and stainless steel 410. Current, voltage and welding speed are all considered process characteristics, and the final tensile strength determines the quality of the weld. The primary impact graphs revealed that current, gas pressure, and welding speed were the significant influencing elements on the ultimate load. With a welding current of 130 A, voltage 24, and a welding speed of 80 mm/s, the ideal parameter setting for the ultimate tensile strength of 808.3 N/mm2 was determined experimentally.

Devakumar et al., (2016) investigated GTAW welds in duplex stainless steel and hot-rolled steel (DSS / HRS) by characterizing the weld microstructure, examining the micro composition part using power dispersive X-ray evaluation (EDAX) to determine metallurgical properties and micro hardness test, tensile test, and bending test to determine mechanical properties. In contrast to the DSS parent metal, which has long grain austenitic with ferrite, and the HRS parent metal, which has long grain austenitic, the results show the production of a triangular ferrite microstructure. The DSS/HRS weld is more efficient with fine ferrite grain. The creation of the dendritic delta ferrite microstructure appears to be the result of energy-dispersive X-ray analysis (EDAX).

Kumar et al., (2016) used the Taguchi technique for MIG and TIG welding to investigate the welding features of AISI 4130 . they discovered that when welding austenitic stainless steels using the MIG method, the hardness value (BHN) at 130A for MIG is 162.3 and 196.54 for MIG. As a result, he concluded that the MIG technique is appropriate for low currents. He also concluded that the MIG welding pattern could sustain a final load of 57600N, whereas the MIG welding pattern can withstand 56160N. As a result, the MIG welding pattern can withstand more load than the MIG welding pattern.

2.3. Characterization of Welded joints

The characterization of MIG-welded metal joints has been the subject of much research. They primarily focus on microstructure qualities, mechanical properties, and the impact of various input parameters on weld quality. Cores-columnar grains are common in weld fusion zones because of the prevailing heat conditions during weld metal solidification. As a r *with all combination of welding process parameters the butt joint was selected. Based on conducted experiment the most significant control parameter was welding current with maximum contribution of 63% whereas welding speed was the second parameter with 35% contribution. At optimized welding parameters; the maximum tensile strength was 671Mpa. The maximum optimal hardness value of welded joint was 409 HV from desirability function analysis result. As conducted by liquid penetrant test; With all combination of welding process parameters the butt joint was selected. Based on conducted experiment the most significant control parameter was welding speed with maximum contribution of 63% whereas electrode diameter was the second parameter with 35% contribution. At optimized welding parameters; the maximum tensile strength was 761Mpa. the maximum optimal hardness value of welded joint was 409HVfrom desirability function analysis result. As conducted by liquid penetrant test; the welding defects (porosity, under cut, lack of penetration and others) were observed on sample* result, weld mechanical characteristics and resistance to hot cracking are frequently compromised. The quality of welded joint is usually controlled by the solidification behaviors of the welded metal. It manages weld metal microstructure, grain structure, mechanical properties, etc.

Arora et al., (2020) used the Taguchi technique to investigate the mechanical and morphological properties of inert tungsten gas welded IS4130 tick metal likes ,mild steel carbon steel pipe joints, selecting important parameters such as welding speed, welding current, and shielding gas flow rate. Micro-hardness, the breadth of the heat-affected zone, residual stresses, and microstructural characteristics were used to assess weld quality. The hardness of the weld bead decreases with maximum welding current and low welding speed, and the optimal settings for minimal Hardness and minimum HAZ are current (90A), speed (2mm/s), and gas flow rate (5 L/min), according to the results. In this case study, minimal welding heat input resulted in the development of equiaxed grains, whereas high input resulted in dendrite formation. It has also been.

Moslemi et al., (2015) used welding currents of 80, 90, 100, and 120 to investigate the effect of current on mild Steel Welded Joint Characteristics, including Microstructure and Mechanical Properties (A). Tensile testing, Hardness (HV), and Metallographic inspection assessed the welding quality. As a result of the findings, it was discovered that.

- ✓ The maximum tensile strength, achieved from 130A, was 761 MPa.
- ✓ The specimen with the highest hardness value among the specimens was 130A, indicating that 130A is the best MIG arc current for this material to achieve a satisfactory weld joint.

The breadth and depth of the weld pool are increased as the welding current is increased. *With all combination of welding process para With all combination of welding process parameters the butt joint was selected. Based on conducted experiment the most significant control parameter was welding speed with maximum contribution of 63% whereas electrode diameter was the second parameter with 35% contribution. At optimized welding parameters; the maximum tensile strength was 761Mpa .The maximum optimal hardness value of welded joint was 409HV from desirability function analysis result. As conducted by liquid penetrant test; the welding defects (porosity, under cut, lack of penetration and others) were observed on sample number 1 and 7 whereas samples numbers are relatively defect free which was welded with optimum welding parameters.*

Lakshminarayanan et al., (2009) investigated the effects of welding procedures such as shielded steel arc welding, gas metal arc welding, and gasoline tungsten arc welding on the tensile and impact properties of ferritic stainless steel according to the AISI 409M standard. Compared to shielded metallic arc and fuel steel arc welded joints, gas tungsten arc welded ferritic stainless metal joints have superior tensile and affect homes, primarily due to more refined grains in the fusion sector heat-affected quarter. The experiment Optimization of 4130 mild Steel Weld Joint Characteristics Using Taguchi Technique was carried out by (Bharath and Sridhar 2014). Current, speed and welding speed have been found to influence the material's tensile and bending strength. According to the results of the analysis of variance (ANOVA), welding speed (46.51 percent contribution) has a more significant impact on bend strength, whereas current (96.75 percent) has the greatest impact on tensile strength. Furthermore, root gaps have influenced both tensile and bend strengths due to changes in weld materials and grain sizes formed during the welding process.

2.4. Optimization of Different MIG Welding Processes parameters

Process parameter optimization is important in the welding process because it helps to determine the best process parameters for a high-quality weld while also reducing the number of trials. As a result, choosing the right MIG welding process parameters and setting them at the right values is critical for getting the best mechanical characteristics and bead shape (Ayoola, Suder, and Williams 2019; Choudhary, Kumar, and Unune 2019). Researchers are constantly developing statistical models to correctly optimize the welding process and produce higher-quality welds. Experimental Analysis and Optimization of any welding procedure is difficult due to the high cost, time commitment, and numerous interconnected aspects that must be considered (Ruggiero et al. 2011). Optimization is considered after several investigations on the parameter. By selecting the influential parameters (welding current, welding speed, and filler diameter and welding voltage), (Natrayan, Anand, and Kumar 2020) explored the optimization of process parameters in MIG welding of AISI 4130 mild steel using the Taguchi technique. The material they chose was AISI 4130 mild steel, which was welded using the MIG welding method, and the final weldment quality was confirmed using the tensile strength. The results suggest that welding speed is a more important parameter than welding current or wire diameter, according to the ANOVA results. The welding current at level 1 (250A), weld speed at level 3 (5mm/sec), and wire diameter at level 3 (3.6mm) are the optimal process parameters for tensile strength. Pardeshi, (2020) used the DOE Taguchi technique to investigate the parametric study of the MIG welding parameter for SS316L steel. Welding current, voltage, and gas flow rate are process parameters, whereas Bending and Tensile tests are response variables. The welding current was shown to be the most influential parameter in tensile strength, followed by voltage and GFR. It can also be seen that voltage has the greatest impact on bending strength, followed by GFR and welding current. The best input process parameters for tensile strength during MIG welding are 65A current, 25V voltage, and 16 lit/s gas flow rate, while the best input process parameters for bending strength are 60A current, 25V voltage, and 16 lit/s gas flow rate.

Moi, et al., (2019) used three influential process parameters (welding current, welding angle and welding speed) to perform experimental work on the Design Optimization of the MIG Welding Process for AISI 4130 mild Steel. Under the work, they looked at Ultimate Tensile Strength, hardness, and Weld Width as response variables. In addition, the weldment's microstructure is studied. That is demonstrated by the results of their experiment.

- ✓ The most important element impacting TS is gas flow rate, with welding current and welding speed coming in second and third place, respectively.
- ✓ In the case of weld width, welding speed is the most important component to consider.
- ✓ Welding speed and GFR both have an equal impact on impact strength.

The weld metals with moderate heat input exhibit very fine skeletal δ-ferrite and with low heat input exhibit dendritic lathy δ-ferrite structure in a simple austenitic matrix. The optimum welding combination for optimizing all the responses simultaneously obtained by desirability function approach is current =130 A, speed =80 cm/min and welding voltage = 24 cm/min, and predicted UTS = 761.55 MPa, impact strength = 50.87J and weld width = 7.26 mm.

Moi, Rudrapati, et al., (2019) examined the Impact Behavior of MIG Weldments on IS 4130 using Hybrid RSM and CSO. Welding Current, Speed, and welding angle are the process parameters for maximal impact strength. The most important element impacting impact strength, according to the findings, is welding speed. The welding voltage and welding current are the next two important parameters to consider. Welding current = 130 A, welding speed = 24 cm/min, welding voltage= 80 welding angle, and matching impact strength = 51.62J were the optimal parametric settings predicted by the CSO algorithm. By using gas flow rate, welding current, and welding speed as process factors**,** (Mohanavel, Ravichandran, and Suresh Kumar 2018) studied their findings on the optimization of tungsten inert gas welding parameters to achieve optimum impact strength in AA6061 alloy joints using Taguchi Technique. The welded joint's quality was tested using the maximum impact strength. The test results revealed that the welding angle is the most important factor affecting weld joint impact strength, followed by welding speed and welding current. Welding Current: 130 A, welding voltage: 22L/min, and welding speed: 70 mm/sec were found to be the best level combinations for optimum impact strength.

The Experimental Investigation and Optimization of MIG Welding Parameters on metal 4130 Alloy Using Firefly Algorithm was studied by (R. Kumar et al. 2017). Welding Current, welding speed, and Current polarity were chosen as parameters, with Ultimate tensile strength as the response parameter. At 175A welding current, 9 l/min gas flow rate, and current polarity, the maximum value of ultimate tensile strength is 137.104 MPa (0). And, according to the firefly algorithm, the optimal value of UTS is 98.896 MPa, which is a combination of welding current 150A, the gas flow rate of 10 l/min, and polarity of -1.

Wahule & Wasankar, (2018) used Grey Relational Analysis to perform an experimental study on Multi-response Optimization of Process Parameters of MIG Welding for Metals (IS Fe-4130) and found that the optimum value for tensile strength was 120A of the current, welding speed 80,, and mm of voltage parametric set. ANOVA revealed that the largest contribution was 47.38 percent of current, with a speed of 37.95 percent and a voltage of 14.67 percent following. 120A of current, 16L/min of gas flow rate, and 1mm of root gap were found to be the best values for percentage elongation. The highest contribution, 62.88 percent, came from current, followed by gas flow rate, 24.08 percent, and root gap, 13.04 percent, according to ANOVA.

Moi et al., (2018) found that the determination of Metal Inert Gas Welding Input Parameters to Attain Maximum Tensile Strength Of 4130 Austenitic mild Steel is affected not only by NTS but also by UTS, and that welding current and welding speed are important factors in this regard. The weld metal has a greater micro hardness rating than the HAZ and base metal. Welded joints have been proven to have higher tensile strength than base metals.

Sanjay Kumar et al., (2017) used Taguchi's Analysis and Response Surface methodology to optimize MIG welding process parameters. They concluded that voltage is the most important factor in hardness and bending strength. The highest hardness was obtained with the (A2B3C1D1) parametric set at 70 A (2nd level of current), 50 V (3rd level of voltage), and 0.5mm (1st level of root gap), and 16 liter/min (1st level of gas flow rate). The largest bending strength, on the other hand, is found at the (A2B1C1D3) parametric configuration, which includes the 2nd level current, 1st level voltage, 1st level root gap, and 3rd level gas flow rate. According to the results of the ANOVA, voltage is the most influential factor in modifying the temperature.

Gupta, (2016) experimented with Optimizing Conditions for Performing GMAW (MIG) Welding on Ultra 4130 Specimens and found that when the current was varied while the gas flow rate was kept constant, the welding joint was not produced below 120A and above 200A, and the specimen began to burn.

Patil & Waghmare, (2013) conducted an experimental study on MIG Welding Parameter Optimization for Improving Welded Joint Strength. They concluded that welding speed has a considerable impact on the tensile strength of welded connections. To improve welding settings, a Taguchi orthogonal array, the signal-to-noise (S/N) ratio, and analysis of variance (ANOVA) were used.

By selecting process parameters such as welding current, welding speed, and electrode distance, (Pasupathy and Ravisankar 2013)investigated the Parametric Optimization of MIG Welding Parameters Using the Taguchi Method for similar Joint. Strength was used to test the weldment's final response. Finally, the results of the work demonstrate that the experimental value obtained from ideal welding conditions is 61.37 MPa, with an S/N ratio of 16.45.

By considering advanced speed, welding amperage, and preheating temperature, (Salehpour-Oskouei et al. 2021) explored the Experimental Investigation of metal Inert Gas Welding Input Parameters Effects on Mechanical Characteristics on SS316. The study's reaction output was distortion and tensile strength. The results reveal that increasing amperage reduces welding component strength due to plate edge burn defects, which can be mitigated by increasing welding speed and lowering the influence of intense heat on the edges. Finally, the optimal conditions of the adjustment parameters in butt-welding were gained among existing samples for welding 316 stainless steel by examining the effect of the input parameter on the output.

Maneiah et al., (2019) conducted an experimental investigation on MIG Welded Butt Joints of metal Alloy 2061-T6 to Determine Tensile Strength at 30°, 45°, and 60°. The results revealed that the tensile specimens were tested in a variety of heat treatment techniques, including annealing, water quenching, and heat treatment without heat treatment. The highest strength, 109 MPa, and the highest percent elongation, 5.6 percent, exhibit better ductility upon annealing, welded at a 60°-degree angle. Without heat treatment, the strength reached 100 MPa when welded at an angle of 30° degrees. As a result, heat treatment techniques and weld angles have an impact on the weld joint's strength and tensile qualities.

Surjeet Singh et al., (2016) used MIG welding to test the tensile strength of IS 4130 at various process parameters such as current, voltage, and shielding gas flow rate. To produce a Tensile strength response, AA 4130 and AA 4047 were employed as filler materials. When the current is increased from 80 Amp to 120 Amp, the tensile strength increases by 4.5 percent on average. When compared to AA 4047, AA 4043 produces better results.

Anand Rao & Deivanathan, (2014) used MIG process parameters such as current, filler materials, and welding speed to conduct an Experimental Investigation for Welding Aspects of Stainless Steel 310 for MIG welding. The quality of a weld is determined by its mechanical and microstructural qualities. Welding current 120A and electrode 309L achieved tensile strength of 454.6MPa, according to the results. A welding current of 80 A with an electrode of 316L, on the other hand, resulted in a specimen with a minimum tensile strength of 51.79 MPa. The welding current of 120A with electrode 316L produced a maximum bending strength of 646.55MPa in the bend test, while the same welding current with electrode 347 produced a minimum bending strength of 211.37MPa for the specimen studied. The tensile and bending strength of the 309L filler material has improved. Microstructure images show that 309L has prominent second phase formation because of varying chromium percentage retarded transformation and uncontrolled heat input.

Experimental Research on Gas Metal Arc Welding of mild Steel-An Overview was conducted by (Devakumar and Jabaraj 2014). Low heat input is recommended when welding AISI 4130 mild steel sheets of steel using the GMAW process to ensure good tensile strength and elasticity. In comparison to the weld metal and base metal regions, the heat-affected zone and grain coarsening obtained in the weld joint are less, and the hardness is less in the HAZ region. The GMAW technique achieves an enhanced strength value of roughly 10% for SMAW joints and 20% for GMAW joints. In addition, as the current is increased, the Bowing distortion increases.

2.5. Some studies on Weld geometry

Welding process factors have a big impact on weld bead geometry variables, and they're also important for determining welding mechanical qualities including tensile, hardness, and bending. Using process parameters such as welding speed, welding current, and gap-width, (Ondieki, L. N. A. M. C., & Odhong 2021) investigated an Experimental Investigation of MIG Welding Parameters in Butt- Joint Configuration of Mild Steel by DOE technique. Penetration depth, bead width, heat-affected zone, and ultimate tensile strength were used to evaluate weld quality. The Welding Current was discovered to be an important factor in the heat energy input equation that determines the weld joint quality parameters. Low welding currents reduce heat-affected zones, but they impair weld penetration depth and weaken the tensile strength of the joint. Increases in welding current result in an average or complete depth of penetration, which has a favorable effect on the joint's tensile strength. Metal spatter, porosity and severe weld penetration are all problems caused by excessive welding currents. MIG weld creation with good or excellent quality requires a current of 100Amps-140Amps.

Panwar & Kakirde, (2021) used relevant characteristics such as welding current, voltage, and welding speed to perform an Experimental Investigation of the metal Inert Gas Arc Welding Process Parameter of Mild Steel. Weld width, weld penetration, HAZ breadth, depth of HAZ, cross-sectional weld area, and arc spread are all used to assess weld quality. According to the findings, increasing the welding current from 50 A to 90 A increases the bead width, and increasing the welding current from 50 A to 90 A also increases penetration.
It has been noticed that as the welding speed is increased from 14 mm/min to 44 mm/min, the bead width begins to drop. The penetration in the weld joint is greater at a lower speed, such as 14 mm/min, and it is lower at a higher speed, such as 44 mm/min.

Kumar et al., (2021) conducted an experimental examination on Inconel 625 pulsed MIG welding utilizing several fluxes, including Al2O3, TiO2, and V205. Penetration depth, bead width, and ultimate tensile strength were used to evaluate the joint's quality. Full penetration was not obtained in any welding trials, according to the results. Maximum penetration was achieved using the V205 flux. When V205 was utilized as a flux, the depth of penetration increased by 0.3 mm. When Al203 was employed as the flux material, the ultimate tensile strength was achieved. When Al203 was employed as the flux material, the tensile test was raised by 12%.

Using Groove Angle (Degree), Root Face (mm), and Root Gap (mm) as process parameters, (Kailas A. Gite & Ramkisan S. Pawar 2016) calculate the Effect of Welding Geometry Parameter on Hardness for AISI304 MIG. The test's response parameters were tensile strength and microhardness, which they obtained from the results.

- It has been noticed that as the groove angle increases, so does the hardness.
- Micro hardness is also reported to decrease when the root faces approach 1.5 mm. After then, the micro hardness rises to 1.5 mm to 2 mm.
- As the root gap widens, so does the hardness of the soil.

- MIG welding gave a higher micro hardness of 236 Hv at 60 groove angle, 1 mm rib thickness, and 1.5 root gap.

P. Singh & Singh, (2014) used the TAGUCHI technique to choose the parameters, current, gas flow rate, and several passes for an Experimental Investigation of the Deposition Rate of MIG Welding of Grade 316 Stainless Steel. Responses such as metal deposition rate and weld bead hardness tests were used to assess weld quality. According to the findings, the number of passes is the most important factor in Stainless Steel (SS316) welding, followed by current and gas flow rate, for deposition rate, and gas flow rate is the most important factor, followed by no of passes and current, for hardness as the reaction.

2.6.MIG Welding on Mild Steel

Various trials and research on the MIG welding technique on mild steel have been conducted, considering the grades and process parameters. Following are some research and experimental experiments' used the DOE approach to investigate GMAW welded ER70-3 plates with shape memory alloy as a filler wire. They used process factors including welding current, welding speed, and tip plate distance. Tensile strength and ferrite number are the response variables, and the model is optimized with the help of a design expert. Finally, it was discovered as a result of the study. Tensile strength was shown to increase as welding speed and welding current (amp) were increased. With increased welding speed (mm/min) and welding current, the ferrite number was shown to decrease. The 10 best solutions and stabilizing runs demonstrate the optimization of the chosen design. Between the model and the test runs, the average error percentage was lower than the similarity.

Saha, (2020) evaluated the effect of MIG welding parameters on welded joints made of stainless steel , considering process parameters including current, gas flow rate, speed, and filler rod diameter. The TAGUCHI method was used to plan the experiment, and the quality of the weld was assessed using tensile, hardness, and depth of penetration tests. The ideal parameter combinations for ultimate tensile strength and hardness differed only in terms of current for optimum UTS, according to the findings. It was necessary to use a greater current (180 amp) a lower current value (150 amp) was, on the other hand, ideal for optimum hardness. However, higher current resulted in improved DOP (Depth of penetration), hence the best UTS combination (A3B3C2D3) was chosen. Using optimum welding settings, the tensile strength improved from 515 MPa to 556 MPa, resulting in a 10.56 percent increase in joint strength. Using optimum welding settings, the hardness improved from 92 HV to 100 HV, a 7.36 percent increase in hardness.

Sanjay Kumar et al., (2019) used ANOVA to experiment with the effect of welding parameters on MIG-welded joints. The influencing parameters were (Voltage, Current, speed, and Root Gap), with AISI 4130 mild steel as the basis material. The test was carried out using the butt-welded TIG welding process, and the tensile strength of the weldment was used to determine the weld's final quality. The results of the test revealed that:

- The tensile test demonstrates that the UTS and elongation of all the samples are comparable to the base metal. As a result, the resulting joint has good mechanical qualities.
- The response value graph shows that current is the most influential parameter in the case of tensile strength. The highest tensile strength was attained at the highest current level (80 A). The voltage at its first level, i.e. (24 V), is the next moving issue, followed by the Root gap (1.5mm R) at its second level, and GFR (18 liter/min) as the fourth satisfying issue.

Mandavia, (2017) used the Design of Experiment Taguchi approach to explore the Experimental Investigation of MIG Welding for Stainless Steel 304, considering process parameters such as current, groove angle, and welding speed. The study's output reaction was Distortion. The welding speed is the most influential parameter for distortion, followed by groove angle and current, according to the results.

Rohit et al., (2017) conducted an Experimental Analysis of MIG Welded 304 Stainless Steel Using the Artificial Intelligence Tool, concluding that the research reveals the successful use of AI-based on the Adaptive Neuro-Fuzzy Inference System for the prediction of the tensile strength of MIG-welded AISI 304 stainless steel specimens, with the obtained results indicating the accuracy over another prediction concept. The specimen's average tensile strength is 638. 5185MPa. However, given the comparable process parameters of voltage 12V, welding current 50A, gas flow rate 12litre per meter, and speed 1mm per minute, the maximum tensile strength obtained is 664MPa.

By selecting current, welding voltage, and gas flow rate as welding parameters, (Jeevahan et al. 2016) evaluated the effect of welding current, voltage, and gas flow rate on welding properties of MIG-welded IS 4130 material. Tensile, hardness, and impact tests are used to assess the quality of welded joints. Finally, altering the welding current, welding voltage, and gas flow rate improves the welding properties.

- Tensile strength is increased at 160-200 amps, 60-90 volts,
- Hardness strength is higher at 180 amps, 70 volts, and 5 L/min.
- Impact strength is stronger at 180 amps, 60 volts, and 4 L/min.

Ghadi & S., (2016) used a complete factorial design to explore the Analysis of MIG Welding Process Parameters for Stainless Steel . The process parameters chosen were current, gas flow rate, and filler wire diameter, and the weld joint was evaluated using tensile, bending, and hardness tests. The results reveal that a combination of high current and inert gas flow rates combined with a smaller filler wire diameter yields the highest tensile strength. Maximum bending strength is achieved by combining low current and smaller diameter with a greater inert gas flow rate. Low current, low inert gas flow rate, and smaller diameter offer the harness maximum toughness.

Ramachandran, (2015) carried out an experimental analysis and investigation of weld properties for IS 4130 MIG welding. He determined that welding factors such as welding current, voltage, and gas flow rate have a substantial effect on the weld joint after executing numerous destructive and non-destructive tests. For this amp and voltage, the highest penetration depth is achieved with the least amount of failure.

By considering conduction, radiation, and convection effects during both air and inert gas flow rates, (Akbari Mousavi and Miresmaeili 2008) investigated experimental and numerical studies of residual stress distributions in the MIG welding process for 36L stainless steel. The experiment was carried out with a thermo-elastoplastic constitutive equation and the X-ray diffraction method. According to the findings of the investigation,

- The tensile residual stress peak recorded for the u-grooved configuration is lower than expected for the v-grooved configurations. The estimated residual stresses match the results of the X-ray diffraction investigations quite well. It is further demonstrated that when mechanical limitations are introduced, the amplitude of the transverse residual stresses nearly triples.
- In addition, the confined structure has less Distortion than the unconstrained form. The kinematic and isotropic hardening constitutive equations provide the best agreement between residual stress distributions and X-ray tests.

The exposed root gap in the butt-welded metal exhibited below is due to a lack of full penetration. During the welding process, this gap can be allowed to allow for a better, stronger weld than the base metal. The section of the gap that isn't filled can attract moisture and corrode faster than the rest of the system this part is part of. The welded part of the material has poor strength and is a site of failure if it is not fully penetrated. The illustration below demonstrates a weld that failed because of a lack of full penetration.

Metallurgical and mechanical properties of HAZ

Metallurgical characteristics of the weld metal similarly further as heat affected zone (HAZ) are important because this directly influence the weld mechanical properties and joint performance. It's well respect to distributions of pearlite, ferrite, and grain size counting on the weld condition adopted. In pass of the welding touch, the material 1s rapidly heated to the utmost temperature and allowed to relax more slowly by conduction of heat into the bulk of the parent metal. Phase changes can occur looking on the temperature reached. Sufficiently removed from the weld pool, the material remains unaffected (Srivastava, S., Garg, R.K. (2017).

The region next the fusion zone where microstructure changes have occurred but no melting of base metal are sick with heat generated because of welding process. Such microstructure changes can affect the mechanical properties of the weld and want to be controlled. At lower energy input (i.e. with low level of current), the time for solidification may be a smaller amount. The rapid cooling promotes smaller grains. With higher energy input, the time required for solidification decrease, and thus cooling rate slows down which yields coarse grain. Coarse grain within the microstructure indicates lower hardness and low strength. Mechanical properties are important characteristics of the weldment that ought to clarify to the applying feasibility also as functional requirement of the welded joint. These include hardness, yield strength, ultimate strength, percentage elongation, resistance to wear and corrosion etc. these mechanical properties greatly depend upon weld microstructure, which in turns is expounded to cooling condition, composition of base metal, wire electrode yet as flux. Moreover, welding process parameters also, I prove direct/indirect influence on weld mechanical properties and microstructure. Examined the implications of two fluxes of various basicity's when used with two experimental wires and a Columbia bearing base plate, the flux basicity was seen to possess an impression on the transfer of harden ability element of the weld deposit and on the result and microstructure and impact properties. Quantitative image analysis was accustomed document the effect of flux basicity on microstructure and non-metallic inclusion found that filler material and flux composition in MIG would influence the expansion of austenite consideration. It does demonstrate that the notch toughness of the course grained HAZ decreased with increased in energy input. They also found that stress relieving reduced the notch toughness of both the weld metal and HAZ as results of embrittlement caused by carbide precipitation (Saskatchewan, July 2016).

The other paper provides some information to accommodate form of the important mechanical properties and described style of the innovative treatment under development for the assembly of upper welds or for the exploration of welding technologies in novel.

Finally, the results showed that the micro shear test method is additionally developed as a supplement test method investigated the effect of coarse initial grain size with varying heat input on microstructure and mechanical properties of weld metal and heat affected zone. it absolutely was concluded that the coarse initial grain size had an exquisite influence on the microstructure, hardness and tensile of HAZ of low steel. The investigators recommended the next heat input to induce maximum toughness of the HAZ within the welding grain-coarsened low steel, taking into consideration the plate thickness an experiment made with all weld metal deposited with various varieties of electrodes and reported the role of varied alloying elements like manganese, carbon and chromium on the tensile properties, hardness yet as within the microstructure of MIG weldment. The experiment suggested criteria for selecting the weld metal composition of strength and toughness. it absolutely was concluded that an increase in MN, C or Cr individually produced an increase of durability and harness the link between microstructure and toughness of weld deposit was studied by means of hardness, V-notch metallographic tested in specimens at transversely the weld beads

2.7.1. The nature of the heat affected zone

A heat affected zone (HAZ) of a weld is that a part of the welded joint
which has been heated to a temperature up to solids of the parent material leading to varying degree of influence on micro structure which may lead to change in mechanical properties as a consequence of heating and cooling cycle the temperature distribution around a metallic arc butt the vanguard of the temperature pattern is compressed, because the arc is continually moving cold metal and edge becomes extended because the leaves preheated metal in its wake. A part of HAZ which is heated to beyond the critical temperature of grain growth and extend up to the fusion boundary zone is named grain coarsened heat affected zone (CGHAZ). During this region, adjacent to the fusion boundary, the first microstructure has been reaustenitised at temperatures and retention times sufficient for marked grain growth to occur. The austenitic grain size attained will vary per variety of things like distance from the fusion boundary, being greatest immediately adjacent thereto. Weld energy input, as a function of peak temperature and relative retention time. Original grain size: under the non-equilibrium conditions, finer austenite grain sizes may result from finer microstructures. Steel compositions, particularly with relation to the presence of refractory carbides or nitrides which are

difficult to dissolve within the available times scale at heat have also effect during this region. Finer austenite grain sizes may result from finer original microstructures.

2.7.2. Importance of heat affected zone properties

The overall aim in a welded joint, with respect to fitness-for-purpose, must be to obtain a joint in which the three component parts consists of parent steel, HAZ and weld metal, are each capable of withstanding the demands which the application places upon them, bearing in mind the probable size and location of defects either present after fabrication or developing during service. The degree of attention which the engineering industry has focused on each of these three types of material has varied from time to time, depending on the major current problems

In the early days of brittle fracture, the major cause of concern was the fracture toughness of the parent material, leading to the wide spread use of the hardness test to classify materials, as an aid to selection of steel for applications of varying severity

Other studies of the factors affecting hardness led to a long process of improvements in steel composition and processing, has led to a situation where, it is possible to conclude that, for the majority of structural applications, the range of steels currently available is adequate to guarantee safety against fast fracture over those parts of the structure unaffected by welding. As steel properties have improved, and as welded structures have developed into larger and more complex designs, increasingly operating under more severe conditions and with serious commercial and safety penalties in the event of failure, complementary developments in welding consumables and procedures have been necessary

The offshore oil and gas field exploitation, and the accompanying distribution systems and processing plants, have resulted in a marked increase in fundamental work and commercial development work on both manual and automatic consumables and procedures, such that the properties required, particularly fracture toughness, have been achievable in massive complex structures. Defect tolerance approaches to design, facilitated by improved stress calculation methods and inspection techniques have played a vital role. Interest in the HAZ has varied from time to time, in technical terms, and has in more recent years assumed strong commercial aspects.

In the past, the importance of HAZ toughness has been closely considered with the incidence of hydrogen induced cold cracking, on which an enormous amount of research work has, and is being meted out. It’s now clearly understood that three conditions must be present for H2 cracking to occur:

- An HAZ with a susceptible hardened micro-structure, promoted by higher carbon equivalent values (CEV) and faster cooling rates

Until relatively recently, the properties of the HAZ have only been regarded within the sense of their ability or otherwise to tolerate the presence of spasmodic hydrogen cracking. The relative defect tolerance of the HAZ against other potential failure modes has, by comparison, received much less attention, historically, perhaps for the superb reason that it's almost impossible to get any failures during which the HAZ has been the prime cause, except within the presence of H2 cracks. The measures taken to style out hydrogen cracking (lowering of CEV, reduced cooling rates, etc.) will tend to enhance the fracture toughness of the HAZ a dual gain in joint reliability. Therefore, the potential failure modes are initiation from lack of fusion/penetration defects, after fabrication, or because of environmental effects during service (fatigue, stress corrosion, corrosion fatigue) The toughness required to face up to preexisting fabrication defects may be assessed using well established defect tolerance approaches, based during this case on the grain coarsened HAZ properties, along with knowledge of the service stresses and NDT discrimination level. A thing with relevancy in-service cracking is extremely complex, particularly when corrosive environments are involved. Design procedures against fatigue in normal atmospheres are well established and now being included in British Standards. HAZ's are of interest because the likely initiation sites at the perimeters of the weld reinforcement, as an example, will make sure that the growing crack will, firstly, have its tip located within the HAZ for the primary a part of its growth, and, secondly, will, during this era, be subjected to the most stress concentration factors thanks to the weld profile and any geometric effects related to the weld location. It’s relatively easy, however, to define a worst case after the potential fatigue initiation sites are identified and to calculate the fracture toughness required to confirm the survival of the structure over this interval of cleft growth. Variety of things combine to cut back the probability of failure from fatigue cracking: The region of lowest toughness, the grain coarsened HAZ, usually has the very best strength, and an advancing crack will tend to show rapidly away into softer material, of upper toughness

This phenomenon presents constant problems within the fatigue pre cracking of HAZ test pieces, particularly where cracks adjacent to the fusion boundary are required. The outer areas of the HAZ and therefore the parent plate, which acquire play because the crack grows, are of upper toughness and might provide the required increased defect tolerance, once this first danger period is over. In many instances, e.g. fillet welds, the strain concentration factor related to the cleft initiation sites decays very rapidly, and this effect in addition to the probability of skyrocketing crack tip toughness, can cause a progressive decrease in crack rate of growth

The crack tip fracture toughness, per se, could also be reduced, leading to a lower tolerable defect size. Crack growth can continue under lower stress ranges, making matters of sessile noncritical cracks less likely. The relatively high strength of some parts of the HAZ, as compared to the parent plate, and also the presence of residual stresses from welding can sensitize the areas adjacent to welds to certain sorts of environment cracking. In some cases, the resistances of the parent steel to more generalized kinds of cracking are going to be important. The consideration of those environmental effects, which are of prime interest at this time within the oil and gas recovery and processing fields, are, however, outside the scope of this report, but may have some influence on attitudes towards the properties of welded joints under less severe conditions. Steel and/or weld procedure selection is also constrained, for example, by a maximum HAZ hardness criterion. Another important aspect which has reduced the effect of local embrittlement is that the narrowness of the band of fabric worst affected, generally 1 mm or less. Unless the properties are at or, near the lower shelf of the transition behavior, or loading is extremely rapid, the plastic zone at the crack tip are going to be able to grow, under increased loading, to such an extent that tough material on either side becomes involved within the pre fracture process zone, giving increased crack tip toughness. Ductile crack growth, if it occurs and therefore the mechanical constraints on crack propagation don't seem to be too severe; will tend to favor movement into softer and tougher HAZ regions. there's an in depth similarity to things noted above for advancing fatigue cracks, in this once an initial danger period is past, true at the crack tip can improve markedly. This inability of most HAZ's to contain a critical event is that the possibly reason for the absence of failure case histories citing the properties of sound HAZ's as a reason behind failure, and has led to the advice within the UK that it's unnecessary to hold out HAZ testing, on the traditional styles of structural steels, where the weld energy lies between 1.5 kJ/mm and 4-4.5 kJ/mmt1-7)- there's, of course, great commercial interest in increasing productivity by using higher weld energies, but it becomes advisable then to assess the effect of HAZ degradation, since the increased HAZ width may allow the HAZ to assume a potentially more significant role in possible failure modes

Heat affected zones in elector-slag welds are an extreme case, being not only extremely wide, of the order of 5-8 mm, but having an extended region of very coarse austenitic grain size adjacent to the fusion boundary. The mixture of low toughness and enormous width make the reliability of the

HAZ for structural purposes very suspect. The weld metal, similarly, with a rough as-cast structure, has very poor toughness, and it's been usual to normalize electro slag welds intended for service at ambient temperatures. The economic advantages of the method still motivate development work, directed towards improving the as-welded properties of electro slag welds, like narrow gap welding to cut back heat input, improved alloyed weld metals, and also the use of steels more tolerant of high heat inputs

2.7.3. Effect of heat input on HAZ

Heat input is a relative measure of the energy transferred per unit length of weld. It is an important characteristic because, like preheat and inter pass temperature, it influences the cooling rate, which may affect the mechanical properties and metallurgical structure of the weld and the HAZ. It is calculated from equation 1 below

$$H=\frac{60\mathrm{EI}}{1000\mathrm{s}} \tag{1}$$

H = Heat input (kJ/inch or kJ/mm)

E = Arc voltage in Volts

I = Current (Amps)

S = Travel speed (inch/min or mm/min)

Starting from the universal differential Eq. (2), Analytical models of heat conduction in welding were derived that describe the effect of momentary and movable heat sources on

This is a second order homogenous partial linear differential equation of parabolic type that provides the connection between the temperature change rate of a given point and the temperature distribution in the environment of that point. The effect of heat input on microstructure has been extensively investigated by researchers. For example, Kumar et al.,(2019) studied the influence of heat input on the microstructure and mechanical properties of gas tungsten arc welded 304 stainless steel (SS) joints. Three heat input combinations designated as low heat (2.563 kJ/ mm), medium heat (2.784 kJ/mm) and high heat (3.017 kJ/mm) were selected from the operating window of the gas tungsten arc welding process. The results of the investigation indicate that significant grain coarsening was observed in the heat affected zone (HAZ) of all the joints and it was found that the extent of grain coarsening in the heat affected zone increased with increase in the heat input. The average dendrite length and inter-dendritic spacing in the weld zone was found to increase with increase in the heat.

2.7.4. Effect of cooling rate on HAZ

The cooling rate of weldments depends on the heat input by the welding arc. Heat input is controlled by three variables, namely: current, voltage and travel speed. It's generally believed that travel speed affects heat input and warmth input affects the cooling rate. With higher heat input the cooling rate is quicker and contrariwise. During welding, an oversized amount of warmth is applied. Solidification of the weld pool takes place followed by cooling to temperature. The warmth applied is transferred during and after welding by conduction from the molten pool to the bottom metal and creates the warmth affected zone. The cooling rate could be a primary factor that determines the ultimate metallurgical structure of the weld and HAZ. There are many models developed for understanding the concept of cooling rate in an exceedingly welded joint. The results showed a big cooling rate near the HAZ. It had been found that the main influential property in reference to cooling rate is heat loss. It's well established that microstructure and micro-hardness rely upon the cooling rate. Increasing cooling rate generally will lower the austenite to ferrite transformation start temperatures. The effect of cooling rate on residual ferrite content and composition was evaluated. It showed that because the cooling rate increased, the quantity of retained ferrite increased, the ferrite's chromium content decreased, and its nickel content increased. The effect of cooling rate on the evolution micro structural product like allotriomorphic ferrite and pearlite was studied. The study concluded that lower cooling rates cause the event of other phases like allotriomorphic ferrite or pearlite but a high-volume fraction of acicular ferrite may be achieved using two stage continuous cooling cycles. The role of cooling rate during a welding process is critical in obtaining improved toughness, ductility and minimal residual stresses within the weld. It's also necessary to grasp the soundness of ferrite under multiple-pass welding conditions or during elevated-temperature applications by utilizing cooling rate information

2.8. Metal Inert Gas welding

Metal inert gas welding could also be a process during which the source of heat is an arc format between consumable metal electrode and also the work piece, and also the arc and thus the molten puddle are shielded from contamination by the atmosphere (i.e. oxygen and nitrogen) with an externally supplied gaseous shield of gas either inert like argon, helium or an argon-helium mixture or active like greenhouse gas, argon-carbon dioxide mixture, which is chemically active or not inert Initially MIG was called as /MAG, GMAW/ welding because only inert gasses were used to protect the molten puddle. The applying of this process was restricted to aluminum, deoxidized copper and bronze. Later it had been used to weld ferrite and austenitic steels, and mild steels, successfully by using active gasses in place of inert gasses and hence was term MAG (metal Active Gas) welding The American Welding Society refers to the tactic metal inert welding process to cover inert moreover as active shield gasses. MIG is actually a semiautomatic process, within which the arc lengths of electrode and also the feeding of the wire are automatically controlled. The welding operator’s job is reduced to positioning the gun at an accurate angle and moving it along the seam at a controlled travel speed. Hence less operator skill is required with this process as compare to TIG. Yet training is required within the putting in place of the equipment and manipulation of the gun must be provided to produce to the operator to create sure quality MIG welding(Hameed Majeed, Esmaeel Radhi, and J. Abid 2021).

MIG welding process overcome the restriction of using small lengths of electrodes and overcome the restriction of using small lengths of electrodes and overcome the dearth of the submerged-arc process to weld in various positions. By suitable adjusting the tactic parameters, it's possible to weld joints within the thickness range of 5mm in all welding position.

All the foremost important commercial metals is welded by MIG process, including carbon steels, low alloy and high alloy steels, stainless, aluminum, and copper titanium, zirconium and nickel alloys. MIG is additionally employed in mechanized and automatic forms to eliminate the operator factor and to increase the productivity and consistency of quality

Mild steel is steel that contain fine grain with ferrite phase structure. The mechanical properties for low steel are better due to soft matric ferrite with good ductility. These become the factor to low steel to possess good mechanical properties which is from the high in yield and strength and also high absorption force. Apart from that, a mechanical property for low steel is depends on others various factor like ferrite mechanical properties which contain carbon and fine grain size. Final strength for ferrite structure is set through the decrease of carbon content within the material. The reduction of carbon indirectly will increase the elongation of low steel when there's a tensile load. This shows that a ductility property of the fabric is increased. The ductility of the low steel is additionally being influence by the increment of fraction grain boundaries which is able to increase the amount of dislocation sources which successively would increase the frequency of the dislocation density and high strength carbon steel. Low steel are going to be able to absorb a high shock impact and this mechanical properties is basically needed in housing industry to soak up any force that being to the bridge frame to create sure the structure of bridge always in strong condition and didn't collapse easily. Welding process that created on the low steel material is one amongst the factor that influence the change in mechanical properties because this process will control the fabric phase size, volume fraction et al. phase formation in low steel material. This because, welding process will create heat which is being called heat affected zone (HAZ). The heated given on low steel will come from welding process which change the ferrite phase to and austenite phase and into ferrite phase. This can increase the strength of fabric but the ductility will decrease due to hardness material is increased. Next, it'll decrease the extent of absorption shock that being to the fabric. Low carbon steels are produced for various applications like in automotive industry and industry. Mechanical property for low steel is greatly influenced by the phase structure of the fabric et al. alloy elements that being added into low steel. The content in low steel influenced the ferrite phase structure within the material. (Property of mild steel)

2.8.1. Gas Metal Arc Welding (GMAW)

The metal-inert gas (MIG) welding technique is another name for GMAW. Metals are melted using an electric arc created between an electrode (filler metal) and base metals in GMAW welding. During the solidification of the molten weld pool, the gas is used to shield the weld from undesired air entrapment. Argon and helium are utilized as inert gases to safeguard the arc and the molten weld pool. Because of the inert shielding gas, the process is spotless, and the weld area is uniform and slag-free (Nagesh and Datta 2002)(Hameed Majeed, Esmaeel Radhi, and J. Abid 2021).

2.8.2. Shielded Metal Arc Welding (SMAW)

This welding process uses a flux-coated electrode to join the metals, and heat is generated by delivering an electric current through the electrode. A gaseous barrier protects the molten metal from atmospheric air, and the electrode is protected by slag, resulting in a clean weld. SMAW welding is primarily used to join high-strength steels that are prone to hydrogen cracking (Nagesh and Datta 2002)

Msomi & Mabuwa, (2020) studied the bending and tensile strength of a friction stir processed MIG-welded AA5083-H111 joint in an experimental study. The MIG-welded (unprocessed) joint was compared to the FSW processed jointly. Tensile, bending, and microstructure tests were used to assess the joint's quality. As a result, the processed joints' tensile characteristics were found to be higher than the unprocessed joints. The processed joint has a higher bending strength than the unprocessed joint. For both treated and unprocessed joints, the flexural strength of the face was found to be higher than the root of the joint. The microstructural analysis revealed that the coarse grains dominated the friction stir in the unprocessed joint, while the refined grains dominated the friction stir.

Naik & Reddy, (2016) used Taguchi's Orthogonal array experimental design on Duplex Stainless Steel (2205) to investigate the Experimental Analysis of MIG Welding and Comparison between A-MIG and TIG on Duplex Stainless Steel (2205). They found the effect of various input parameters on specific performance measures. He concludes that time and current are important factors in tensile strength; tensile strength is highest at 180 seconds and 250 amps, although the gas flow rate is low. The current has a major impact on hardness, and it is complete at 250A, 150 sec, and 6L/min.

In a review of various welding techniques, (Kazi et al. 2015) found that when the speed and current rise, the heat-affected zone increases as well. He also determined that MIG welding has a higher hardness than MIG welding and that MIG welding has a higher ductility than TIG welding based on their findings. TIG welding specimens can withstand higher loads, yield stress, and tensile strength than conventional specimens. According to the findings, all MIG welding parameters are superior and optimal for steel.

(Patel and Patel 2014) conducted an experimental study on effect of Activating Flux in TIG Welding and found that most welding parameters, such as welding flux, welding current, welding speed, and depth to width ratio, are commonly utilized in research. TIG welding can be done on a variety of materials, including MS, Titanium alloys, brass, carbon, and stainless steel. He also uses theoretical equations to determine welding penetration, depth to width ratio, and welding joint strength, which he then measures empirically with the use of various input parameters. The austenitic type of stainless steel with grade E321 was chosen as the result of experimental work and the research of several journals, and fluxes were SiO_2 and TiO_2.

Aravinth et al., (2012) conducted a study on MIG Welding Process Failure Mode and Effect Analysis. Porosity is the most dangerous fault in MIG welding, according to a Criticality Study, and incorrect shielding is also a serious problem. As a result, before welding, corrective action should be taken, and proper maintenance should be performed for practical welding.(take friction)

2.9. Effect of process parameters

Ruggiero et al. (2017) optimization is considered after several investigations on the parameter.Moi, Rudrapati, et al., (2019) examined the Impact Behavior of MIG Weldments on SS275 using Hybrid RSM and CSO. Welding Current, Speed, and Gas Flow Rate are the process parameters for maximal impact strength. The most important element impacting impact strength, according to the findings, is welding speed. The gas flow rate and welding current are the next two important parameters to consider. Welding current = 126.62 A, welding speed = 15.39 cm/min, gas flow rate = 8.85 l/min, and matching impact strength = 51.62J were the optimal parametric settings predicted by the CSO algorithm. By using gas flow rate, welding current, and welding speed as process factors**,** (Mohanavel, Ravichandran, and Suresh Kumar 2018) studied their findings on the optimization of tungsten inert gas welding parameters to achieve optimum impact strength in AA6061 alloy joints using Taguchi Technique. The welded joint's quality was tested using the maximum impact strength. The test results revealed that the gas flow rate is the most important factor affecting weld joint impact strength, followed by welding speed and welding current. Welding Current: 200 A, gas flow rate: 10 L/min, and welding speed: 58 mm/sec were found to be the best level combinations for optimum impact strength. Gupta, (2016) experimented with Optimizing Conditions for Performing GMAW (TIG) Welding on Ultra 904L Specimens and found that when the current was varied while the gas flow rate was kept constant, the welding joint was not produced below 50A and above 200A, and the specimen began to burn. By considering advanced speed, welding amperage, and preheating temperature, (Salehpour-Oskouei et al. 2021) explored the Experimental Investigation of Tungsten Inert Gas Welding Input Parameters Effects on Mechanical Characteristics on 4130mild steel. The study's reaction output was distortion and tensile strength. The results reveal that increasing amperage reduces welding component strength due to plate edge burn defects, which can be mitigated by increasing welding speed and lowering the influence of intense heat on the edges. Finally, the optimal conditions of the adjustment parameters in butt-welding were gained among existing samples for welding 4130 mild steel by examining the effect of the input parameter on the output

2.10. Analysis of mechanical property

by (Vennimalai Rajan et al. 2020). Tensile strength, hardness, and bend tests inspected the weld quality. The results showed that the tensile strength was 507.902 N/mm2 at a peak load of 49.880 KN, the bending strength was 31.213 N/mm2 at a peak load of 3.140 KN the Rockwell hardness was 78kgf. Satputaley et al., (2021) evaluated the influence of MIG welding on maximum tensile strength for 4130 Chromoly and 7075T6 aluminum in an experimental investigation. The results demonstrate that Chromoly 4130 has a weld strength of 396.69 MPa, the same as Al 7075T6, resulting in poor weld mechanical properties and poor welding performance. Al 7075T6 has low weld penetration when used for high-strength applications. MIG welding on Chromoly 4130 produces great weld penetration without compromising the material's characteristics. Devakumar et al., (2016) investigated GTAW welds in duplex stainless steel and hot-rolled steel (DSS / HRS) by characterizing the weld microstructure, examining the micro composition part using power dispersive X-ray evaluation (EDAX) to determine metallurgical properties and micro hardness test, tensile test, and bending test to determine mechanical properties. In contrast to the DSS parent metal, which has long grain austenitic with ferrite, and the HRS parent metal, which has long grain austenitic, the results show the production of a triangular ferrite microstructure. The DSS/HRS weld is more efficient with fine ferrite grain. The creation of the dendritic delta ferrite microstructure appears to be the result of energy-dispersive X-ray analysis (EDAX). Arora et al., (2020) used the Taguchi technique to investigate the mechanical and morphological properties of inert tungsten gas welded SS304 thin pipe joints, selecting important parameters such as welding speed, welding current, and shielding gas flow rate. Micro-hardness, the breadth of the heat-affected zone, residual stresses, and microstructural characteristics were used to assess weld quality. The hardness of the weld bead decreases with maximum welding current and low welding speed, and the optimal settings for minimal Hardness and minimum HAZ are current (90A), speed (2mm/s), and gas flow rate (5 L/min), according to the results. In this case study, minimal welding heat input resulted in the development of equiaxed grains, whereas high input resulted in dendrite formation.

As a result, choosing the right TIG welding process parameters and setting them at the right values is critical for getting the best mechanical characteristics and bead shape

2.11. Analysis of MIG welding quality

The characterization of MIG-welded metal joints has been the subject of much research. They primarily focus on microstructure qualities, mechanical properties, and the impact of various input parameters on weld quality. Cores-columnar grains are common in weld fusion zones because of the prevailing heat conditions during weld metal solidification. As a result, weld mechanical characteristics and resistance to hot cracking are frequently compromised. The quality of welded joint is usually controlled by the solidification behaviors of the welded metal. It manages weld metal microstructure, grain structure, mechanical properties, etc.

Ayoola, Suder, and Williams 2019; Choudhary, Kumar, and Unune (2019) researchers are constantly developing statistical models to correctly optimize the welding process and produce higher-quality welds. Experimental Analysis and Optimization of any welding procedure is difficult due to the high cost, time commitment, and numerous interconnected aspects that must be considered Maneiah et al.,

(2019) conducted an experimental investigation on TIG Welded Butt Joints of Aluminum Alloy 6061-T6 to Determine Tensile Strength at 15°, 30°, 45°, and 60°. The results revealed that the tensile specimens were tested in a variety of heat treatment techniques, including annealing, water quenching, and heat treatment without heat treatment. The highest strength, 109 MPa, and the highest percent elongation, 5.6 percent, exhibit better ductility upon annealing, welded at a 60°-degree angle. Without heat treatment, the strength reached 100 MPa when welded at an angle of 30° degrees. As a result, heat treatment techniques and weld angles have an impact on the weld joint's strength and tensile qualities.

Saha, (2020) evaluated the effect of MIG welding parameters on welded joints made of stainless steel SS304, considering process parameters including current, gas flow rate, speed, and filler rod diameter. The TAGUCHI method was used to plan the experiment, and the quality of the weld was assessed using tensile, hardness, and depth of penetration tests. The ideal parameter combinations for ultimate tensile strength and hardness differed only in terms of current for optimum UTS, according to the findings. It was necessary to use a greater current (180 amp) a lower current value (150 amp) was, on the other hand, ideal for optimum hardness. However, higher current resulted in improved DOP (Depth of penetration), hence the best UTS combination (A3B3C2D3) was chosen. Using optimum welding settings, the tensile strength improved from 515 MPa to 556 MPa, resulting in a 10.56 percent increase in joint strength. Using optimum welding settings, the hardness improved from 92 HV to 100 HV, a 7.36 percent increase in hardness.

2.12. Investigation of welded joint of micro structure

An experimental study (Dak and Pandey 2021) investigated dissimilar welded joints of P92 and AISI 304L mild steel. This research aims to look at the material's microstructure, mechanical characteristics, and residual stresses. The welding was done using an optical, multi-pass gas tungsten arc welding (GTAW) procedure to determine the weldment's microstructure and mechanical properties (tensile, Charpy impact, and microhardness) microscope and scanning electron microscope. To homogenize this heterogeneous microstructure generated toward the P92 side, a post-weld heat treatment (PWHT) at 760 C for two h followed by air cooling was carried out. As a result, the weld fusion zone and SS304L heat-affected zone (HAZ) microstructure are unaffected by this PWHT, and PWHT, on the other hand, changes the situation.

Using DOE Taguchi and ANOVA methodologies (Kausar 2019) analyzed and studied the weld quality parameters of tungsten inert gas welding on different metal plates SS316L and IS2060. Process parameters such as current, voltage, and gas flow are chosen, and weld quality is determined by tensile strength, hardness, and microstructure. The findings demonstrate that voltage has the most significant impact on stiffness, followed by the gas flow and current. And the most important parameter is tensile current, followed by voltage and gas flow. The optimum parameters for hardness are 130 (Amp), 60 (Volts), and 9 (Liters/min) Airflow, while the optimum parameters for tensile strength are 130 (Amp), 50 (Volts), and 10 (Liters/min) Airflow. Good flow indicates that the connection is vital when it comes to microstructures.

The Analysis and Experimental Investigation of Weld Characteristics for MIG Welding in carbon steel Metals on SS275 and MS1062 was examined

An experimental study (Dak and Pandey 2021) investigated dissimilar welded joints of P92 and AISI 304L austenitic stainless steel. Sanjay Kumar et al., (2019) used ANOVA to experiment with the effect of welding parameters on MIG-welded joints. The influencing parameters were (Voltage, Current, Gas Flow, and Root Gap), Metal Inert gas (MIG) is another name for GTAW (MIG). A Tungsten wire is used to produce the weld, and the electrode used doesn't get consumed. The arc that forms between the work piece and the electrode melts the metals that will be welded together to produce the weld pool (Jeyaprakash, Haile, and Arunprasath 2015). The thickness of the base metals determines whether filler material is used. To avoid oxidation and safeguard the weld pool, argon or helium, or a combination of both, is employed (Balaji et al. 2012). It's best for welding narrow portions because it requires less heat and can be done on a variety of metals.

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.

2.13. Research Gap

In the literature survey of experimental investigation and parametric optimization of metal inert gas welding process parameters during welding of AISI 4130 mild steel plate metals like welding current, welding speed, and welding voltage, welding angles, work piece material weld-ability, which affects the desired output like strength, hardness, and micro-structure for different material like mild steel, carbon steel was studied. But the optimization of welding parameters and characterization of AISI 4130 mild steel plate welded by metal inert gas welding process were few studied as well as few published. Therefore, it is vital to study the optimization and characterization of welding parameters for AISI 4130 mild steel plate. Based on the literature survey and many challenges identified in the literature; it is decided to experimentally investigate the following aspects of the welding process parameter optimization in this thesis as a research gap.

- Identifying the significant factors (welding current, welding voltage, welding speed and welding angles) that affect the surface quality of GMAW welding process for AISI 4130 mild steel plate with thickness of 5mm.
- Difficulties in welding operation of AISI 4130 mild steel on MIG welding process and how to over-come those challenges by selecting optimal welding parameters.
- In addition, even though, many research works has been conducted on AISI-4130 mild steel material using different optimization techniques were parametric optimization using Taguchi method is less covered. In addition, especially by considering the versatile application of mild steel plate material research is not conducted on the parametric optimization AISI 4130 mild steel plate weld metal inert gas welding. That is why my thesis is focused on the experimental investigation of welding parameters.

2.14. Summary of literature review

Most of the writers emphasize on the influence of fusion zone especially in investigation on Microstructure of the fusion zone and mechanical Properties of metal chemical element (MIG) butt welded joints. The conclusions which might be made up of the review paper are study of the mechanical properties of the weld is extremely important because the most purpose of the welding is to strongly join the 2 metals together because the application of the welded structure could also be at dynamic or static loading conditions. It’s important to test the enduringness of the weld and also the factors affecting the integrity of the weld. During literature review; mostly within the consideration of the main problems formed with steel metal welds was at risk of formation of inter-metallic compounds at the interface which affect the properties and efficiency of the weld. So as to enhance the strength of the mechanical properties metals weld intermediate layers at the interface with suitable qualified consumables, Proper preheat and necessary to cut back the residual stresses imparted during welding with suitable heat treatments. The heated given on low steel was from welding process which change the ferrite phase to and austenite phase and back to ferrite phase. This may increase of strength of material, but the ductility was decreased due to hardness material was increased. Next it'll decrease the amount of absorption shock that being to the material.

2.15. Gaps in the literature reviewed

From the literature review, limited research on Investigation on Microstructure of the fusion zone and mechanical properties of Metal Inert Gas (MIG) butt welded joints especially in our country. Many researchers focused on SMAW while others studied on the highest thickness of plate like 8 mm, 10 mm, 12 mm and 2-3mm or different thickness. In these studies, focused on lowest thickness of plate 5 mm to fill the gaps.

CHAPTER -3

MATERIAL AND METHOD

3.1. Introduction

After surveying the literature, some advice and expertise on the correct work piece and welding position material selection, managing process parameters, research methodology, electrode, and welding conditions are now available. Using a manual MIG welding machine, an experiment will be carried out using a proper selection of orthogonal arrays for an experimental plan, considering MIG welding process parameters such as welding current, welding speed, and welding voltage and welding angles metal (AISI 4130).

3.2. Experimental Procedure (Methodology)

To meet the thesis goal outlined in Chapter 1. The schematic diagram of the framework of the applied techniques are shown in Figure 3.1.

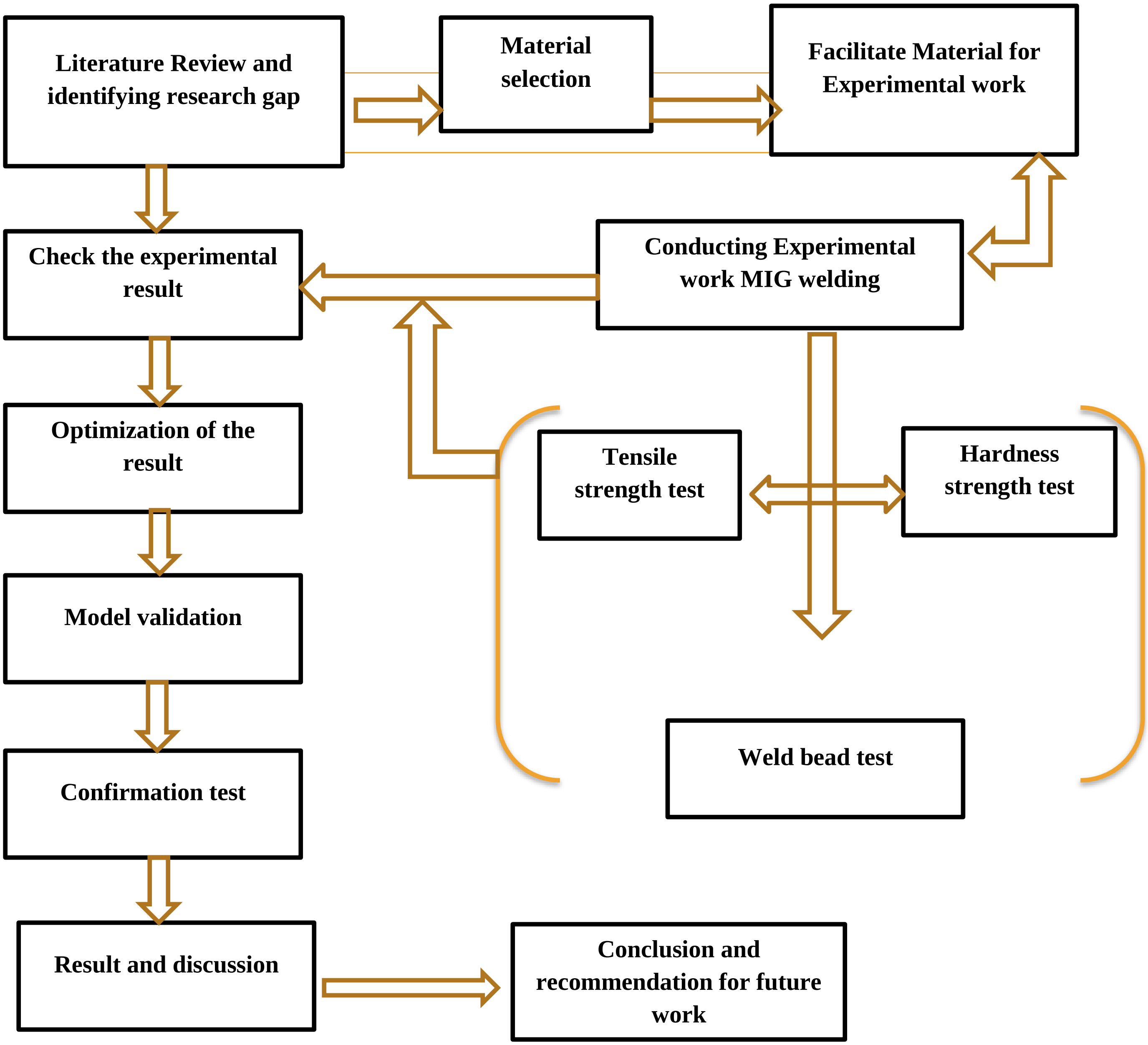


Figure 3. 1. Flow chart for experimental work design (research methodology)

3.3.1 Material selection

The work piece material employed in this experiment will be mild steel plate (AISI 4130).

3.3.2. Base material

3.3.3. AISI 4130 mild steel plate

Type AISI 4130 is a ferrite steel with an iron concentration of 98.35% to 98.85%. The inclusion of carbon improves general hardness, wear resistance as well as strength at high temperatures. This material has the same properties as ASTM AISI4130 steel is commonly referred to chromyl steel except it is high quality structure material carbon steel machine components like shaft, pulley, sprocket, gear, pipe, tankers and rollers, pins, structural steel and automobiles, machine body, tankers, and fencing processing equipment parts are some examples of typical applications.

3.4. AISI 4130 Carbon steel

AISI 4130 is the material to be investigated is standard 4130 steel plates from Conquest Steel & Alloys, India, cherish ASTM standard 4130 mild steel offers high tensile and good yield strength, good mechanical strength, ductility, hardness, and good weld ability. These plates show high tensile strength at good formability and wear resistance. Plates provide excellent wear resistance property like resistance to corrosion, wear resistance to erosion, and resistance to oxidation. It's also resistance to chloride stress cracking and resistance to several acids like nitric, chloride, sulfuric, in sulfide and reducing the environment carbon steel with a Vickers hardness range of 210 to 270 and a tensile strength range of 319 to 677 MPa. Machinability, strength, ductility, and weld ability are all excellent. It resists induction hardening and flame hardening due to its low carbon concentration (eFunds,2012). AISI 4130 steel can be used in a wide range of industrial applications to improve weld ability and machinability. It is employed in a range of applications including general engineering parts and components, machinery parts, shafts, camshafts, and others. illustrate the chemical composition and mechanical properties of AISI 4130 mild steel. steel. Figure 3.2 shows the base materials.

Figure 3. 2. Base metals AISI 4130

3.5. Weld ability of mild steel AISI 4130 materials

The ferrite class of low alloy steel containing chromium and molybdenum as strengths agent the steel has good strength and toughness, mild steel plate offers very good weld ability, and the additional alloying elements in mild steel also makes strengthening them a cost-effective option for many welding applications is used for somewhat greater strength will still having a good ductility. machinability of 4130 steel is quite good, rating against the standard steel of 100 % machinability 4130 steel has good ductility and it is readily formed by standard methods.

. The most common specifications of weld ability and welding wire (ER70S- 3) often used for mild steel that clean, oil free and rust free while ER70S-6 contains deoxidizer and it used for mild steel that contaminated with corrosion The corrosion resistance must also be considered while selecting the wire metal. Due to the structure of the weld metal, a higher alloyed wire metal may be required. This steel does not require any preheating. It is uncommon to heat treat a weld after it has been completed. The heat conductivity of ferrite steels is only 20-30% that of non-alloyed steels. Due to their lower fusion point than -alloyed steels, ferrite steels must be welded with lower heat input mild steels. Higher welding speeds must be used to avoid overheating or burn-through of thinner sheets (MakeltFrom.com). Welding AISI 4130 can be done with the most common welding processes. Cold-drawn or turned and polished steel is more weld able. When the metal has been heat-treated or carburized, it is recommended that the welding technique be avoided (et.al Funds,2016).

3.6. Chemical composition of base and weld metals

The mild steel's composition will always be a compromise. It can be costly to obtain desirable weld ability and hardness, although a higher compromise in those aspects can lower price The elements and their effects on weld ability and other properties of the metal.

Carbon (C): Carbon is required for steel to build strength, yet it is inexpensive. Carbon concentration increases tensile strength and hardness while decreasing ductility and weld ability. Steels with a low carbon content (0.33% percent wt) (Hannerz, 2022).

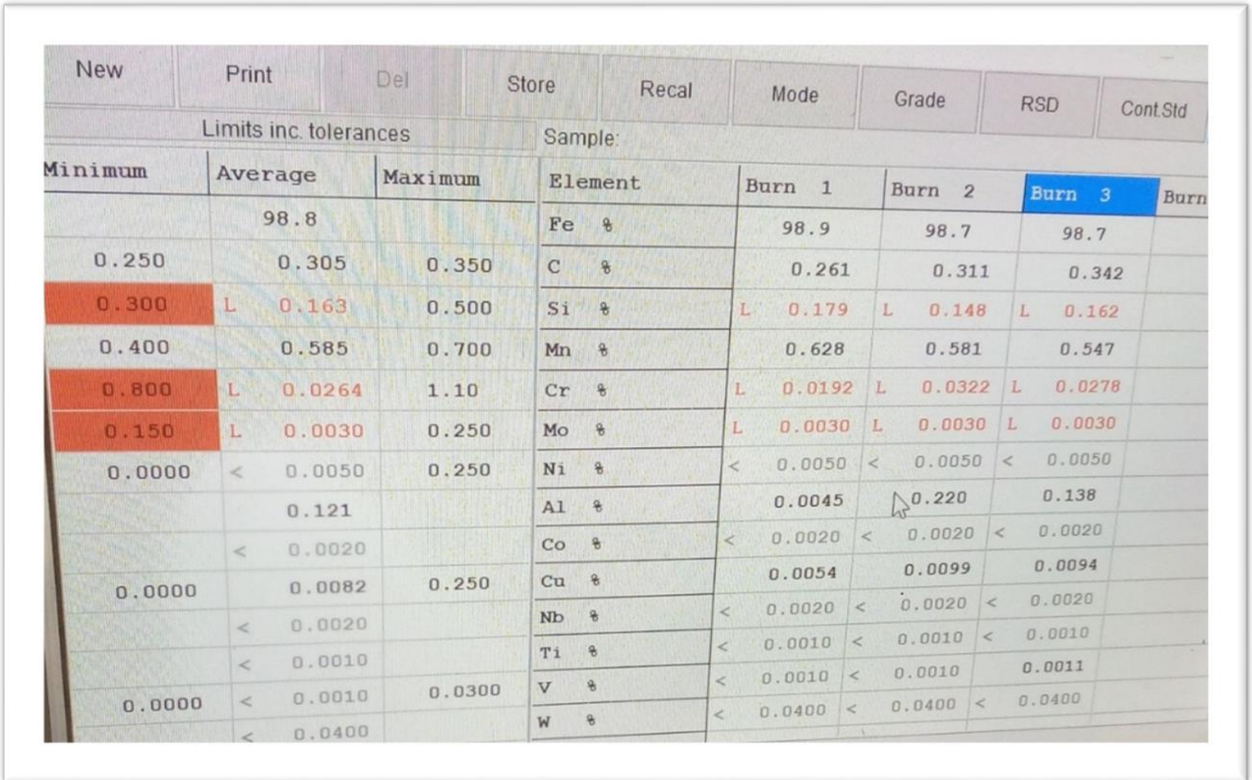
Chromium (Cr): Increased chromium content can have a deleterious effect on reheat cracking up to 0.8-1.10 percent wt., but after that, the danger of reheating cracking reduces as chromium content increases (Maalekian, 2007

Molybdenum (Mo): Molybdenum increases pitting corrosion resistance in austenitic steels and strengthens and hardens low alloy steels at high temperatures

Manganese (Mn): Steel manganese content is proportional to carbon content; carbon content necessitates higher manganese content, and vice versa Steel can become brittle if carbon and manganese levels are too high. Manganese should be 0.4-0.6 percent. to promote weld ability. However, manganese has a positive effect on weld ability in most situations.

Phosphorus (P): Phosphorus levels in contemporary steels are typically controlled below 0.0350 percent of weight. It improves toughness Although phosphorus can improve machinability in some steels,

Sulfur (S): Sulphur reduces ductility while increasing machinability. In steel, it is usually less than 0.040 percent by weight.



Minimum	Average	Maximum	Element	Burn 1	Burn 2	Burn 3	Burn
	98.8		Fe %	98.9	98.7	98.7	
0.250	0.305	0.350	C %	0.261	0.311	0.342	
0.300	L 0.163	0.500	Si %	L 0.179	L 0.148	L 0.162	
0.400	0.585	0.700	Mn %	0.628	0.581	0.547	
0.800	L 0.0264	1.10	Cr %	L 0.0192	L 0.0322	L 0.0278	
0.150	L 0.0030	0.250	Mo %	L 0.0030	L 0.0030	L 0.0030	
0.0000	< 0.0050	0.250	Ni %	< 0.0050	< 0.0050	< 0.0050	
	0.121		Al %	0.0045	0.220	0.138	
	< 0.0020		Co %	< 0.0020	< 0.0020	< 0.0020	
0.0000	0.0082	0.250	Cu %	0.0054	0.0099	0.0094	
	< 0.0020		Nb %	< 0.0020	< 0.0020	< 0.0020	
	< 0.0010		Ti %	< 0.0010	< 0.0010	< 0.0010	
0.0000	< 0.0010	0.0300	V %	< 0.0010	< 0.0010	0.0011	
	< 0.0400		W %	< 0.0400	< 0.0400	< 0.0400	

Figure 3. 3. chemical composition data of AISI4130

Table 3. 1: Chemical composition of studied base metals

Materials (AISI designation)		Chemical composition (wt.%)							
		C	MN	P	Si	Cr	S	Mo	Fe
Base	AISI 36	0.280	0.4	0.035	0.20	0.264	0.04	0.15	
metals	AISI102	0.33	0.6	0.03002	0.35	0.192	-	0.25	98.8

Table 3. 2: mechanical properties SS29 (MakeItFrom.com Funds, 2017)

Mechanical properties	Value
	AISI4130
Ultimate tensile strength	394.72 MPa
Yield strength	294.74 MPa
Percentage elongation(in 50mm)	36.5 %
Vickers hardness (HV)	228HV
Mean Coefficient of thermal expansion (100°C)	21.50 µm/m*K

3.7. The material used for filler

Wire material with a diameter of 1.mm was employed as wire metals. ER-70S-6**:** Welding low carbon molybdenum-bearing ferrite alloys with ER70S-6 is the most common use. This wire metal has the same chemical composition as ER70S-6, with the exception that the carbon concentration is limited to percent to prevent intergranular carbide precipitation.

ER-70S-3: The silicon and manganese levels in ER0S-3 are adequate for general-purpose welding over clean to light levels of rust and mill scale, The ER70S-3 can deliver trouble-free performance in a wide range of applications. from heavy-duty, high-speed spray or pulse applications to lighter-duty, Lower-Speed short-arc applications. ER70S-3 produces a clean, stable arc with minimum spatter even in the most demanding situations, resulting in a weld a bead that ties in evenly with the sides and has a smooth completed appearance (Unbrace corporation,2000).

- Shielding gas used: carbon dioxide
- Metal thickness: 5mm
- wire metal diameter: 1mm

3.8. Experimental Work

Experiments are conducted at the Centre of Excellence of Engineering (Cee), around Wesson, Addis Ababa and nifas silk poly technic collage. workshop on BLUMIG Superior 320 MIG welding machine as per DOE Taguchi by considering
process parameters like welding current, welding voltage, and welding speed metals at 4 levels which gives L16 Orthogonal array and analyze the output results based on ANOVA.

- **Welding Current:** directly affects the penetration and lack of fusion
- Is the most affecting variable in arc welding process which influences the electrode burn off rate, the depth of fusion and the geometry of the welded joints.
- **Welding voltage:** The welding voltage primarily controls the arc length which is the distance between the molten weld pool and the wire filler metal at the point of melting within the arc. As the voltage is increased, the weld bead will flatten out more and have an increasing width-to depth ratio.
- **Welding speed:** Penetration into a base material increases when the travel speed of a weld increases, and vice versa. At slower travel speeds, the arc is directly above the center of the molten weld pool. Consequently; the metal that; is transferred from the melting filler metal to the weld pool which has deposited into the center of the weld pool.
- **Welding angle:** a torch angle is typically 70 to 80 degrees (10 to 20) degree from perpendicular to base metal.

Table 3.5 shows process parameters and their levels.

Table 3. 3: selected process parameters and their levels

S. No	**Process parameter**	**Units**	**Levels**			
			1	**2**	**3**	**4**
1	Welding current	Amp (A)	110	120	130	140
2	Welding voltage	Mm	18	20	22	24
3	Welding speed	L/Min	70	80	90	100
4	Welding angle	Position	15	30	45	60

3.9. Sample Preparation and welding condition

As illustrated in the figure 3.7, mild steel stock sheets with dimensions of 100mmx100mmx5 mm are sectioned. The grinding machine is subsequently used to cut the produced stock into plates. To make the but weld joint, the edge preparations will be arranged. Finally, 100mm x 100mmn x 5mm specimens are manufactured, and butt joints are formed using these specimens. The edges of the work components will be adequately prepared before welding. Using a wire brush, dust will be removed from the edges and the space surrounding them.

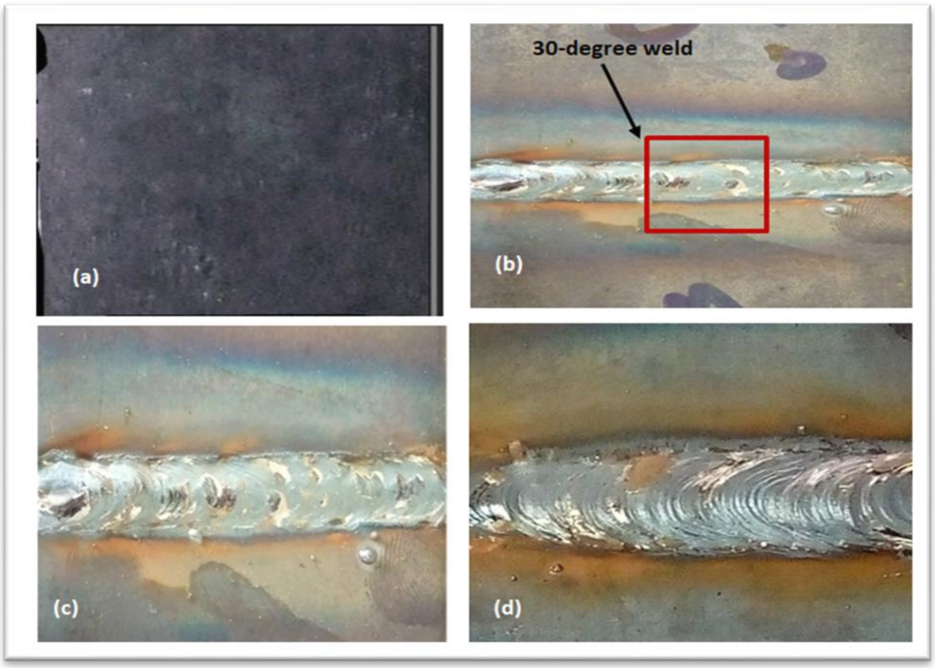


Figure 3. 4. Welding angle (a) Base metal 413 , (b) 15 oC (c)30o C and (d) 45oC

3.10. Experimental setup

The welding setup has the following parts as shown in figure 3.10.

- **MIG welding machine:** Direct current with a negative electrode was used. During welding, current and voltage are delivered. Depending on the current setting, a current range of 50-400 amps and a voltage of up to 380 V will be used.
- **Cylinder for front and back purging gas:** MIG welding uses carbon dioxide gas, which is fed into the welding flame at a specific flow rate to provide an inert atmosphere and a steady arc.
- **Work holding table**: A surface plate (made of cast iron) is used to hold the back purging tool, on which a work piece is secured so that the welding gap between the tungsten electrode and the work piece can be manually maintained between 1 to 5mm. The work parts to be welded are then positioned concerning one another, and the welding process is carried out at a constant voltage with the wire diameter in a flat (down hand) position. However, according to 16 combinations of data from

the L16 orthogonal array shown in table 3.6, the welding current, welding voltage, welding speed, and welding angle metals vary for each test. (figure)

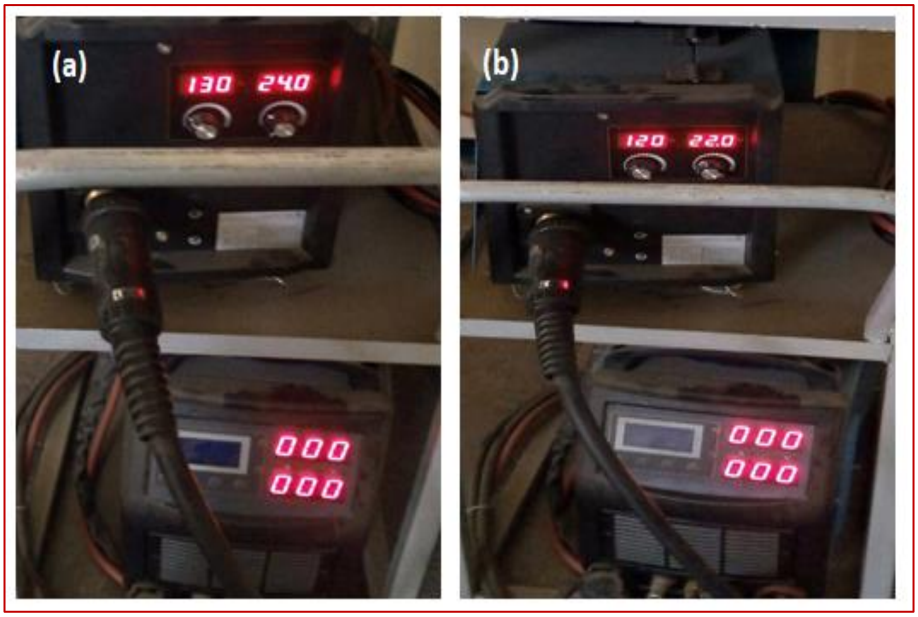


Figure 3. 5. Photo of MIG welding machine, (a) current 130 A and (b) 120 A

Table 3. 4. Experimental plan for welded metal (L16)OA

Sample No	*Welding Current (A)*	*Welding voltage)*	*Welding speed (C)*	*Welding angle (D)*
SS1	110	20	60	15
SS2	110	22	70	30
SS3	110	24	80	45
SS4	110	26	90	60
SS5	120	20	60	15
SS6	120	22	70	30
SS7	120	24	80	45
SS8	12	26	90	60
SS9	130	20	60	15
SS10	130	22	70	30
SS11	130	24	80	45
SS12	130	26	90	60
SS13	140	20	60	15
SS14	140	22	70	30
SS15	140	24	80	45
SS16	140	26	90	60

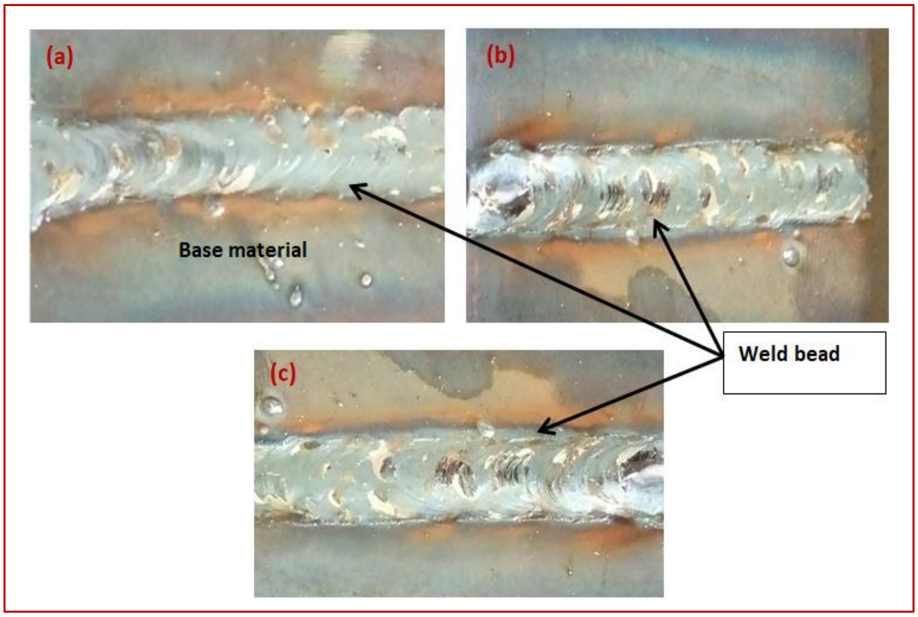


Figure 3. 6 . Welding bead for different angles, put welding parameters for each (a) 15 oC (, (b) 30 ^{o}C and (c) 45- oC

3.11. Weld Bead Geometry Testing

MIG welding (metal inert gas) is a multi-objective, multi-parameter metal manufacturing process Several process parameters interact in a complicated way, having direct or indirect effects on weld bead geometry, mechanical properties, metallurgical aspects of the weldment, and weld chemistry. MIG weld quality is mostly determined by the geometry of the weld bead and weld penetration. Welding process parameters such as welding current, welding speed, welding voltage and welding angle greatly influence bead geometry variables such as heat-affected zone, bead width, bead height, penetration, and area of penetration, and it also plays an important role in determining the mechanical properties of the weld such as tensile strength, hardness, and bending strength of the weld (Esme et al., 2019).

3.11.1. Bead width geometry of the weld

The width of each welded sample was measured with 0.01 mm least count Vernier calipers to determine the weld bead width. Because the width of each welded sample varies depending on the parameter utilized, the weld with the smallest bead width is considered a good weld.

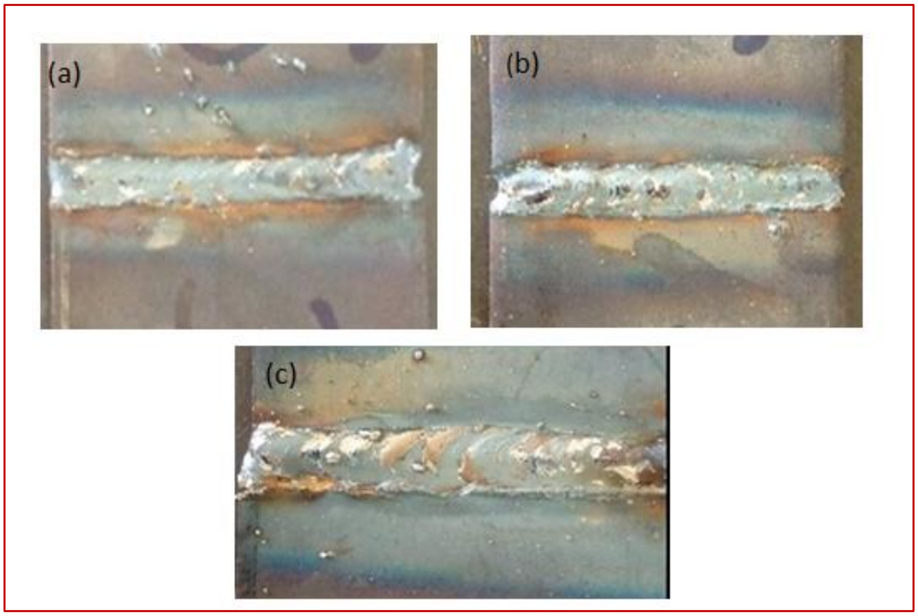


Figure 3. 7. Welding bead diameter (a) 7.6mm , (b) 7.1

3.12. Welding Defects Using Non-Destructive Testing (NDT)

A faulty weld fails to meet any or all the standards of a certain specification or code. It's impossible to evaluate a faulty weld. Without a reference to a specific standard or criteria about the weld's intended purpose.

3.13. Liquid penetrant test (PT)

Liquid or dye penetrant testing (PT) is a non-destructive material testing method that employs capillary forces to locate and see surface cracks or holes. It can identify faults on the surface, like as fractures, laps, and porosity. The penetration of liquid penetrant through open surface discontinuities is the basis of PT. Surface flaws such as surface cracks, porosity, absence of fusion, and intergranular corrosion is detected using the dye penetrant method. Welds and parent material are subjected to dye penetrant testing. PT testing can be used on any non-porous clean material, whether metallic or non-metallic, however, it is not recommended for extremely- rough surfaces. Surface cleaning is an important aspect of penetrant testing.

3.14. Experimental Procedure

The initial surface area of test piece is evaluated. Then, using a multi-purpose cleaner, pre-clean the area to remove any superfluous material such as, slag, grease, oil, paint, and the like. Cleaning with chlorinated hydrocarbons, volatile petroleum distillates, or acetone, some dwell time should be allowed for the evaporation of the volatile cleaner from discontinuities before the penetrant is applied. Then the penetrant is applied to the surface area of the test Samples by spraying. After the penetrant is applied some dwell time was allowed until the capillary action allows this to permeate small fractures or pores. After carefully removing the remaining test media from the surface, a developer is used to draw the dye penetrant out of the pores and cracks, sufficient time should be allowed after the developer has been applied to permit it to draw or blot out the penetrant from any discontinuities which Resulting in indications that may be analyzed as a defect. Finally, the test specimens were cleaned with solvents following the completion of the examination as shown in figure of penetrant.

Figure 3. 8 . a) PT process pre cleaning sample by using general purpose cleaner, (b)application of developer, (c)inspection pent surface and (d) cleaning anti-corrosion solution

3.14. Mechanical Property Testing

3.14.1. Tensile Strength Testing

Tensile strength is that the maximum stress that a specimen can sustain in tension. In other words, we will say the number of applied loads per cross sectional area that a material can withstand before failure. Mathematically it's calculated because the ratio of maximum tensile load to the initial crosses section area. One in all the foremost common ways to check a material's strength is by using tensile testing. Tensile tests measure the strain over the stress of a material under uni-axial loading conditions. Because testing is completed under one stress state (only one direction), it is concluded from the test that the strengths during this test are the most a specimen at a particular thickness and temperature can withstand. For various testing, MIG-welded experimental specimens were created from welded AISI 4130 metals and machined using ASTM to determine the necessary dimensions for studying their properties. The HUT 600 servo-hydraulic with a piston speed of 0.1-120mm/min with the max force of 600KN and EN 10002-1; DIN 50.125 and UNE 7184 Servo-hydraulic universal testing machine with a max force of 2000KN exist at federal Technical Institute (FTI) were used for tensile respectively. UTM is quick, precise, and simple to use. It gets its name from the wide range of tests it can perform on various types of materials for example tension, compression, and shear tests. Tensile testing is a fundamental material science and engineering test in which a sample is subjected to a controlled tension until failure. Properties that are directly-measured via a tensile test are ultimate tensile strength, breaking strength, maximum elongation, and reduction in area (Davis, 2004b).

. The main difference between these testing machines is how the load is applied to the materials (Davis,2004). The tensile properties for any base material are also applied as the same procedure and specimen preparation it is important that the tensile properties of the base metal, the weld metal, the bond between the base metal and weld metal, and the HAZ conform to the design considerations of the weldment. where but joints are used, the weld metal should usually develop the minimum tensile properties of the base metal (AWS committee, 2000).

3.15. Specimen preparation and test procedures

Preparation of test specimens depends on the purposes of testing and the governing test method or specification. A tensile specimen usually has a standardized sample cross-section. As shown in Table 3.7 and Figure 3.17. It has two shoulders and a gauge (section) in between. The shoulders and grip section are generally larger than the gauge section by 33% so they can be easily gripped (Davis, 2004b). The specimens prepared for testing were shown in figure 3.18.

Table 3. 5: ASTM standard for tensile test specimen (Davis, 2004)

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

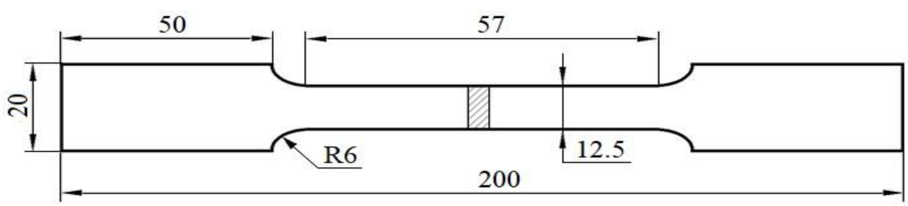


Figure 3. 9 . Tensile test specimen standard dimension

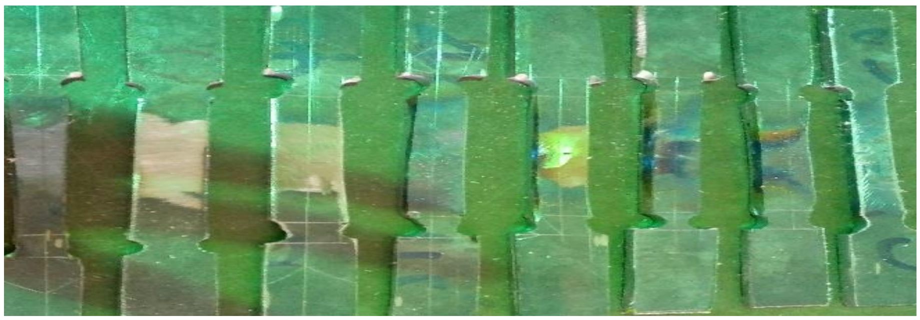


Figure 3. 10 Specimen prepared for tensile strength

The experimental procedure was carried out at Ethiopian Technical Institute using a HUT 600 servo-hydraulic Universal testing machine with a piston speed (strain rate) of 8mm/min as After specimens were prepared and the UTM machine was set up Properly the test process was performed by placing the test specimen in the testing machine and Slowly extending it until it fractures, the elongation of the gauge section is recorded against the applied force. The data is manipulated so that it 1S not specific to the geometry of the test sample. The elongation measurement 1s used to calculate the engineering strain, ε, using the following equation (Davis, 2004).

$$\varepsilon = \frac{\Delta L}{L} \tag{3.1}$$

where AL is the change in gauge length, Lo is the initial gauge length, and L is the final length.
The force measurement is used to calculate the engineering stress, σ, using the following equation:

$$\sigma = \frac{F}{A} \tag{3.2}$$

$$A = b * t$$

where F is the tensile force, A is the nominal cross-section of the specimen is the width of the specimen and t is the thickness of the specimens. The machine does these calculations as the force increases so that the data points can be graphed into a stress-strain curve.

Figure 3. 11 . Tensile test experimental set -up (at FTC)

3.16. Hardness Testing

Hardness is the ability of materials to resists penetration, abrasion, scratching or cutting. It is the property by which material resists permanent deformation. Various hardness tests are available such as Rockwell Hardness Test, Brinell Hardness Test, Brinell Hardness Test, Knop Hardness Test, Scleroscope Test and Durometer Test. Hardness testing of this specimen was performed in accordance to ASTM A18-07 standard using Rockwell Hardness Test to convert Brinell Hardness Testing Machine. Hardness refers to a material's ability to resist deformation, which is determined by a standard test that measures surface resistance to indentation. In a calibrated hardness testing equipment, the hardness of a weldment or welded specimen is assessed by pushing a hardened steel ball or diamond point into a flat surface on the weldment or welded specimen with a prescribed load and measuring the size of the resulting indentation (AWS committee, 2000). Vickers's test, Brinell test, and Rockwell test are the three most used hardness testing equipment. The Rockwell hardness test is among these machines because it is quick, inexpensive, and largely non-destructive, leaving just a tiny indentation on the specimen. The Rockwell test method can be
used on any metals unless the indentations are too large for the specimens, or the shape of the specimen prevents it from being used. The essential elements of the Rockwell hardness test are a crank and anvil, which are used to place the specimen to be tested. The Rockwell hardness test also includes an elevating Screw, which has the function of moving the specimen using the handle. The

results of the test are displayed on a screen. The Rockwell hardness test is very easy to perform. However, some precautions must be taken, such as a good surface finish on the specimens for more accurate and repeatable results, the bottom side of the specimens must securely contact the anvil without interference from debris or other loose material, and the specimens must be held stably throughout the test unless the specimen can affect the result. In most cases, a steel ball or a diamond indenter is used in the Rockwell hardness test. Rockwell hardness values are represented by a combination of a hardness number and a scale symbol that symbolizes the indenter as well as the major and minor loads. The symbol HR and the scale designation are used to represent the hardness number of any substance.

3.7.2.1. Experimental procedure

Polished specimens were evaluated using ASTM E-16 (20x2Ox5 mm), and the hardness Strength of the Welded samples was examined using a Vickers hardness testing equipment With ball shape indenter at a force of 100ke for 20 seconds as depicted in figure 3.21. The test was performed on the welded specimens at three distinct places, and the average result for the base metal zone, (BM) heat affect (HAZ) and weld zone (WZ) was recorded as the hardness of the weld joint. The experimental work took place at the. Two methods of testing were used in each testing session. The HV hardness of the weld is first determined using a conventional Rockwell hardness test machine with a ball shape indenter, and then the hardness of the material is determined using an EQUOTIP2 Digital Vickers hardness testing machine.

Figure 3. 12 . Conventional Vickers hardness test machine.

The Vickers hardness testing, a modest load is applied to the welded specimen with 10Kg as reference (minor load). Following that, the main load of 120Kg is imposed. Finally, the hardness test value is calculated using the increased depth of penetration caused by the major load, and the result is displayed on the machine's dial display. An impact body with a hard metal test tip is driven against the surface of the test piece by spring force in a portable digital Vickers hardness tester. When the impact body collides with the test surface, deformation occurs, resulting in kinetic energy loss. This energy loss is determined by comparing velocities vi and vr for the impact and reflection phases of the test when the impact body is at a specific distance from the surface. A permanent magnet in the impact body provides an induction voltage in the coil, which is properly positioned in the impact device, which is used to measure velocity. The voltage observed is proportional to the impact body's velocity. Following that, signal processing provides the hardness reading.

3.8. Micro-structure and micro-hardness testing

The microstructure and micro-hardness of this study were Computed at Adama science and technology university (ASTU) using the optical microscopy Model: HUVITZ. HR-300 series at the material science engineering laboratory. Scanning electron microscopy (OM) (JCM- 6000Plus optical microscopy) for microstructure, morphological, and fractural mechanisms testing of the weld zone was used at the biology laboratory. Micro-hardness testing using Vickers's hardness testing machine at the material engineering laboratory.

3.9. Taguchi Method

Taguchi's, which is one of the Designs of Experiment (DOE) applications, is used to investigate the effect of a variety of parameters and their behavior by conducting a small number of experiments and evaluating their impact on certain behavior. It can determine the best conditions for the experiment at the same time, resulting in a superior outcome. According to Taguchi, there are three primary phases: planning, conducting, and analysis Four parameters were evaluated in this process: welding current, welding voltage, welding speed, and Welding angle. The use of an orthogonal array is determined by the total degrees of freedom of the process parameters in the Taguchi DOE concept.

The number of comparisons required to optimize each parameter (factor) with the selected levels is accounted for or defined as the degree of freedom. With four components and four levels of the experiment, Minitab L16 statistical software is used to develop experimental design of process parameters and numerical analysis. During MIG welding of comparable 36 mild steel with AISI 4130 mild steel, the influence of welding parameters on tensile strength, hardness, micro structure, and weld bead width was investigated at four levels of study. These MIG welding settings were chosen based on the information gathered from the literature, the guidelines of the American Welding Society (AWS), and the advice of experienced and certified people at the welding shop, Centre of Excellence of Engineering (Cee), around Wesson, Addis Ababa and Nifas Silk poly technic collage

3.9.1. Orthogonal Array

Before choosing the orthogonal array, estimate the minimum number of experiments to execute based on the total number of degrees of freedom. The total degrees of freedom provided must be more than the number of experiments required to study the factors (Krishnaiah N Shahabudeen, 2012). In this study, the number of layers of Various factors was used to identify which orthogonal array to use. Four factors were chosen for the experiments, each having three levels,

$$DOF\ P^{*}\ (L-1) \qquad (3.5)$$

Where, DOF= degree of freedom

P= number of factors and

L= number of levels

DOF 4(4- 1)= 15 (0A> DOF, So OA has 16 experimental runs)

After calculating the Degree of Freedom (DOF), the number of experimental runs was chosen from an orthogonal array. The total number of orthogonal array (OA) experiments should be larger than or equal to the computed value, hence the L16 orthogonal array was chosen for the experiment design.

3.9.2. Signal to noise ratio (S/N ratio)

The Taguchi technique emphasizes the value of evaluating response variation using the signal-to-noise ratio, which reduces the effect of uncontrollable parameter variation on quality characteristics. The desired value (mean) for the output characteristic is referred to as signal, while the undesired value (deviation, SD) is referred to as noise in the Taguchi method. As a result, the S/ N ratio equals the average to SD ratio. Taguchi used the S/N ratio to assess the quality attribute that deviates from the desired value. There are numerous S / N ratios available depending on the type of characteristic; smaller is better, nominal is best, and larger is best (Karna & Sahai, 2012; Ross, 1996).

A. Larger the better (Maximization)

B. Smaller the better (Minimization)

C. Nominal the best

Standard SN ratio formula:

$$\frac{S}{N}\text{ratio} = -10\log\left[\frac{1}{n}\sum_{j}^{n} = 1\,\frac{1}{Yij^2}\right] \tag{3.6}$$

Where 'i' is the number of a trial; "Yi' is the measured value of quality characteristic for the i^{th} trial and j^{th} experiment, 'n' is the number of repetitions for the experimental combination.

3.10. Multi-response optimization

Optimization of the multi-response problem is a challenge to optimizing output responses altogether. Among the simultaneous optimization methods. most of the authors used approaches that combine all the different response requirements into one composite requirement. Hence, the Compromise solution is obtained in a much simpler way (S. Raissi and R- Eslami Farsanı, 2019).

3.10.1. Desirability Function Analysis

Harrington invented the desirability function to simultaneously optimize many responses, and Desirability function analysis is a widely used technique in academics and industry for Simultaneous optimization of several responses (Harrington, Edwin, 1965). Derringer and Suich Were eventually modified to increase their usefulness, and they became quite popular (Derringer & Suich, 1980). The desirability function approach is one of the most widely utilized multi- response optimization strategies in practice. The desirability scale ranges from 0 to 1, and it measures how near an answer is to its ideal value. The desirability of response is 0 if it falls within the unacceptable intervals, and 1 if it falls within the ideal intervals or the response reaches its ideal value. Meanwhile, the desirability ranges from 0 to 1 when a response falls within the tolerance intervals but not the ideal interval, or when it fails to reach its ideal value. The closer the response comes to the ideal intervals or ideal values, the more desirable it becomes. According to the objective features of a desirability function, the nominal -the-best (NB) answer, the larger-the-better (LB) response, and the smaller-the-better (SB) response can be classified. The proposed desirability function converts each response into a desirability rating ranging from 0 to 1. A composite desirability function can be created by combining all the desirability functions to turn a multi-response problem into a single-response problem.

3.10.1.1. Steps in desirability function analysis

For the proposed methodology, the following stages must be followed:

A. Identification of the goals and their characteristics, as well as the creation of a decision matrix to reflect performance characteristics concerning various variables.

B. For each response, the desirability index (di) value is calculated. The nature of the corresponding output determines the di value. Steps desirability

When the output response is Larger-is-better":

The bigger the value of ỳ is predicted to be. the better. The desirability value equals I when the Surpasses a specific criteria value, which can be considered a requirement; if the is less than a specific criteria value, which is unacceptable, the desirability value equals 0.0,

ý≤ ymin

$$di = \left(\frac{\tilde{y} - \text{ymin}}{\text{ymax} - \text{ymin}}\right)^r, \text{ymin} \leq \acute{y} \leq \text{ymax}, r \geq 0 \qquad (3.7)$$

ý ≥ ymax

1,

When the output response is "target value"

The value of ý is required to get a particular target T. When equals T, the desirability value is 1; if ỹ exceeds a certain range from the target, the desirability value is 0, and this is the worst-case scenario.

$$\text{di} = \left(\frac{\acute{y} - \text{ymin}}{T - \text{ymin}}\right)^s, \quad \text{ymin} \leq \acute{y} \leq \text{T}, S \geq 0$$

$$di = \left(\frac{\acute{y} - \text{ymax}}{T - \text{ymax}}\right)^t, T \leq \acute{y} \leq \text{ymax}, t \geq 0$$

$$\text{di} = \quad 0 \qquad (3.8)$$

When output response is smaller the better":

The value of ỹ is expected to be the smaller the better. When the ỳ is less than particular criteria value, the desirability value equals 1; if the ý exceeds a particular criteria value, the desirability value equals 0.

1,

ý≤ ymin

$$di = \left(\frac{\tilde{y} - \text{ymin}}{\text{ymax} - \text{ymin}}\right)^r, \text{ymin} \leq \acute{y} \leq \text{ymax}, r \geq 0 \qquad (3.9)$$

$ý \geq ymax$

0,

Where the ymin represents the lower tolerance limit of ý, the ymax represents the upper tolerance limit of ý and r represents the weight. The weights s, t, and r in the above Equations are defined according to the user's requirements. The weight can be set to a larger value if the corresponding response is expected to be closer to the target, otherwise, the weight can be set to a smaller value.

C. . Compute the Composite desirability index: To calculate the total desirability, the individual desirability values were added together.

$$Dg= \sqrt[W]{d1^{w1} * d2^{w2} * \ldots * di^{wi}} \qquad (3.10)$$

Where Di and Wi are the individual desirability and weight of the response Yi, W is the sum of the individual weights and Dg is the Composite Desirability or overall desirability.

D. Determine the optimal parameter and its level combination. The higher composite desirability value implies better product quality.

E. The most significant parameter is subjected to an analysis of variance (ANOVA). ANOVA determines the relative importance of variables.

F. Finally, using the ideal level of design parameters, predict and validate the quality features.

3.10.2. ANOVA (Analysis of variance)

Minitab L16 statistical software is used to calculate analysis of variance for the inquiry, as well as analysis of a response parameter for several experimental responses. The statistical approach of ANOVA is used to determine the influence of all control values. The percentage contributions of each control factor were utilized to measure the associated impacts on the performance characteristics in the analysis of variance. The significance level was set at 5%, which corresponded to a 95% level of confidence. The following formula was used to obtain the percentage contribution of each influential parameter from the analysis of variance (Krishnaiah and Shahabudeen, 2012).

$$P(\%)=\frac{SSTR}{SST}*100 \qquad (3.11)$$

Where P 1s the percentage contribution of individual factors, SSTR is the sum of squares or treatment sum of squares, and SST total sum of squares.

CHAPTER - 4

RESULTS AND DISCUSSION

4.1. Introduction

During the MIG welding process, the influence of welding parameters on mechanical properties, welding joint and microstructural properties of welded mild steel AISI 4130 was investigated. After the welding process was completed, the welded samples were visually inspected for welding defects by micro structure hardness test, strength test and liquid penetrant. After performing non-destructive testing, destructive testing was carried out, and the reaction parameters were measured. The outcome results for each experiment were discussed in this chapter in detail. The response results from an orthogonal array of experimental investigations were analyzed using Taguchi methods to identify the initial optimum MIG welding parameters, and the most influential welding parameters on tensile strength, hardness, micro structure and welding joint geometry for welding were identified by analysis of variance (ANOVA). The initial optimum parametric setting from Taguchi methods was used for multi-response optimization using desirability function analysis. The study focused on the investigation and parametric optimization of MIG welding settings when employing the Taguchi L16 orthogonal array to weld metals. Here under this topic, the effect of welding parameters on mechanical properties and weld bead geometry has been analyzed. Next, the response parameters from the test will be analyzed using the Taguchi technique, and the parameters was identified using analysis of variance (ANOVA). Finally, the parameters are optimized to the optimum parametric setting using a multi-response optimization technique using desirability function analysis (DFA). the welding control parameters and levels utilized during welding of mild steel AISI4130 are shown in Table 4.2 .

Table 4. 1. selected process parameters and their levels

S.No	Process parameter	Units	Levels			
			1	2	3	4
1	Welding current	Amp (A)	110	120	130	140
2	Welding voltage	(V)	20	22	24	26
3	Welding speed	(L/Min)	60	70	80	90
4	Welding angle	(Position)	15	30	45	60

4.2. Welding Defects of Welded Metals

4.2.1. Liquid Penetrant and visual Defect Testing

Liquid or dye penetrant testing (PT) is a non-destructive material testing technique that uses capillary forces to detect and locate surface fractures or holes. PT work was based on the penetration of liquid penetrant via concave surface discontinuities. It can detect surface flaws. Including fractures, slags, and porosity

4.2.1.1. Visual inspection analysis

While the welding was being done, all the samples were visually inspected. A few welding faults, such as a little of undercut at the end, lack of fusion, porosity, and lack of penetration, have been detected in welded samples. These samples are for samples no. 1, and 7 under the specific parametric condition, other all samples have nearly no flaws, have problems, but the rest of the samples are defect-tree.

4.2.1.2. Liquid penetrant testing result analysis

Lack of fusion: There was a lack of fusion in samples number 1 samples number 1. This defect occurred due to minimum current input, arc length, welding angle, and improper welding parameter settings, which contributed to the fusion failure. Lack of fusion can also be caused by improper cleaning of oily or scaled surfaces. These defects are more prone to appear when restricted access to the joint is restricted

Porosity: Dispersed porosity was observed on sample numbers 7 sample number This defect was created by air entrainment in the shielding gas, which results in dispersed porosity and gross surface pore breaking. Porosity is caused by leaks in the gas line, too high a gas flow rate, draughts, and excessive turbulence in the weld pool. For example, porosity happens when contaminants or moisture enter the weld puddle. Contaminants can be found in several locations, including the base. On the metal surface and the filler metal surface, welding fluxes, welding gases, and welding equipment are all employed.

Table 4. 2. Liquid penetrant test result for MIG welded samples

Sample1	Lack of fusion
Sample2	Defect free
Sample3	Defect free
Sample4	Defect free
Sample5	Defect free
Sample6	Defect free
Sample7	porosity
Sample8	Defect free
Sample9	Defect free
Sample 10	Defect free
Sample 11	Defect free
Sample 12	Defect free
Sample 13	Defect free
Sample 14	Defect free
Sample 15	Defect free
Sample 16	Defect free

4.3. Microstructural analysis of welded metals

An optical microscope was used to examine the microstructure of all MIG welded samples, welds, respectively The microstructure of a mild steel plate welded by metal carbon dioxide on welding has been evaluated and microstructure of every of the specimen at the weld, fusion zone and parent metals are investigated. The results of the investigation indicate that significant grain coarsening were observed within the heat affect zone and fusion zone (WZ) of all the joints and it had been found that the extent of grain coarsening within the heat affected zone increased with increase within the heat input.

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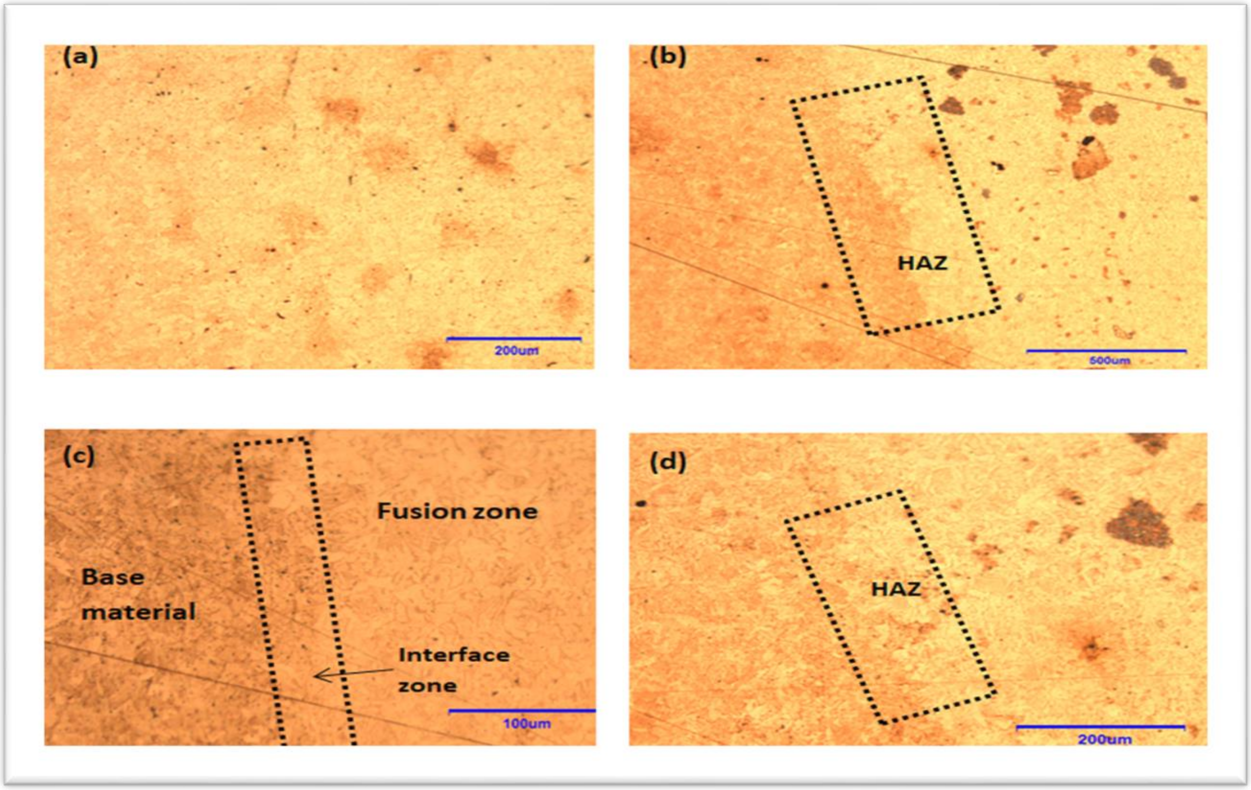


Figure 4. 1. Optical image of microstructure at magnification of 10;

(a) Microstructure of base metal (S4130), (b) Welded sample at 15 $_0$ C for sample 9 , (c) Welded sample at 30 o C and (d) Welded sample at 45 o C

Figure 4.2 shows microstructure of base material and selected welded samples. Fig.4. (b) was Welded sample at 30 oC for sample 9 conducted at welding parameters of the welded zone and heat affected areas were clearly observed that there is no defects such as micro cracks due to heat flow during welding.

Fig.4.2 (c) was Welded sample at 30 ^{o}C for sample 9 conducted at welding parameters of

Three areas or zones observed, base material zone, interface or heat affected zone and fusion zone. The microstructure shows grain structure was very uniform and small infusion zone which shows grain growth and solidification were formed. As a result of which mechanical properties fusion zone was god than interface and base material zone.

Fig.4.1 (d) was welded sample at 45 ^{o}C for sample 9 conducted at welding parameters of The common dendrite length and inter-dendrite spacing within the weld zone was found to extend with increase within the heat input. The microstructure of a mild steel plate welded by metal inert gas welding has been evaluated and microstructure of each of the specimen at the weld, heat affected zone and parent metals are investigated.

The results of the investigation indicate that significant grain coarsening was observed in the fusion zone (WZ) of all the joints and it was found that the extent of grain coarsening in the fusion zone increased with increase in the heat input. The average dendrite length and inter-dendrite spacing in the weld zone was found to increase with increase in the heat input.

4.3Mechanical Properties of Welded Metals

Micro-hardness analysis

Depicts the differences in Vickers micro hardness values as a function of distance from the weld center to the AISI 4130 mild steel in sample 9. In both joints, the hardness values of all weld areas are higher than the base metal hardness. In specimens, the weld has the highest hardness due to finer delta-ferrite. On the mild steel side. The highest hardness value was obtained in the weld zone near the fusion boundary, which was sample 10. This is caused by the creation of harder micro-constituents in this area, which is caused by carbon migration from the mild steel side into the weld metal. The average hardness value in the fusion zone of welded metals was (197HV-235 HV).. Hardness values in the HAZs of AISI4130 mild steel in welds (AISI4130) sides were increased compared to the hardness values of the base metals.

The results of the investigation indicate that significant grain coarsening was observed in the welded zone and heat affected zone of all the joints and it was found that the extent of grain coarsening in the welded zone increased with increase in the heat input. The average dendrite length and inter-dendrite spacing in the weld zone was found to increase with increase in the heat input.

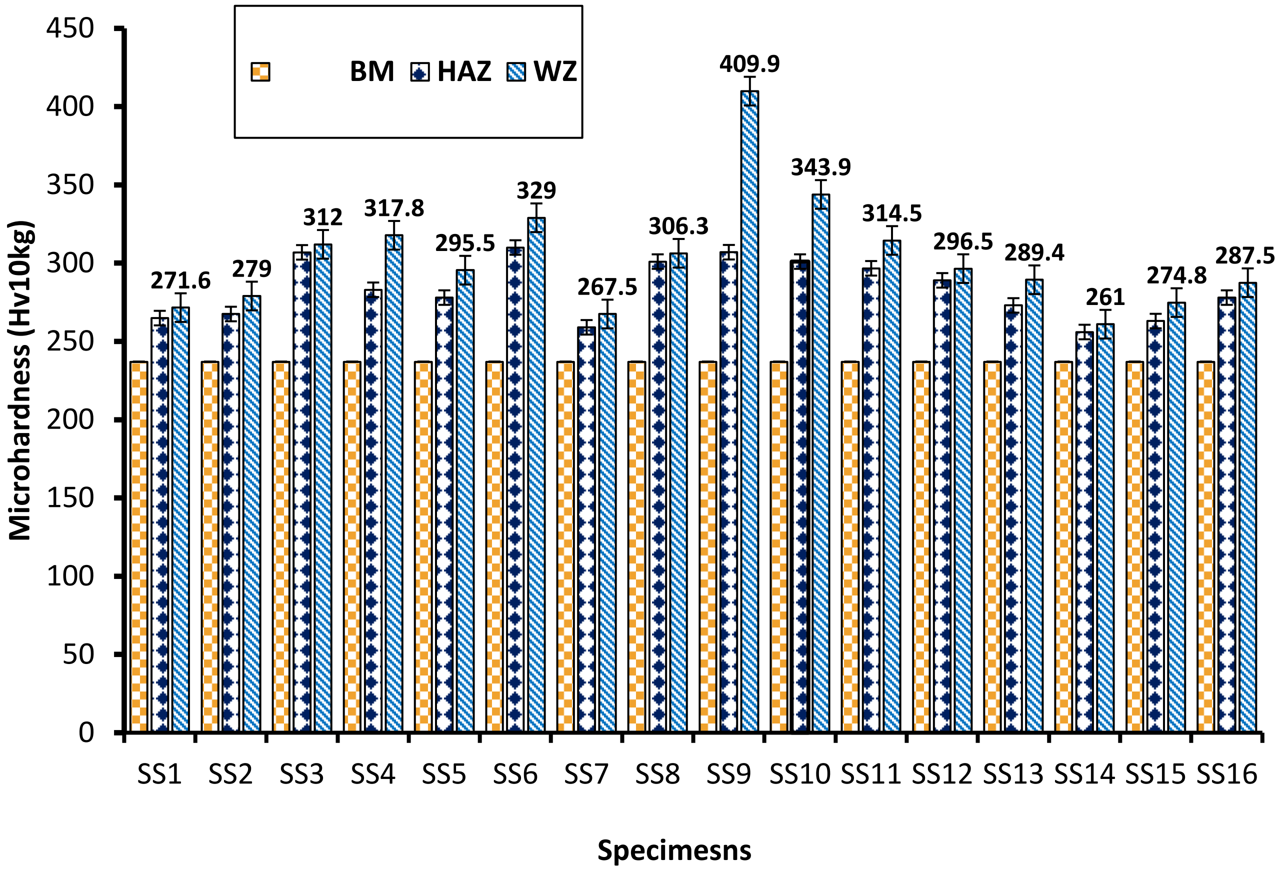


Figure 4. 2. Vickers micro hardness graph for largest value

Figure 4. 3 shows comparison of micro hardness for base material, heat affected zone (interface zone) with fusion zone for mild steel (AISI4130) grade for 16 samples conducted at different welding parameters as indicated in (Table 4.2). The result indicated that for all sample the fusion zone micro hardness was higher than both base material and heat affected zone. This was due to the grain refinement and wire feed acted as alloying purpose to improve the hardness. It can be confirmed from microstructure images shown in Fig.4.2 where the fusion zones were fine grain structures of defect free zones observed. Similar reports were studded by Anten et al.(2022). The maximum micro hardness was achieved for sample 9 as 409.9 HV while minimum was for sample was measured for sample 14 as 261 HV while the average base material micro hardness was 271.6HV. The percentage improvement of micro hardness was 33.74% from base material at sample 9. Therefore, the best welding parameters for this material was at sample 9. For all samples the micro hardness of heat affected zone was less than fusion zone due to the grain growth starts from base material zone to HAZ of columnar grains of larger in size than fusion zone.

Analysis of Tensile Strength

Tensile strength data were collected using a universal testing machine, and the stress formula was again manually calculated using equations. Each test consisted of two specimens, with the average value taken. the measured experimental results of average tensile strength values for each trial experiment. Welding parameter setup optimization for both welding circumstances has been done individually using the DFA technique. The larger the performance qualities, the better the tensile strength (larger is the better) Figure 4.4.

Table 4. 3. Mean tensile strength result

Sample No	Welding Current (A)	Welding voltage (B)	Welding speed (C)	Welding angle (D)	Tensile strength (MPa)
SS1	110	20	60	15	337
SS2	110	22	70	30	434
SS3	110	24	80	45	453
SS4	110	26	90	60	463
SS5	120	20	60	15	513
SS6	120	22	70	30	521
SS7	120	24	80	45	587
SS8	12	26	90	60	609
SS9	130	20	60	15	761
SS10	**130**	**22**	**70**	**30**	674
SS11	130	24	80	45	654
SS12	130	26	90	60	487
SS13	140	20	60	15	462
SS14	140	22	70	30	443
SS15	140	24	80	45	432
SS16	140	26	90	60	416

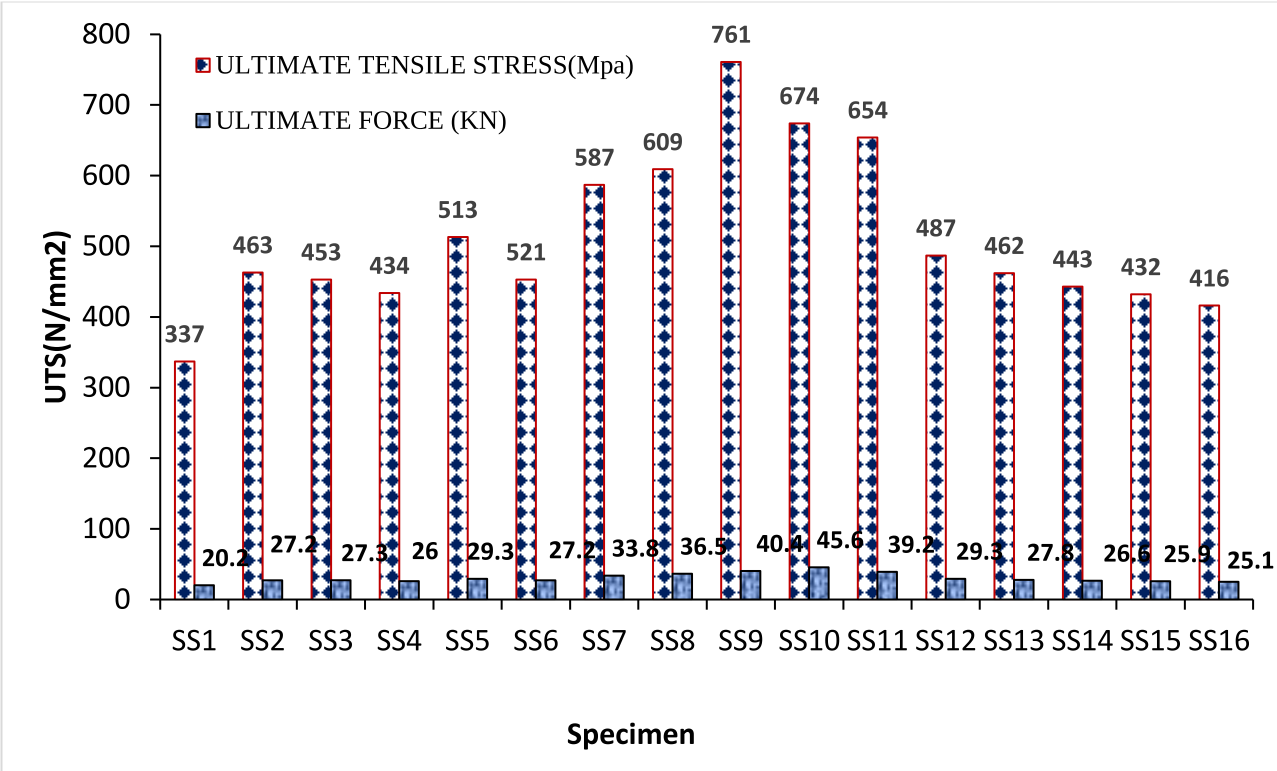


Figure 4. 3. Ultimate Tensile strength result graph

Fig. 4.4 shows the tensile strength of welded sample for 16 samples and compared with base material strength of 274 MPa. The maximum ultimate strength was achieved at sample 9 of 761 MPa. And minimum was 337 MPa for sample 1. Percentage improvement of 63.99 %. This was due to refined microstructure of fusion zone and improved micro hardness. Samples after tensile test was not at welded zone while it was in base material zone as shown in fig 4.3

4.4.1.1. Mean response analysis

A response table is calculated for each response characteristic, such as mean and signal-to-noise ratio. The response table can show which factors have the most impact on the response and which degree of the factor is associated with greater or lower response characteristic values as shown in equation (3.6). The steps for creating a response table are as follows:

1. Calculates the chosen response characteristic for each level's welding current, welding voltage Welding speed and welding angle
2. After that, the delta values, which are the differences between the greatest average response characteristic value and the lowest average response characteristic value for levels of that factor, are determined.
3. The delta values are used to assign ranks from high to low. The factor with the highest

delta value receives the top ranking.

- For example, for factor A, the mean was calculated by:

At each level, the mean for factors B. C, and D is calculated in the same way. The delta value was generated after the average means / SN ratios for each factor have been obtained. The delta value is calculated by subtracting the minimum from the greatest value. That welding current (A) has the highest value and is rated first, welding voltage (B) is ranked second, welding angle (D) is ranked third, and welding speed (C) has the lowest value when compared to other parameters and is ranked fourth by Taguchi (means) analysis. These welding settings (A1B4C2D3) were chosen for MIG welding of mild steel 4130 with a thickness of 5mm as the initial parametric setting. the main effect plot for control factors for means of tensile strength value variations. The numerical value at the largest point in each graph of means of tensile strength represents the parameter's best value at that level. They also show the ideal conditions within the experimental conditions' range. When compared to other welding factors, the welding current weight percentage is the most effective at increasing tensile strength, while the welding speed has the least effect. The Taguchi initial parameters setting was welding current at the first level (130A), welding voltage (24mm/min) at the fourth level, welding angle at the third level (15,30,45,60), and welding speed at the second level (80mm/min).

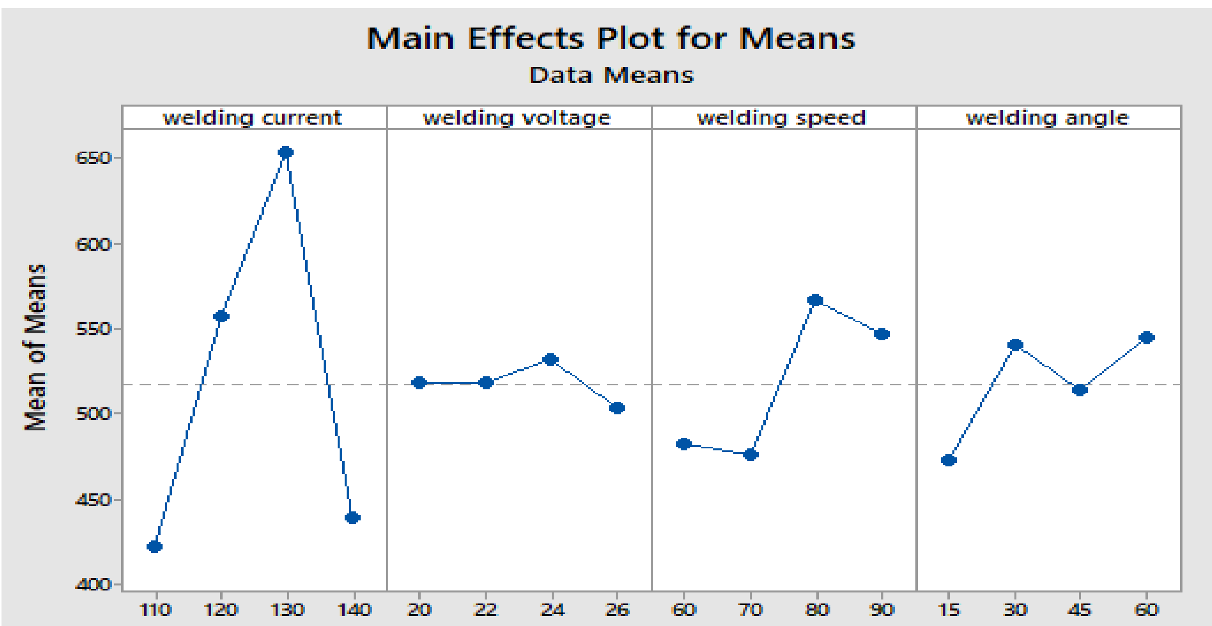


Figure 4. 4. Main effect of pilot for means

4.4.1.2. Signal to noise ratio analysis

Taguchi evaluated the quality attribute that differed from the desired value using the S/N ratio. As a result, the larger the tensile strength, the better the quality. Based on the achieved tensile strength result, the effect of the above parameters on tensile strength was examined.

Table 4. 4. Response Table for Signal to Noise Ratios Larger is better

Level	Welding current	welding voltage	Welding speed	Welding angle
1	52.43	53.92	53.40	53.31
2	54.90	54.15	53.51	**54.51**
3	**56.22**	**54.38**	**54.84**	54.07
4	52.83	53.94	54.64	54.50
Delta	3.79	0.46	1.45	1.21
Rank	1	4	2	3

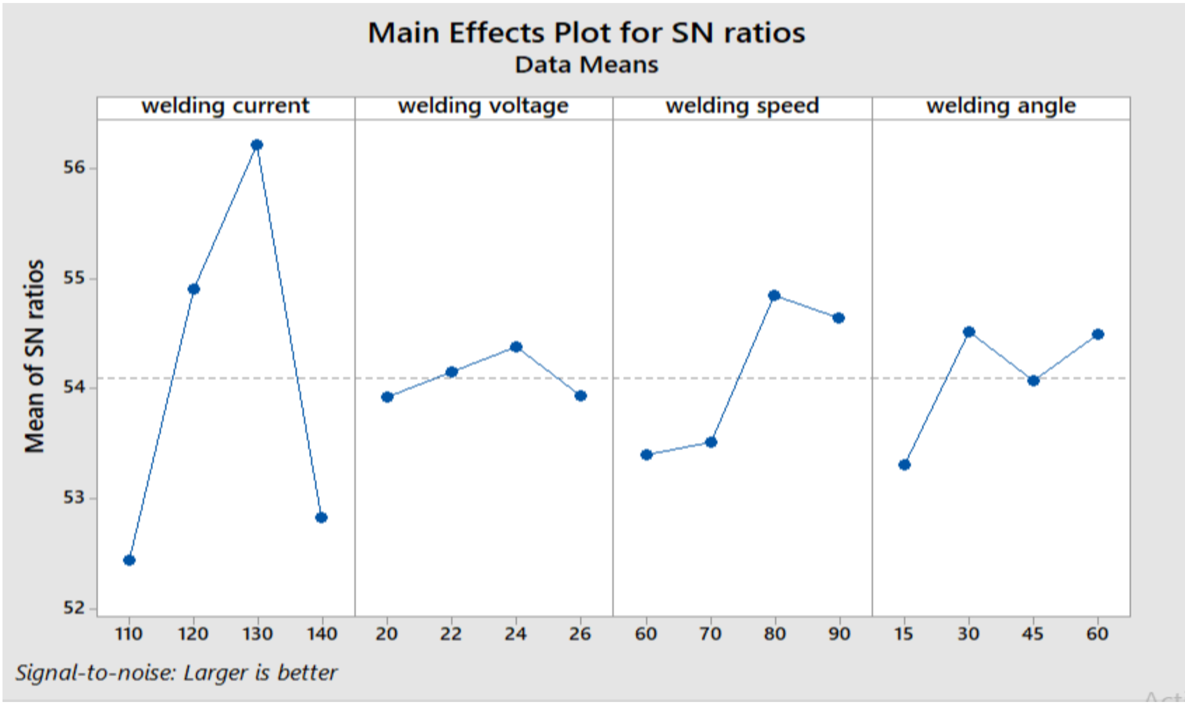


Figure 4. 5. Signal noise ratio

4.4.1.3. Effect of parameters on tensile strength

The effect of welding parameters on tensile strength, as well as the optimum values based on their rank, are shown in Figure. The optimum values to maximize tensile strength, according to the analysis and the main effect plot graph for SN ratios, are current at level one (130A), the welding angle at level three (30 degree), welding voltage at level four (24), and welding speed at level two (80mm/min) which has an initial parametric setting of A1B4C2D3.As seen from the graph above it was shown that the tensile strength was increased as the current raised from level 1(110A) to level 2 (120A). but the UTS significantly decreased from a higher value to a lower one at the current increased from level 2 to level 4 (130A). M. Naga Swapna et al., (2021) and Sanjay Kumar et al., (2019) also reported the same result that the current was the most significant welding parameter. As welding speed increased from level 1 (60) to level 3 (80) the UTS was increased. When further welding speed increased to level 3 (45 degree) the UTS started decreasing but when further the GFR raised to level four then the UTS was increased to a higher value, (Ghadi (2016) also get the same experimental result. The root gap at level 1 (1mm) was given minimum tensile strength, but the gap at level 3 (2mm) was given maximum tensile strength. Wire speed at level two (ER70-6) was best for higher tensile strength and filler at level four (ER70S-3) was given the minimum value of tensile strength.

4.1. Analysis of variance (ANOVA)

The adequacy of developed model is tested using the anova as per this technique, if the calculated value of the F-ratio (critical)of the developed model is less than the standard F-ratio F-table value) the desired confidence 95%then the model is said to be adequate with confidence limit. The coefficient of determination ‘R2’ for the ANOVA found was above --- The most significant parameters that affect the tensile strength of the MIG welded mild steels are identified using analysis of variance (ANOVA). The study was performed based on their S / N ratios to obtain the percentage contribution of each of the factors

Table 4. 5. Analysis of Variance for signal noise ratio

Source	DF	Adj SS	Adj MS	F-Value	P-Value
SNRA	1 1 1	6555	6554.77	18.61	0.050
WC	3	698	232.81	0.66	0.649
WV	3	796	265.19	0.75	0.614
WS	3	553	184.24	0.52	0.708
WA	3	67.29	0.19	0.895	
Error	1	704	352.24		
Total	15		188608		

S= o.7681% R-Sq= 99.63% R-sq =97.20%

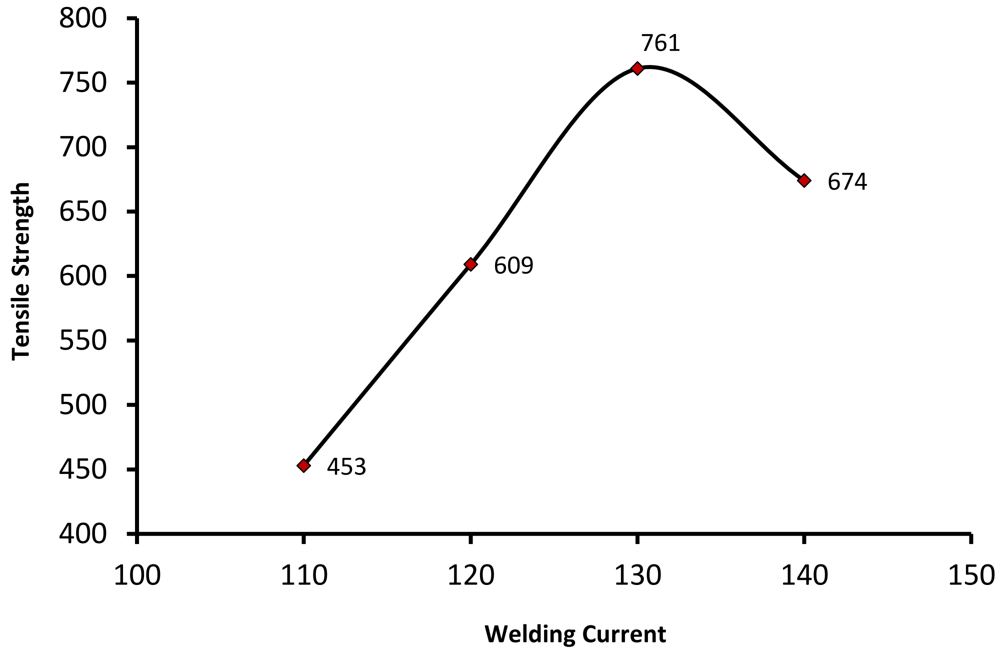


Figure 4. 6. The effect of welding current on Tensile strength

The optimum welding speed at which maximum tensile strength of 761 MPa was achieved at 130 A. From the graph it is clear that as current increased from 110 A to 130 A, strength of the welded sample increased because the heat input to the substrate material was sufficient to cause melting whereas beyond 130 A current can cause damage to work piece then strength was decreased. This was taken the optimum UTS of a given Current (110 A) four strength appeared the graph used to compare the optimum current at maximum UTS. The optimum welding speed at which maximum strength was achieved at 70 m/s .

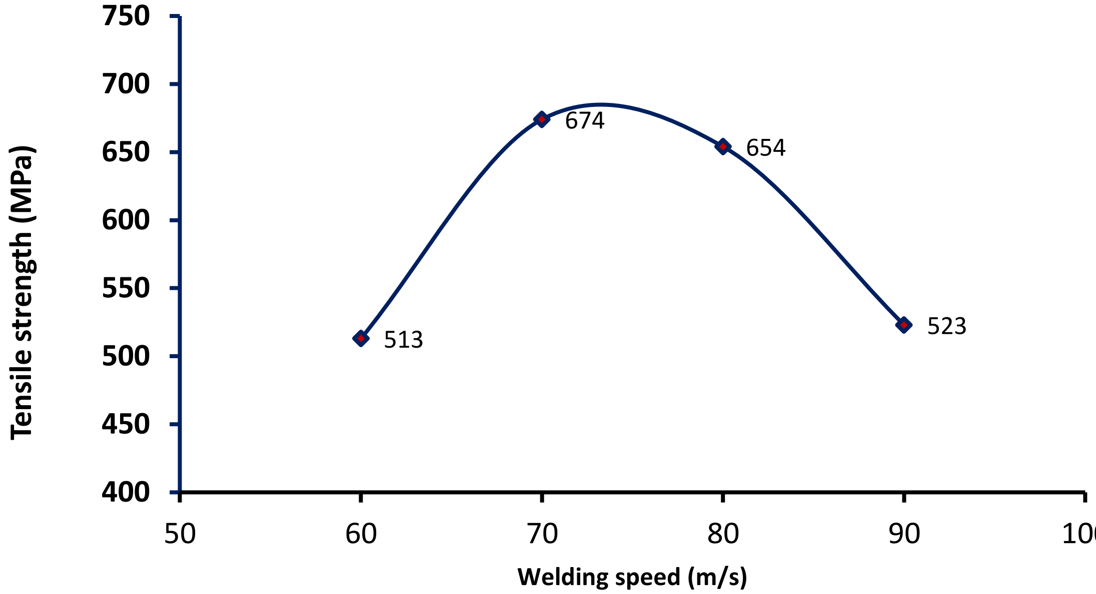


Figure 4. 7 show the effect of welding speed on tensile strength of welded sample. Optimum Welding current was 130 A.

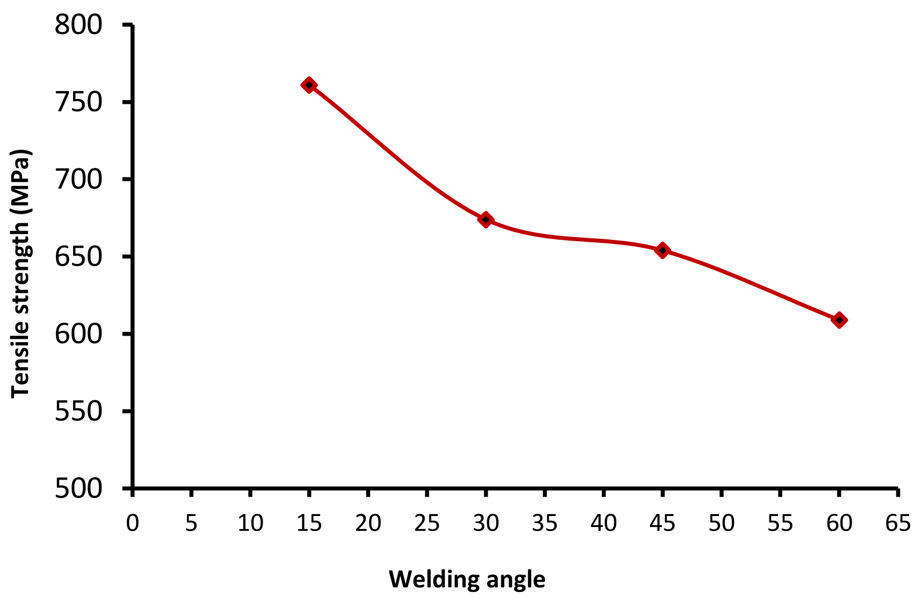


Figure 4. 8. At Optimum welding current of 130 A, effect of welding angle on tensile strength.

As shown in Fig. 4.6. as welding angle increased from 15 ^{o} to 60 ^{o}, the strength of welded sample kept reducing. From this, one can understand that the optimum welding angle using MIG weld for this material was 15 o. When angle increased more material flow from wire tip to work piece damages the weldment surface then the strength was minimum.

4.4.1.7. Effect of parameters on Hardness

Figure 4.16 depicts the effect of welding parameters on hardness, as well as the ideal values based on their rank. According to the analysis and the primary effect plot graph for SN ratios, the optimal values for maximizing hardness are current at level (130A), welding speed at level 1 (70), welding voltage at level three (24mm), and welding angle at level two (AISI 4130). From the graph below, it can be seen that when the current rises from level one to level two, the hardness rises dramatically, but only somewhat increment as the current rises from level two to level three. When the current is increased from level three to four, the hardness increases again dramatically.

The hardness of the material diminishes as the welding speed drops from level one to level three. However, as the weld speed rises from level three to level four, the hardness rises as well. The Welding angle was the third influential parameter; as the welding angle increased from level one to two, the hardness fell from a higher value to a lower value. The hardness returns to growing as the game progresses from level two to three. However, when the gap is raised from level three to level four, the hardness decreases again. The welding speed was the second important welding characteristic; when compared to other parameters had a lower hardness value. The welding speed at level two has the highest hardness value, followed by the fillers at levels three and four, each having a higher hardness value. As seen from the graph shown below the hardness IS minimum at a lower current (Salehpour-Oskouei et al. 2021) also got the same experimental result depending on the current.

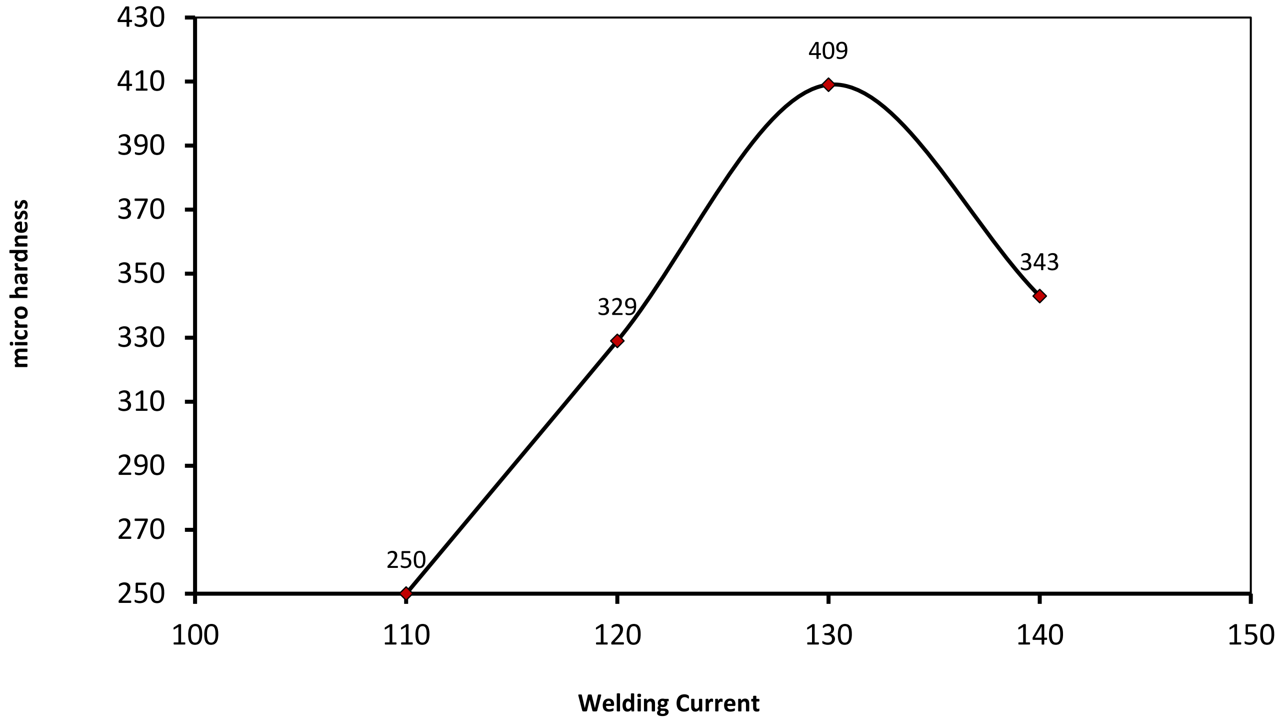


Table 4. 6. Mean hardness testing results

sample no	Welding Current (A)	Welding voltageB)	Welding speed (C)	Welding angle (D)	Micro hardness)	SNRA1
1	110	20	60	15	271.6	48.6786
2	110	22	70	30	279	48.91208
3	110	24	80	45	312	49.88309
4	110	26	90	60	317.8	50.04308
5	120	20	60	15	295.5	49.41115
6	120	22	70	30	329	50.34392
7	120	24	80	45	267.5	48.54648
8	120	26	90	60	306.3	49.72294
9	130	20	60	15	409.9	52.25356
10	130	22	70	30	343.9	50.72864
11	130	24	80	45	314.5	49.95241
12	130	26	90	60	296.5	49.44049
13	140	20	60	15	289.4	49.22997
14	140	22	70	30	261	48.33281
15	140	24	80	45	274.8	48.78033
16	140	26	90	60	287.5	49.17276

Table 4. 7. Response Table for Means

Level	WC(A)	WV(B)	WS(C)	WA(D)
1	295.1	316.6	300.6	274.1
2	299.6	303.2	286.4	297.3
3	341.2	292.2	322.3	309.7
4	278.2	302.0	304.6	332.9
Delta	63.0	24.4	35.8	58.7
Rank	1	4	3	2

The parameters best value at the level shown by maximum signifying point as below each graph. The also display optimum setting within the experiment parameters. When compared to welding variable, welding current and angle weight has greatest impacts on improving hardness, welding speed are least impact on hardness.

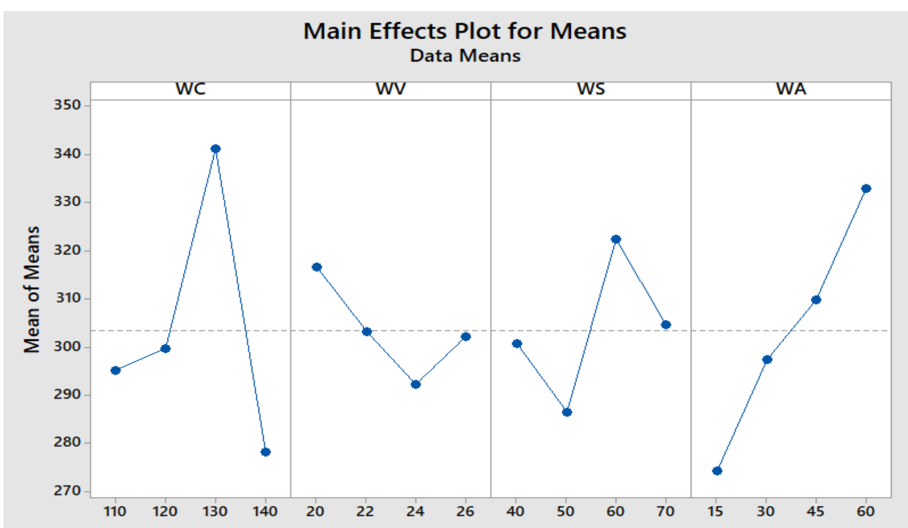


Figure 4. 9. Main effect of pilot for hardness

4.12.1. Signal to noise ratio analysis

From the S/N ratio analysis, it was observed that the welding current weight percentage has a higher effect (Delta = 44.7 Rank =,1^{st}.) followed by welding angle (Delta =12.99, rank =,3^{nd}) welding speed (Delta =35.8, rank 3^{rd}) as shown in table 4.9 below. Welding voltage (Delta = 5.99, Rank =,4^{th}) has the smallest effect on the (S/N) ratio. On larger the better, hardness character, the initial parameter combination is (A1B4C2D3) for enhancing the hardness of MIG-welded 5mm AISI4130 mild steel are selected

Table 4. 8. Response Table for Signal to Noise Ratios Larger is better

Level	WC(A)	WV(B)	WS(C)	WA(D)
1	49.38	49.89	49.54	48.75
2	49.51	49.58	49.14	49.45
3	50.59	49.29	50.05	49.80
4	48.88	49.59	49.64	50.36
Delta	1.71	0.60	0.91	1.61
Rank	1	4	3	2

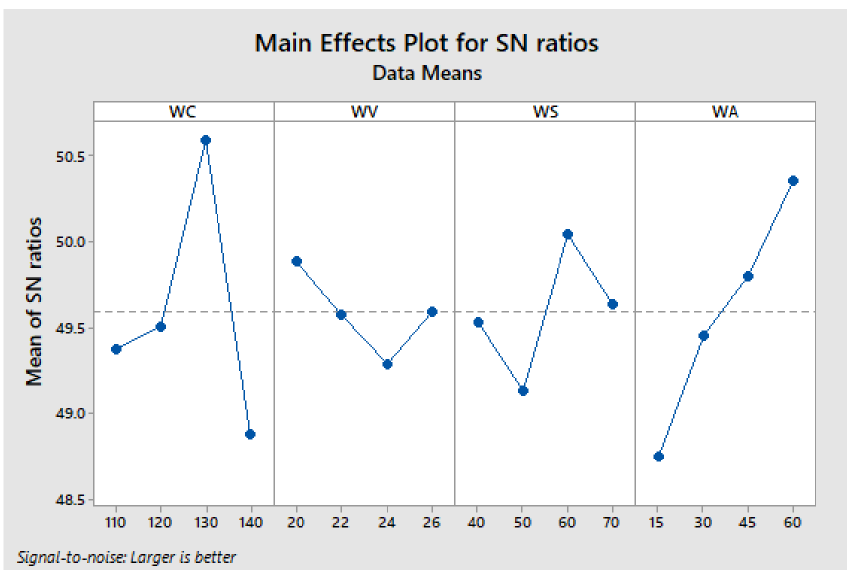


Figure 4. 10. Signal noise ratio

4.12. Analysis of variance (ANOVA)

Using analysis of variance (ANOVA) the most important characteristics of most significant parameters that determine the hardness of MIG welded mild steel are display in table 4.4. the study conducted using their S/N ratios.

Table 4. 9. Analysis of Variance for s/n ratio of hardness

Source	DF	Seq SS	Contribution	Adj SS	Seq MS	F-Value	P-Value
WC	3	8594.4	44.71%	8594.4	2864.8	17.20	0.02
WV	3	1206.2	5.99 %	1206.2	402.1	2.41	0.244
WS	3	2614.3	12.99%	2614.3	871.4	5.23	0.104
WA	3	7206.0	35.83%	7206.0	2402.0	14.42	0.027
Error	3	499.6	0.48%	499.6	166.5		
Total	15	20120.6	100.00%				

S =0.105205% R-sq R-sq =99.81% R-sq=98.57%

F-Value=2.49 < F-ratio so the parameters were significant, and as shown in the percentage graph in figure 4.9, the welding current weight percentage (44.7%), welding voltage (5%), welding speed (12,99%), and welding angle (35%) all have a significant impact on the hardness of MIG-welded AISI 4130 of mild steel with a thickness of 5mm. As a result, the welding current and welding angle has a highly significant impact on the hardness.

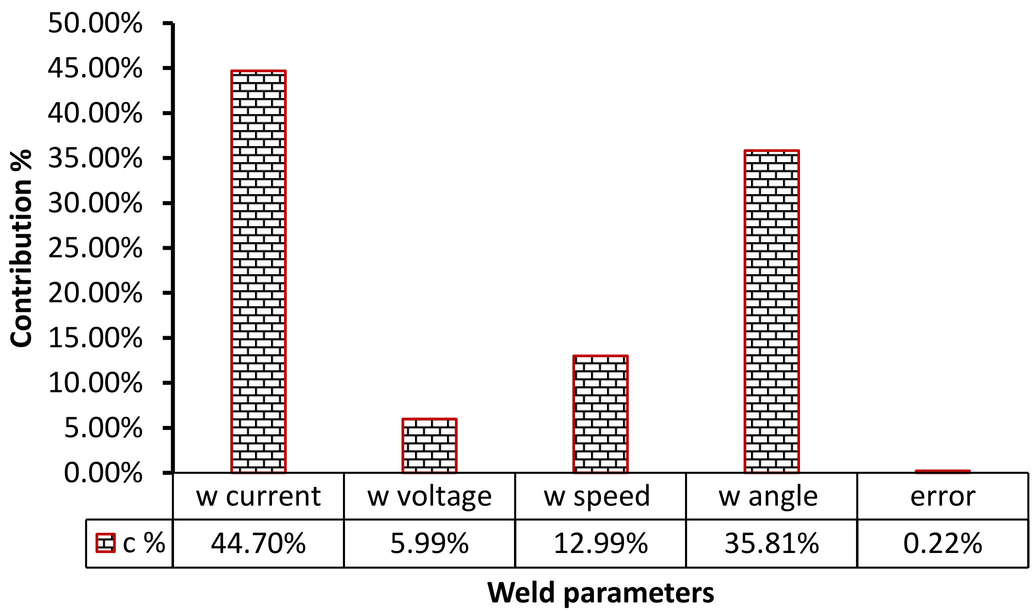


Figure 4. 11. Percentage of contribution on hardness

4.4.2. Bead width result Analysis

Table 4. 10. Experimental result of bead width

Welding Current (A)	*Welding voltageB)*	*Welding speed (C)*	*Welding angle (D)*	*Tensile strength (MPa)*	*weld bead*
110	20	60	15	337	7.2
110	22	70	30	434	6.9
110	24	80	45	453	7.8
110	26	90	60	463	8.3
120	20	60	15	513	7.6
120	22	70	30	521	7.3
120	24	80	45	587	7.1
120	26	90	60	609	7.6
130	20	60	15	761	7.2
130	22	70	30	674	7.9
130	24	80	45	654	7.8
130	26	90	60	523	8.2
140	20	60	15	462	7.4
140	22	70	30	457	7.9
140	24	80	45	443	7.8
140	26	90	60	432	8.2

The greatest width of the deposited weld metal is the weld bead width. The welded metal's bead width was determined by measuring the width of the material deposited between the base metals with Vernier calipers with a 0.0I accuracy. In each welded specimen, three readings were collected, and the average value was calculated, For each trial experiment, the measured average experimental results of bead width geometry values. Smaller bead width was projected to be the preferable option for the higher economic performance of bead width.

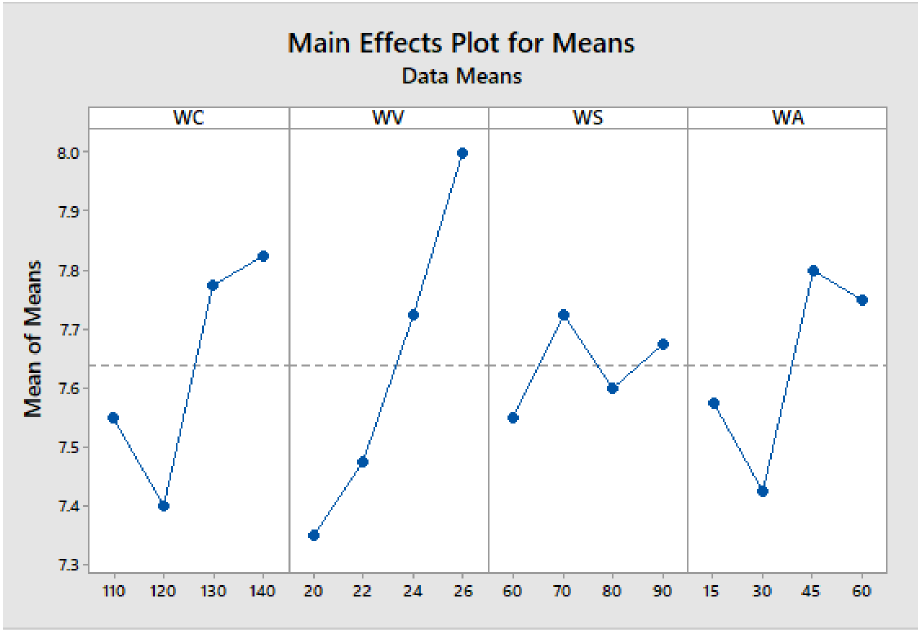


Table 4. 11. Main effect of welding current, voltage, speed and angle Response Table for Means

Level	w current	w voltage	w speed	w angle
1	7.550	7.350	7.550	7.575
2	7.400	7.475	7.725	7.425
3	7.775	7.725	7.600	7.800
4	7.825	8.000	7.675	7.750
Delta	0.425	0.650	0.175	0.375
Rank	2	1	4	3

4.4.2.1Signal to noise ratio analysis of bead width

The welding current weight percentage has the major influence, according to the signal to noise ratio value indicated in table (Delta = 0.73, Rank =,1^{st}) followed by welding current (Delta =0.48, Rank =,2^{nd}), and welding angle (Delta =0.44, Rank =,3^{rd}). The welding speed has the smallest impact on the (S/N) ratio (Delta = 0.18, Rank =, 4^{th}.) The parameter combinations A2B1C4D3 based on the smaller the better, weld width character is the first optimum parameter combination for enhancing the bead width with the smallest the better response.

Effects of parameters on bead width size

the welding factors influence bead width, as well as the best values for each factor based on their rank. According to the analysis and primary effect plot graph for SN ratios, the optimal values for minimizing bead width are voltage at level 1 (24v), welding current at level 2 (130min/sec), welding angle at level three (30), and welding speed at level three (80), with an initial parametric setting of A2B1C4D3. As the voltage rises from level one to level three, the bead width of the weld grows proportionally with the current input. As the current is increased from level three to level four, the bead width (weld width) increases significantly Ramachandran, (2015). The width of the weld narrows as the welding speed rises from level one to level two, which is desirable. As the welding speed from level two to level four, the bead gets bigger. The second influential component was the welding current; when the current climbed from level one to three, the bead width decreased from a greater to a smaller amount. When gaps rise from level three to level four, the bead diameter widens considerably. As a result, the best bead width was chosen at stage three. The filler metal type was the list relevant welding attribute; level two current had a wider bead width value than other metals.

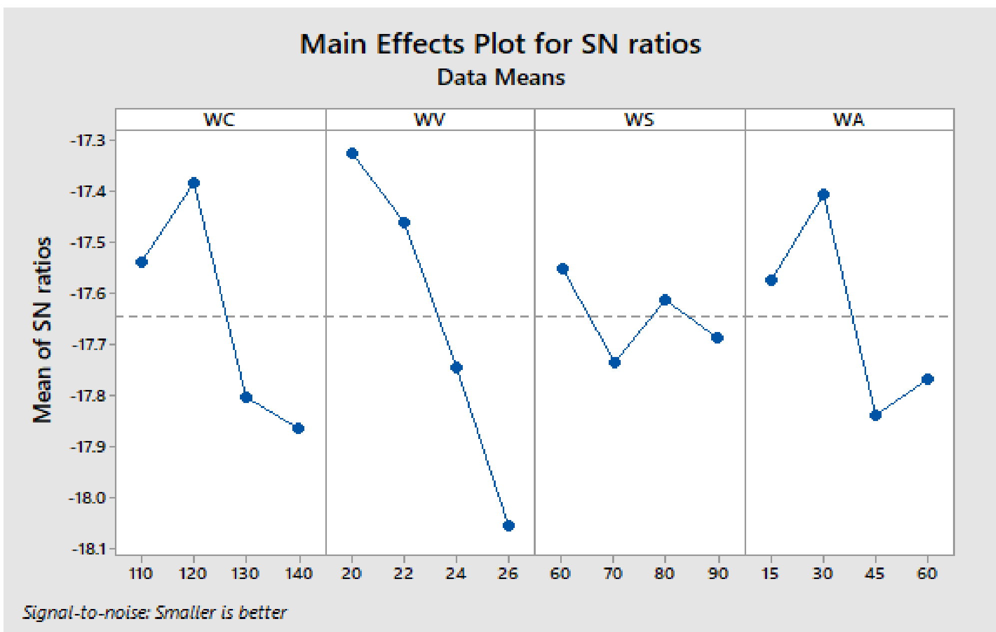


Figure 4. 12. Signal to noise ratio analysis of bead width

Table 4. 12. Response Table for Signal to Noise Ratios Smaller is better

Level	WC	WV	WS	WA
1	-17.54	-17.32	-17.55	-17.57
2	-17.38	-17.46	-17.74	-17.40
3	-17.80	-17.75	-17.61	-17.84
4	-17.86	-18.06	-17.69	-17.77
Delta	0.48	0.73	0.18	0.44
Rank	2	1	4	3

4.4.3. Desirability function analysis (DFA)

It's a common method for large-scale industries to optimize multi-responses by combining multiple response characteristics into a single response characteristic. In this study, Taguchi methodology was used to determine the best process parameters for single performance characteristics only, whereas desirability function analysis was used to determine the best process parameters for multiple performance characteristics at the same time. The original parametric set was computed using the Taguchi technique to get the anticipated parametric set by using desirability these values were used in each result and analysis of tensile strength, hardness, and bead width.

4.4.3.1. Steps in Desirability function analysis

First: The design of a decision matrix to reflect performance characteristics in connection to numerous variables, as well as the identification of goals and their features.

Table 4. 13. Result tables for all response

Sample No	*Welding Current (A)*	*Welding voltage B)*	*Welding speed (C)*	*Welding angle (D)*	Micro hardness (HV)	*Tensile strength (MPa)*	*Bead width (mm)*
MS1	110	20	60	15	271.6	337	7.6
MS2	110	22	70	30	279	434	7.8
MS3	110	24	80	45	312	453	7.3
MS4	110	26	90	60	317.8	463	8.1
MS5	120	20	60	15	295.5	513	7.6
MS6	120	22	70	30	329	521	7.56
MS7	120	24	80	45	267.5	587	7.91
MS8	120	26	90	60	306.3	609	8.38
MS9	130	20	60	0	409.9	761	8.76
MS10	130	22	70	30	343.9	674	7.5
MS11	130	24	80	45	314.5	654	7.4
MS12	130	26	90	60	296.5	523	8.2
MS13	140	20	60	0	289.4	462	8.5
MS14	140	22	70	30	261	443	7.8
MS15	140	24	80	45	274.8	432	8.2
MS16	140	26	90	60	287.5	416	7.9

There are three responses in table 4.19, however, the expected positive reaction in each response was different depending on the aims that were needed. For example, the goal (objective) for tensile strength was maximization, and the bead width goal was minimization. Each answer is calculated according to its objective. Second: The individual desirability index (di) value is calculated for each response. Di value is determined by the type of the relevant output. Using equation (4.3) for Maximization and equation (4.4) for minimization.

$$\acute{y} \leq \text{ymin}$$

$$di = \left(\frac{\tilde{y} - \text{ymin}}{\text{ymax} - \text{ymin}}\right)^{r}, \text{ymin} \leq \acute{y} \leq \text{ymax}, \text{r} \geq 0 \tag{4.3}$$

$$\acute{y} \geq \text{ymax}$$

1,

$$di = \left(\frac{\tilde{y} - \text{ymin}}{\text{ymax} - \text{ymin}}\right)^{r}, \text{ymin} \leq \acute{y} \leq \text{ymax}, \text{r} \geq 0 \tag{4.4}$$

$$\acute{y} \geq \text{ymax}$$

Where the *y*min represents the lower tolerance limit of ý, the *y*max represents the upper tolerance limit of ỳ and r represents the weight. The larger is the better: So, for Tensile strength, hardness, and flexural strength the objectives are maximization For tensile strength: specimen no1: d1

$$d1(tensile) = \left(\frac{337-416}{761-337}\right)^{0.5} = 1.023$$

For hardness: specimen no 1:

$$d1(hardness) = \left(\frac{271.6-261}{409.9-261}\right)^{0.5} = 0.94$$

Since the previous three responses maximize the response variables, this is how all of the responses for trials 2 through 16 for each response parameter were done. The smaller the better: The objective of the bead width response parameter is minimization. As a result, the equation used to calculate the individual desirability index for bead width differed from the responses above.

For bead width: specimen no 1:

$$\text{d1 (bead width)} = \left(\frac{7.6-7.3}{7.3-8.7}\right)^{0.5} = 0.89$$

The individual desirability index for smaller is the better was calculated using this equation for all 2 to 16 trials.

Table 4. 14. Individual desirability index and composite desirability index

Sample No	**Micro hardness** (HV)	***Tensile strength (MPa)***	***Bead width (mm)***	**HV**	***Mpa***	***BM mm***	***rank***
SS1	271.6	337	7.6	0.266	0.431	0.458	16
SS2	279	434	7.8	0.347	0.767	0.585	12
SS3	312	453	7.3	0.585	0.346	0	7
SS4	317.8	463	8.1	0.617	0.396	0.74	10
SS5	295.5	513	7.6	0.481	1.598	0.458	8
SS6	329	521	7.56	0.675	0.661	0.421	6
SS7	267.5	587	7.91	0.208	0.638	0.646	5
SS8	306.3	609	8.38	0.551	1.126	0.86	4
SS9	409.9	761	8.76	1	0	1	1
SS10	343.9	674	7.5	0.746	1.722	0.37	2
SS11	314.5	654	7.4	0.599	1.491	0.261	3
SS12	296.5	523	8.2	0.488	0.67	0.785	6
SS13	289.4	462	8.5	0.436	0.391	0.906	11
SS14	261	443	7.8	0	0.3	0.585	13
SS15	274.8	432	8.2	0.304	0.29	0.785	15
SS16	287.5	416	7.9	0.421	0	0.641	14

Third: Compute the Composite desirability index: To calculate the total desirability, the Individual desirability values were added together.

$$Dg_1 = \sqrt[w]{d1^{w1} * d2^{w2} *..* di^{wi}} \quad (4.5)$$

Where Di and Wi are the individual desirability and weight of the response Yi. W is the sum of the individual weights and Dg is the Composite Desirability or overall desirability. So, from the above individual desirability index, the composite desirability index was computed.

$Dg= \sqrt[w]{d1^{w1} * d2^{w2} * d3^{w3}} =$

CDI (dg) were analyzed after their composite desirability index (dg) was determined based on their rank. The CDI (dg) in the first place was used as the CDI's initial parameter setting.

Table 4. 15 : initial parametric setting

Initial setting	UTS(MPa)	HARDNESS (HV)	BM(MM)	CDI(dg)
A1B2C3	761	409	7.6	0.746

Fourth: Determine the optimal parameter and its level combination. The higher composite desirability value implies better product quality. Conduct Taguchi's experimental work with this CDI value as the response parameter to obtain the best parametric configuration.

4.7. Confirmation test

The confirmation test is required after the experimental optimization to validate whether the optimized parametric configuration is accepted or not. As a result, the confirmation experimental test was carried out at the Addis Ababa Ethiopian Nifas Silk poly technic collage (NSPTC) at the welding training content station. So, from the conformity test, it was gained that the experimental parametric setting results were agreed with the predicted optimum parametric setting result with a minimum accepted validation error of less than 1% for welded metals and percent for welded metals, according to the results of the confirmation test.

CHAPTER - 5

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This thesis investigated and optimized the parameters of metal inert gas welding on mild Steels (AISI 4130) steels. The experimental results were analyzed using a Taguchi L16 orthogonal array and the signal-to-noise ratio method, and ANOVA was used to determine the influential effect of each parameter. To minimize their effect on mechanical and microstructural qualities and bead geometry, DFA was utilized to perform multi-response optimization of input parameters such as welding current, welding voltage, welding speed and welding angle. As result of the experimental findings, the following conclusions were drawn:

1. For metals, nondestructive testing was performed using PT for welding faults, and problems such as porosity, lack of fusion, and lack of penetration were identified on a few samples. The weld zone of sample numbers 9 and 10 for welding methods exhibits a very fine skeletal ferrite along with grain, sub-grain, and migrating boundaries in the plain austenitic matrix due to moderate heat input and moderate cooling rate.
2. Due to very low welding heat inputs, i.e., high cooling rates, sample number 1 for welded metals in clues (A) -ferrite in the form of dendritic lathy-ferrite. The delta ferrite (B) in the MIG weld zone of sample number 14 is coarser. The heat input was increased to 140A on for sample.
3. At the combinations of welding conditions A2B4C3D2 (130A welding current, 80 welding speed,15 welding angle, and 24 welding voltage), a higher tensile strength of 761 MPa was produced in a weld. The most significant characteristic of tensile strength was welding current, followed by welding speed, according to ANOVA.
4. The effect of welding parameters on hardness confirmed that with a combination of 130A welding current, 80 welding speed, 15 welding angle, and 24 welding voltage, a maximum hardness of 97 HRB or 227 HV was reached. Welding current was the most significant factor for hardness, followed by welding speed, according to an analysis of variance (ANOVA).
5. Minimum weld bead width of 7.3mm was achieved at a parametric combination of 110A welding current, 60 welding, 45welding angle, and 20 welding voltage. Analysis of variance

(ANOVA) shows welding current was the most significant parameter for bead width followed by welding angle.

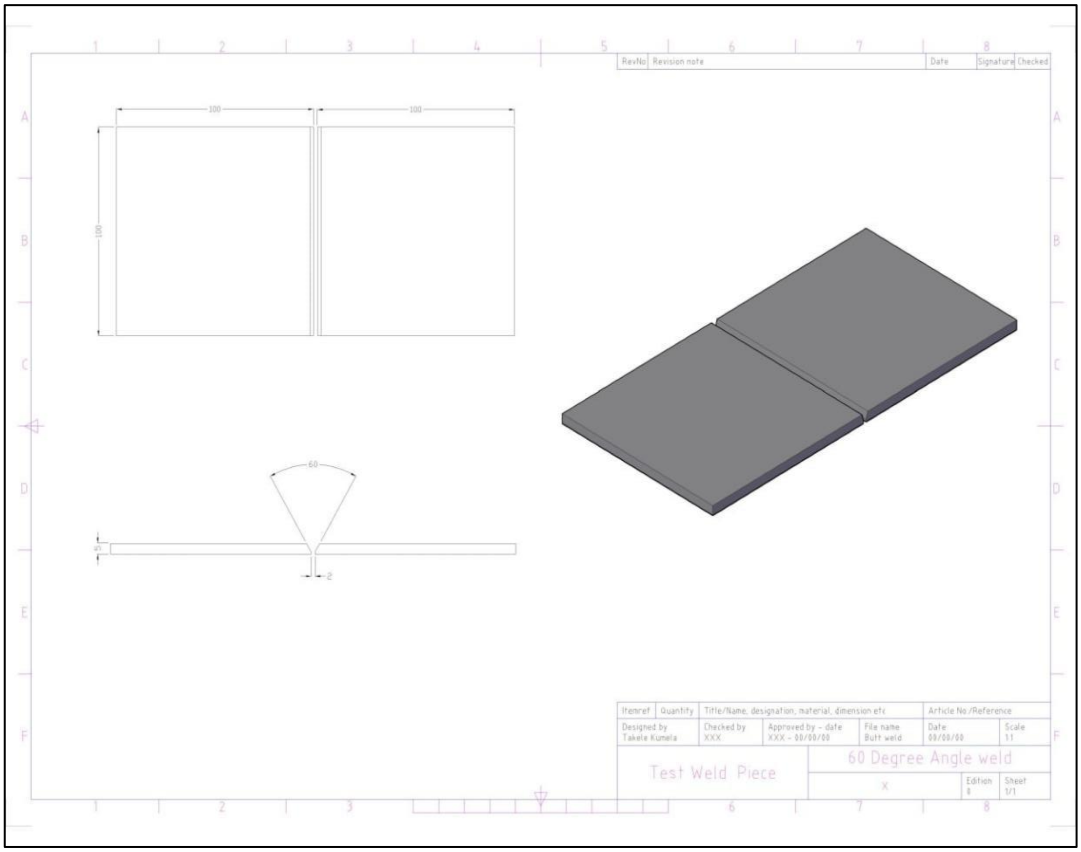
6. From the optimization result, it was shown that all responses were improved from initial setting value to optimum parametric setting value i.e., UTS was improved from 435MPa to 761MPa (%), hardness was improved from 197HV to 237HV (%), and bead width was improved from 7.6mm to 7.3mm (%) and overall optimum parametric setting of (A1B2C4D3).

5.1 Recommendation

The following points were left for future work as recommendation:

1. The finding of this work can be implemented in industry effectively by setting welding parameters.
2. Further referencing of this finding for other reassert inputs is recommended.
3. Simulation and excremental values can be parallel conducted to proof the effects of welding parameter on quality.
4. The optimum welding parameters obse3rved in this thickness shall be tested for more thickens greater than 5 mm.
5. The metallography of welded joint further investigated by SEM imagining.
6. The solidification process shall be studied further analytically using software like heat flow and fluid dynamics.

APPENDIXES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Scale
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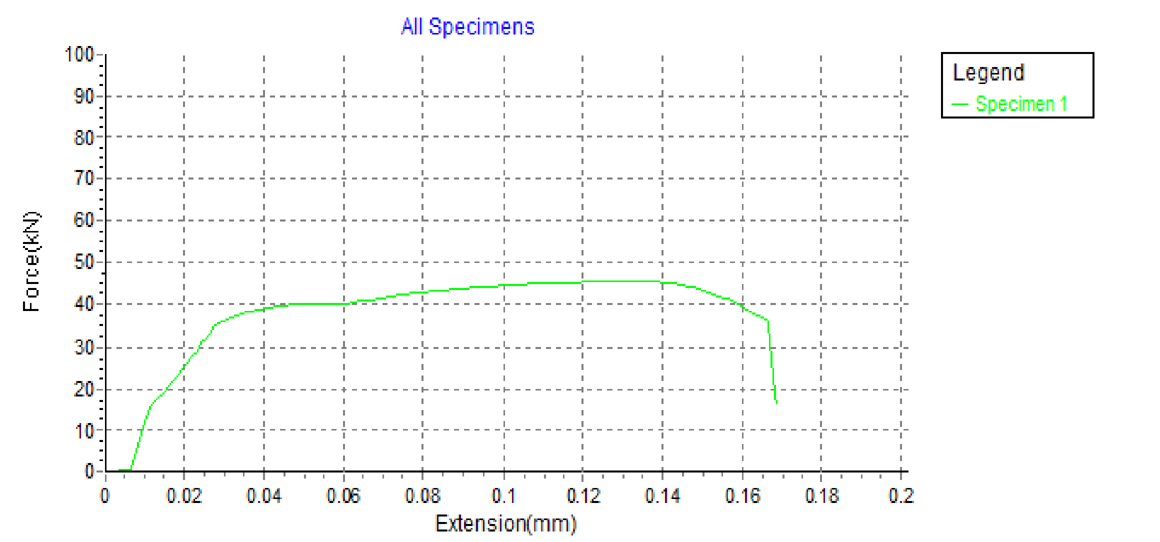
Test Weld Piece
60 Degree Angle weld
X
Edition
Sheet
1/1

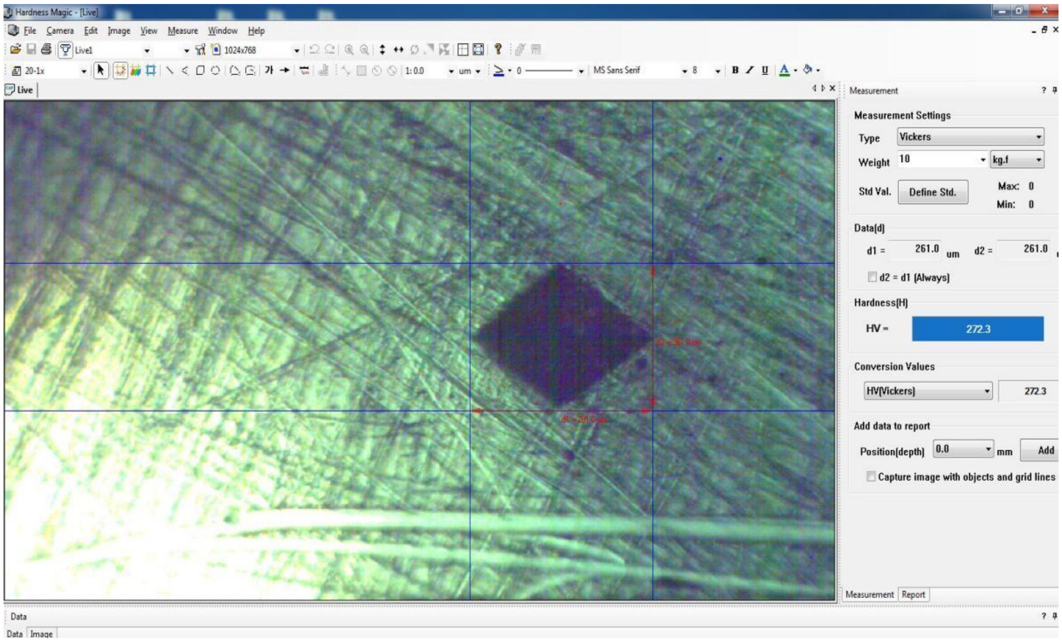
EN-02-Metallic materials-Tensile test-2

(Test data record sheet)

Sample No.				Test Standard					
Laboratory				Customer					
Temperature				Tester					
Humidity				Checker					
Test Date		5/15/2023							

No.	width	thickness	Lo	Fm	FeH	FeL	Fp0.2	Ft1.0	Lu
	mm	mm	mm	kN	kN	kN	kN	kN	mm
1	12	5	200	45.6	0.0	38.5	-0.1	0.0	
No.	A	Rm	ReH	ReL	Rp0.2	Rt1.0			
	%	MPa	MPa	MPa	MPa	MPa			
1	100.0	761	0	641	-1	0			

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File Camera Edit Image View Measure Window Help
Live
Measurement
Measurement Settings
Type Vickers
Weight 10 kg.f
Std Val. Define Std.
Max: 0
Min: 0
Data(d)
d1 = 261.0 um d2 = 261.0
d2 = d1 (Always)
Hardness(H)
HV = 272.3
Conversion Values
HV(Vickers) 272.3
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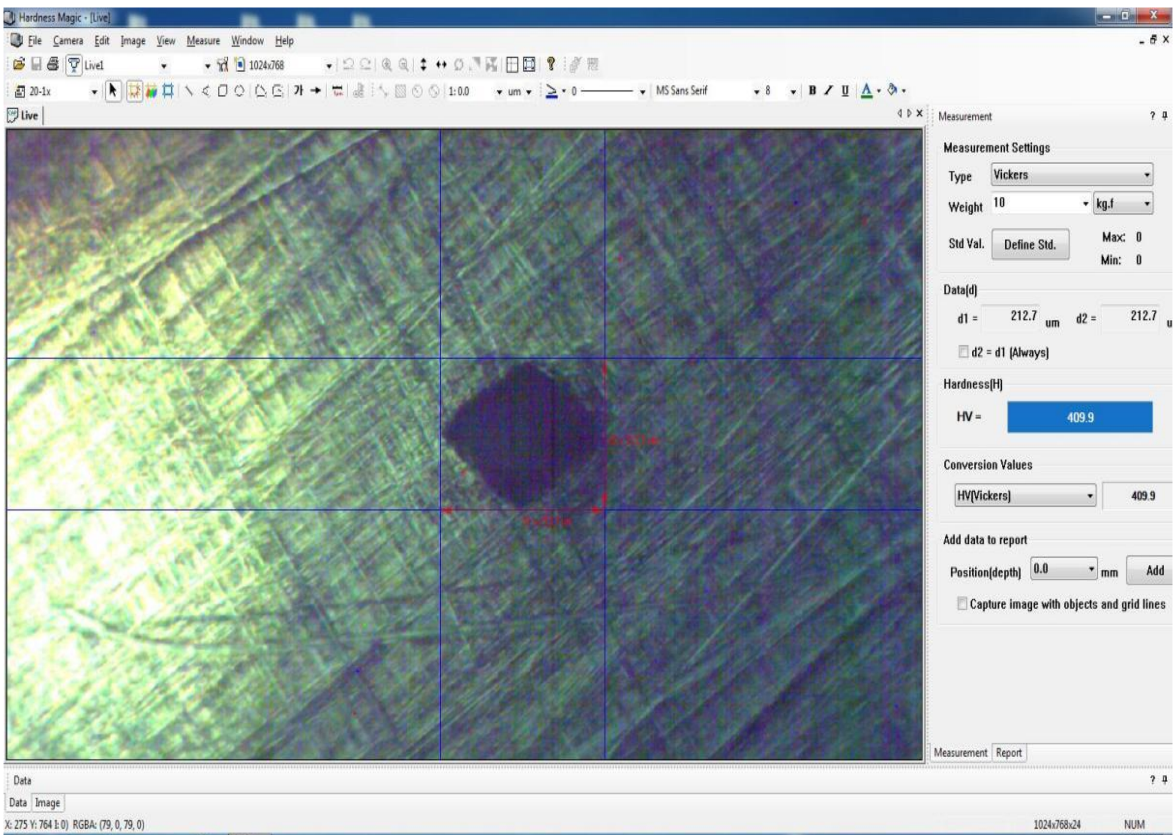
Position(depth) 0.0 mm Add
Capture image with objects and grid lines
Measurement Report
Data
Data Image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Measurement Settings
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Weight 10 kg.f
Std Val. Define Std.
Max: 0
Min: 0
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d2 = d1 (Always)
Hardness(H)
HV = 409.9
Conversion Values
HV(Vickers) 409.9
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Data Image
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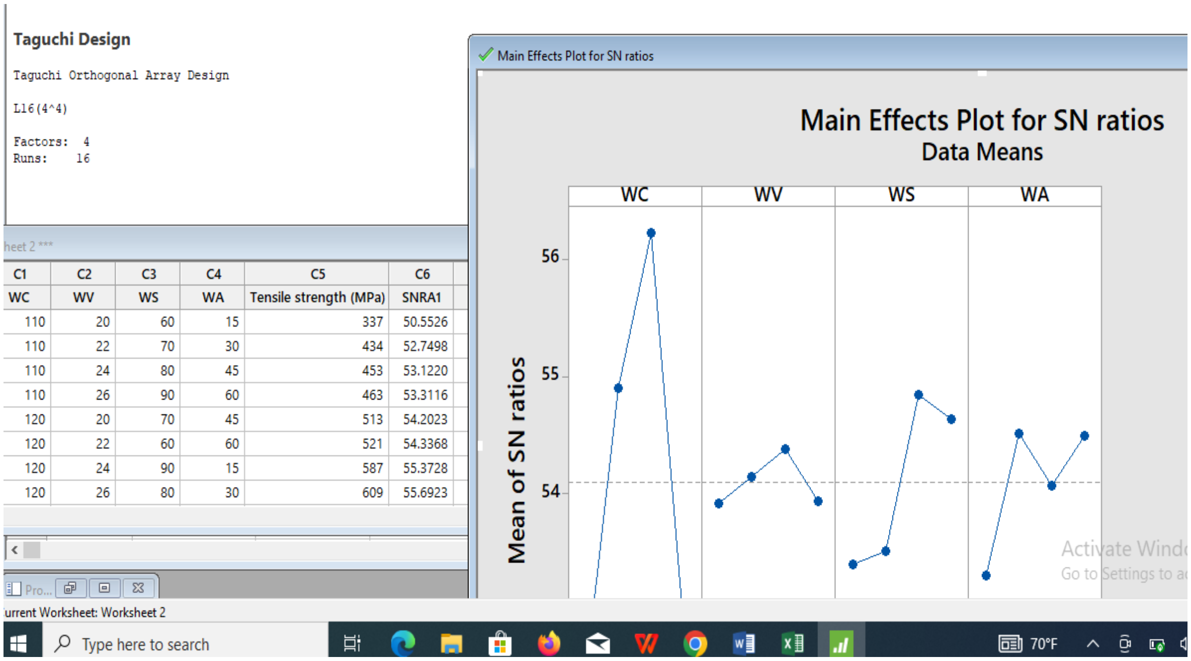
1024x768x24
NUM



C1	C2	C3	C4	C5	C6
WC	WV	WS	WA	Tensile strength (MPa)	SNRA1
110	20	60	15	337	50.5526
110	22	70	30	434	52.7498
110	24	80	45	453	53.1220
110	26	90	60	463	53.3116
120	20	70	45	513	54.2023
120	22	60	60	521	54.3368
120	24	90	15	587	55.3728
120	26	80	30	609	55.6923


Bairoe
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Bairoe

Reference

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