INVESTIGATION OF THE EFFECTS OF TIG WELDING PARAMETERS ON ORBITAL WELDING OF MILD STEEL PIPES OPTIMIZED THROUGH TAGUCHI-BASED HYBRID GREY RELATIONAL ANALYSIS

Baharu Gadisa Hunde

A Thesis Submitted to Department of Mechanical Engineering

Collage of Mechanical, Chemical and Material Engineering

Office of Graduate Studies

Adama Science and Technology University

January, 2026

Adama, Ethiopia

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DECLARATION

I, the undersigned, solemnly swear that the work report titled "**Investigation of the Effects of Tig Welding Parameters on Orbital welding Of Mild Steel Pipes Optimized Through Taguchi-Based Hybrid Grey Relational Analysis**" is based on my work completed during my studies under Dr. Habtamu Beri advisor (Assoc. Prof)). The remarks made and conclusions reached are, in my opinion, the result of the project's work. To the best of my knowledge and belief, the report does not contain any part of any work that has already been submitted for thesis review at this university.

Candidate's name	Signature	Date
Baharu Gadisa	____________	__________

RECOMMENDATION

I, the major advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Investigation of effect Welding Parameters of Tig Welding Orbital Mild Steel Pipe Optimized Through Taguchi Base Hybrid Grey Relational Analysis" prepared under my guidance Baharu Gadisa Hunde Submitted in partial fulfillment for the degree of master's science in manufacturing engineering.

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

Dr. Habtamu Beri (**Assoc. prof**) ____________________ ________________

Major advisor Signature Date

APPROVAL PAGE

I, here by certify that the recommendation and suggestions given by the proposal review committee are appropriately incorporated in to the final thesis proposal entitled **"**investigation of effect welding parameters of TIG welding orbital mild steel pipe optimized through TAGUCHI base hybrid grey relational analysis" **by** Baharu Gadisa**.**

Dr. Habtamu Beri (Assoc. prof) _______________ ________________

Advisor Signature Date

We, the undersigned, members of the Board of Reviewers of the thesis proposal by **Baharu Gadisa** have read and evaluated the thesis proposal entitled "investigation of effect welding parameters of TIG welding orbital mild steel pipe optimized through TAGUCHI base hybrid grey relational analysis" and examined the candidate during the open defense. This is, therefore, to certify that the thesis proposal is accepted and we recommend the implementation of the proposal for degree of Master of Science in Manufacturing Engineering.

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Chairperson Signature Date

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Reviewer 1 Signature Date

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Reviewer 2 Signature Date

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

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Department Head Signature Date

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School Dean Signature Date

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Office of Graduate Studies, Dean Signature Date

ACKNOWLEDGEMENTS

First and foremost, I want to thank Almighty God for giving me the strength and support I needed to complete this research study. I had liked to express my profound gratitude to my Advis or, Dr. Habtamu Beri (Assoc. prof**)**, for giving critical guidance, encouragement, moral support, and on-going assistance throughout this project. Working and studying under your supervision was an incredible privilege and experience. I am incredibly appreciative for everything you have done for me.

I also owe a debt of gratitude to Dr. Birhane Asefa for his relentless advice, suggestion, and support during working at the Centre of Excellence Engineering

My heartfelt thanks and affection go out to my one and only family for their unwavering support and understanding. You have been my inspiration throughout this, and I'm confident you will be my pillar for the rest of my life.

Thank you all

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LIST OF ABBREVATIONS

AISI	American Iron and Steel Institute
AMF	Asella Malt Factory
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
ASTM	American Society for Testing Materials
BS	Bending Strength
CFC	Chilalo food complex
CS	Compressive Strength
DC	Direct Current
DOE	Design of Experiment
DOF	Degree of Freedom
EWP	Pure tungsten
FD	Filler Diameter
GFR	Gas Flow Rate
GMAW	Gas Metal Arc Welding
GRA	Grey Relational Analysis
GRC	Goal Ratio Calculation
GRG	Grey Relational Grade
GTAW	Gas Tungsten Arc Welding
HAZ	Heat Affected Zone
HRB	Rock Hardness B scale
HS	Hardness Strength
HTMMCs	Hybrid Titanium Metal Matrix Composites
RH	Rockwell Hardness
S/N	Signal-To-Noise
SAW	Submerged arc welding,
SMAW	Shield metal arc welding
TGRA	Taguchi-based Grey Relational Analysis
TIG	Tungsten Inert Gas Welding

UTS	Ultimate tensile Strength
WC	Welding Current

ABSTRACT

TIG or Gas Tungsten Arc Welding (GTAW) is a pivotal metal-fusing process essential for manufacturing robust metal structures. Among various methods, GTAW is renowned for producing high-quality welds, particularly in critical industries such as oil, gas, and energy. This research investigates the optimization of TIG welding parameters for 1020 mild steel pipes using a hybrid approach that integrates Grey Relational Analysis with the Taguchi method. TIG welding is valued for its precision, producing strong, high-quality welds in thin materials and non-ferrous metals. It allows filler-free welding, maintains cleanliness, and minimizes heat input, reducing warping.

The study aims to identify key parameters affecting mechanical properties like hardness, tensile strength, and bending strength, addressing prevalent challenges such as inconsistent weld quality caused by variations in welding settings. Experiments adhering to an L9 orthogonal array were executed, examining factors such as welding current, gas flow rate, and filler rod diameter. Results demonstrated significant correlations between these parameters and the mechanical properties of the welds. The findings reveal optimal conditions for achieving enhanced weld quality, with implications for industries requiring high-integrity welded structures. This research not only contributes to understanding the interactions of welding parameters but also promotes improved practices and technological advancements in welding applications.

Keyword: Gas Tungsten Arc Welding, Optimization, 1020 Mild Steel, Grey Relational Analysis, Taguchi Method, Mechanical Properties, Weld Quality, L9 Orthogonal Array

CHAPTER ONE

INTRODUCTION

Welding is a metal-fusing method that uses various fusion techniques and high heat input to repair or fabricate metal structures. It's one of the most extensively used manufacturing methods for producing high-quality joints for a variety of structural Components. Gas Tungsten Arc Welding is a type of electric arc welding that is widely used in industry because it can generate high-quality welds by combining a variety of metal components as well as similar and dissimilar metal junctions. "Pipe welding plays a vital role in various sectors, including oil, gas, geothermal power, as well as the automotive, nuclear, food, and water industries." [(Chaturvedi et al (2023)]. The piping system is responsible for moving oil, gas, and water from one location to another. Orbital pipe welding is commonly employed in piping systems, where the pipe is at rest while the welding flame rotates around it (Abhulimen, I. U. 2014).

Pipelines for oil and gas are among the most significant infrastructure projects undertaken in emerging countries in recent years. Mild steel is utilized for pipelines in the oil and gas industries because it comes in several structural shapes and may be easily welded into a pipe, tube, tubing, or other shapes. Mild steel pipes and tubes are simple to manufacture, readily accessible, and relatively inexpensive compared to other metals. TIG welding, also known as Tungsten Inert Gas Welding or Gas Tungsten Arc Welding (GTAW), is a technique that utilizes a non-consumable electrode, a separate filler metal, and an inert shielding gas. This method is the most prevalent welding technology and is extensively utilized in industrial applications.

The heating cycle that occurs during welding, the composition of the welded alloy, the cooling condition, and the filler material all influence the evolving microstructure of welds. A typical difficulty that the pipeline has faced is the control of the process input parameters to get a good welded joint with the requisite bead shape and weld quality with minimum tensile strength and all places welding (Figueirôa, D. W. 2017).

Welding is a permanent joining technique that creates a strong bond by melting workpieces at the interface. Weld ability is influenced by factors such as oxidation, crack formation at the joint, changes in hardness, and alterations in metallurgy. For a stronger connection, filler materials could be added (Prakash Mohan 2014).

TIG welding was developed in America during World War II using a Tungsten Inert Gas (TIG) welding process which involves arc welding with an electrode made from Tungsten that does not melt during the process. The electrode is maintained in an atmosphere of Argon or Helium gas. TIG welding is crucial when working with complex materials such as aluminum and magnesium, and is now used in other metals like stainless steel, mild steel, high tensile steels, alloys of aluminum and alloys of titanium. Furthermore, the technological progress in power sources has also changed the equipment for TIG welding from ordinary transformers to more advanced electronic devices (Prakash Mohan 2014).

1.1 Background of TIG Welding

The aerospace and nuclear power sectors developed orbital welding in the early 1960s to offer the essential conditions for manufacturing extremely reliable components (Latifi, H. 2012).

A spinning tungsten electrode produced a welding arc around a tube weld joint in the first orbital welding device. The entire process was controlled by the system, which produced results that were more exact and trustworthy than manual welding. In 1961, the first cross-country pipes were mechanized orbitally welded with carbon dioxide, and five different orbital Gas Metal Arc Welding (GMAW) methods were being researched and developed at the same time. Because of the introduction of portable combination power systems that reduced the size of equipment, orbital welding became practicable for many industries by the early 1980s. Multiple in-places welding were achievable because of the portability of the equipment on construction sites (Emmerson, J. G. 1999).

In the late 1990s, advancements in microprocessor technology propelled orbital welding to prominence as a cost-effective and preferred way of joining metals, giving welders of all skill levels more welding alternatives. Orbital pipe welding is now used in nearly every industry, including food, dairy, beverage, power, chemical, oil and gas, pulp and paper, and so on. However, in several developing nations, this welding technology is still relatively new and is not widely used [Kumar,et al. (2019)].

By the early 1950s, TIG (Tungsten Inert Gas) welding became a popular and precise technique, suitable for various applications, including automotive and aerospace. Today, it is favored in the United States for high-quality welds in materials like aluminum and stainless steel, particularly in aerospace and manufacturing. However, its popularity is lower in Europe, where MIG (Metal

Inert Gas) welding is more common, highlighting regional differences in welding practices [Welder, et al (July 2, 2013)].

TIG welding will remain a very important welding process in the future due to its numerous advantages. For the first 20 years, TIG welding was known as argon welding. However, because argon gas is currently employed in a variety of welding methods, the name "argon welding" is no longer limited to one of them. Originally, TIG was solely used for manual welding. However, progress in the direction of more mechanized equipment has been made. Because tungsten has a high melting point, it is used in TIG welding. TIG welding technology was created in the United States in the early 1940s for the difficult-to-weld metals magnesium and aluminum. The trend was sparked by the aircraft industry's requirement for TIG Helium was first utilized as a shielding gas in welding. The gas was then switched to argon, which is less expensive and, in some situations, more effective as a shielding gas. The electrode was initially connected to the plus pole and the welding was done using a direct current. TIG welding had gained widespread acceptance as a welding technology by the early 1950s. It is currently widely used in the United States, although it is less common in Europe.

TIG welding will continue to be a very essential welding process in the future due to its many good properties. TIG welding was known as argon welding for the first 20 years. Because argon gas is now utilized in a variety of welding procedures, the term "argon welding" may no longer be used just to refer to one of them. TIG was originally only used for manual welding. However, progress has been made in the direction of more mechanized equipment. TIG welding uses a tungsten electrode because tungsten has a high melting point.

When a TIG weld electrode heats up but does not melt, we call it a non-consumable electrode. Non-consumable electrodes do not mean they will not endure forever, but they will not melt and become part of the weld. Tungsten Inert Gas welding is a technique that includes heating the metal being welded with a tungsten electrode. Shielding in the form of inert gas, such as argon, is used to protect the weld from contamination during the process and can be used for any metals/thicknesses. TIG welding can be done without filler metal in some cases, but only in limited situations.

Filler metal is commonly utilized to enable a full-strength weld. Because both hands are used to manipulate the flame and the filler rod in TIG welding, the procedures are similar to those used in gas welding. TIG is simply superior.

Generally, this Thesis will be to examine how welding parameters affect orbital mild steel pipe TIG welding. To improve the welding process, it employs a hybrid strategy that combines Grey Relational Analysis with the Taguchi technique. Critical welding parameters will be determined, controlled experiments will be designed, welding quality will be assessed, and Grey Relational Analysis (GRA) will be used to determine the ideal parameters. The study will also look at ways to save costs, make the most use of available resources, and boost output. The results will have applications in manufacturing, construction, and geothermal energy. Additionally, the project would disseminate the findings to industry participants, encouraging the adoption of improved welding practices and the development of welding technology.

TIG welding is valued for its precision and control, making it ideal for thin materials and intricate designs. It produces strong, high-quality welds with minimal defects, especially in non-ferrous metals like aluminum and magnesium. Its versatility accommodates various metals and alloys, and it can be performed without filler material, beneficial for preserving the base metal. The process is clean due to an inert gas shield that prevents contamination. Additionally, TIG welding effectively handles thin sections, reduces heat input to minimize warping, and results in aesthetically pleasing welds, which is important for applications in architecture and art.

1.1.1 TIG welding Quality

TIG (Tungsten Inert Gas) welding is renowned for its high-quality welds and versatility, offering precision and control that make it ideal for thin materials and intricate designs. This process produces clean and aesthetically pleasing welds with minimal spatter, often requiring little to no post-weld clean-up. It is compatible with a wide range of metals, including aluminum, stainless steel, and copper, enhancing its applicability. TIG welding can be performed without filler rods, allowing for strong connections between base metals, while also creating solid joint integrity through continuous welds. The use of an inert gas, typically argon, protects the weld from contamination, ensuring a high-quality finish.

1.2 Problem statement

The process of TIG welding of orbital mild steel pipes is critical in various industrial applications, yet it presents several challenges that can adversely affect the quality and performance of the welded joints. The variability in welding parameters such as current, voltage, travel speed, and gas flow rate can lead to inconsistent weld quality, resulting in defects such as porosity, inadequate penetration, and weak joints.

Despite the known importance of these parameters, there is often a lack of systematic approaches to optimize them effectively. Current practices of the same work piece thickness and applications and costs. Additionally, the high costs associated with TIG welding equipment and argon gas further necessitate the need for efficient parameter optimization to enhance cost-effectiveness without compromising quality.

The government and business sector in Ethiopia have been actively creating or building industries in geothermal energy, manufacturing, water production, construction technology, and automobile sectors. These businesses predominantly utilize 1020 orbital pipe due to its high-quality welds, cost-effectiveness, and suitable performance in low-temperature settings. It is recommended to use TIG welding for 1020 mild steel pipe. During my reconnaissance, I visited various industries, including the Asella Malt Factory (AMF) and the Chilalo Food Complex (CFC) Factory, where I observed challenges with welded joints that led to leakage and breakdowns. The weak strength, low hardness, and low ductility of the welds were identified as primary factors for weld bead failure.

The causes of these failures can be attributed to inadequate selection of welding materials, improper joint configurations, and incorrect settings of welding parameters. To address these constraints and enhance understanding, the study investigates the effect of welding variables on hardness values, tensile strength, and bending strength of the weld using Taguchi-based grey relation analysis on 1020 mild steel pipe. This research aims to systematically evaluate and optimize welding parameters through a Taguchi-based hybrid Grey Relational Analysis approach. By improving the mechanical properties of the weld joints, this study seeks to establish best practices for the TIG welding process in orbital mild steel applications. The findings will contribute to a better understanding of the interactions among welding parameters and provide actionable insights for industries reliant on high-quality welded structures.

1.3 Research Question

1. What are the critical welding parameters that significantly affect the quality of TIG welded joints in orbital mild steel pipes?
2. How do different welding settings influence the mechanical properties of the welded joints, specifically regarding hardness, tensile strength, and bending strength?

3. How can Taguchi-based Grey Relational Analysis be utilized to analyze the experimental results and identify optimal parameter combinations that yield the best mechanical properties?
4. How can the optimal process parameters be validated through the fabrication and testing of samples?

1.4 Objectives of the Study's

1.4.1. General Objective

The major objective of this research is to investigate the optimum levels sitting of 1020 orbital mild steel pipe TIG welding process parameter that results in good mechanical properties using Taguchi optimization technique.

1.4.2 The specific Objective

- To determine the critical welding parameters affecting the quality of TIG welded joints in orbital mild steel pipes.
- To assess the mechanical properties of the welded joints, focusing on hardness, tensile strength, and bending strength, to evaluate the influence of different welding settings.
- To utilize Taguchi based Grey Relational Analysis to optimize the results of the experiments, facilitating the identification of optimal parameter combinations that yield optimum mechanical properties.
- To validate optimal sample process parameters and to testing the sample.

1.5 Scope of Research

The research focuses on optimizing the parameters of TIG welding through the application of the Taguchi Method, which will be employed to design a problem-solving experiment. The study utilizes 1020 mild steel pipe as the base material, with dimensions of 100mm by 3mm. To analyze the results and ensure accurate data interpretation, the MINITAB 19 software is utilized throughout the process. This approach aims to enhance the efficiency and quality of TIG welding by systematically investigating the influence of various parameters on the welding outcome.

1.6 Significance of the research

When a high level of weld quality or great precision welding operation is required, tungsten inert gas (TIG) welding is an incredibly important arc welding process. On the other hand, 1020 mild steel pipe is inexpensive, has good weld quality, is easy to work with, and is widely utilized in the mild steel family. Weld bead failures were caused by improper welding parameter and level setting selection, as stated in the problem statement.

The reader will learn how to select optimal welding parameters and level settings, as well as optimization methods and procedures to obtain quality characteristics and the effect of each process parameter, how to validate experimental tests using the Taguchi method, and which process parameters are the best. This program provides me with the opportunity to gain further skills and knowledge in the field.

1.7 Limitation of the thesis

The study specifically focused on AISI 1020 mild steel pipe materials, utilizing horizontal positioning and butt joint configurations to ensure consistent welding conditions. Experimental tests were primarily aimed at evaluating the mechanical properties of the weld bead, such as tensile strength and hardness. However, the analysis was constrained by the unavailability of Scanning Electron Microscope (SEM) facilities in Ethiopia, limiting the depth of microstructural examination and comprehensive material characterization.

1.8 Importance of the thesis

This study was being relevant to the management of Asella Malt factory on the state of implementation of design of experiment of welding factors and parameters and its effects on quality of mild steel pipe by using tungsten inert gas welding technique. This study was offer in management for the opportunity to know how the welding factors and parameters affect the quality of mild steel Pipe by using tungsten inert gas welding technique. It also provides the current welding factors and parameters in the factory and future researchers can study welding factors and parameters in industry level and can develop implementation framework that fit with the inherent quality culture of the industry.

1.9 Thesis organization

Chapter One

This chapter introduces the study on TIG welding techniques for AISI 1020 mild steel pipes, outlining objectives, the problem statement, significance, scope, and overall importance.

Chapter Two

In this chapter, the scientific principles underlying TIG welding are examined, along with the guidelines for welding mild steel pipes. It reviews various literatures on different optimization techniques and concludes with a summary of findings and identified research gaps.

Chapter Three

This chapter briefly outlines the experimental details, including the materials used, the protocols followed, the equipment employed, and the methodology that was implemented to achieve the study's objectives.

Chapter Four

Results and discussions regarding the experimental data are presented in this chapter. It explores how different process parameters influence the quality of TIG welds on AISI 1020 mild steel pipes while maintaining optimal parameter settings.

Chapter Five

The final chapter summarizes the research findings and offers recommendations for future studies, suggesting areas for further investigation.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The previous work optimization of TIG welding process parameters on mild steel pipe, specifically 1020 pipe was undertaken in this chapter. This chapter provides details on the research that has been conducted in this area.

Many researchers have conducted extensive research in the field of welding technology. These investigations have resulted in a wealth of information, insight, and wisdom in the field of welding technology. The current study will look into the following topics in arc welding: improving the geometry and mechanical properties of weld beads, optimizing welding process parameters utilizing design of experiments, and Taguchi approach. This chapter presents and discusses relevant literature on the mentioned issues, as well as inspiration and emulation of past researchers' findings.

2.2 Basic mechanism of TIG welding

TIG welding is an arc welding process using a non-consumable tungsten electrode to create a weld. The weld area is protected by inert shielding gas and filler metal. Power is supplied from a power source and delivered to the electrode. An electric arc is created between the electrode and the work piece using a constant-current welding power supply. The tungsten electrode and welding zone are protected by inert gas. The electric arc can reach temperatures of up to 20,000^{o}C, allowing for material melting and joining.

Tungsten electrodes, ranging from 0.5 mm to 6.4 mm in diameter and 150-200 mm in length, have varying current carrying capacities depending on their connection to a DC power source. The arc length in manual welding has a constant current output, so natural variations have minimal impact on welding current. Limiting current to set values is crucial when short-circuiting an electrode to prevent damage.

The study examines the impact of welding parameters like laser power, welding current and welding speed on the weld pool characteristics, shape, and dimensions in hybrid laser-TIG welding of AA6082 aluminum alloy. A 3D numerical model is used to simulate heat transfer and fluid flow in the weld pool, while experiments validate and calibrate the model. The analysis of variance (ANOVA) method is used to investigate the precise relationship between welding parameters and weld dimensions (Amir hosseinfaraji 2015).

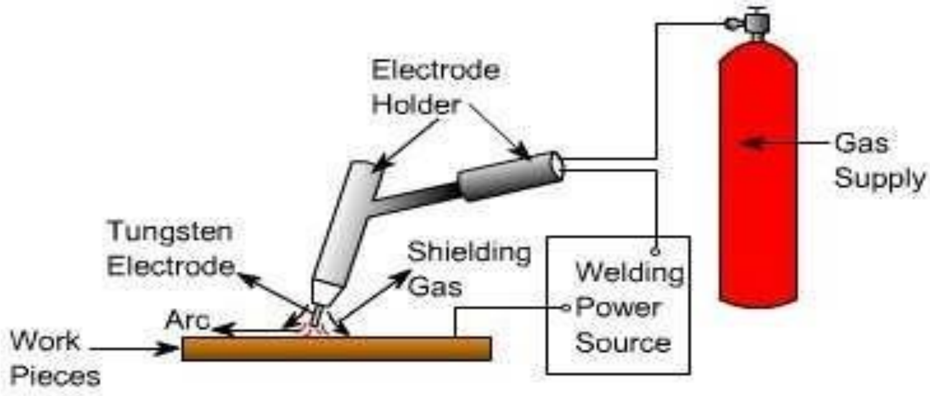

Figure2.1Schematic Diagram of TIG Welding System (Umesh Sharma, VishwasYadav)

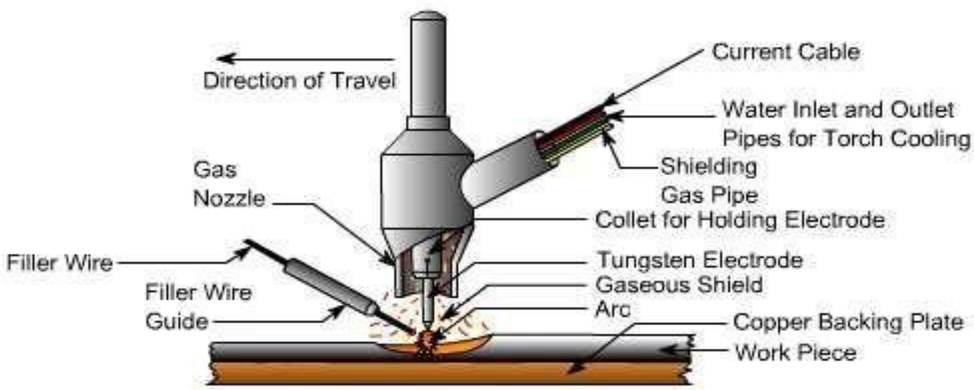

Figure 2.2 Principle of TIG Welding (Umesh Sharma, VishwasYadav)

TIG welding is an arc welding process where coalescence is achieved by heating the work piece with an electrical arc struck between a tungsten electrode and the job. The high-temperature arc melts the base metal surface, forming a smooth weld that requires minimal finishing. The welding process involves using a welding gas such as argon, helium, or nitrogen to prevent atmospheric contamination of the molten weld pool. To achieve the desired mechanical properties, it is crucial to select the proper levels of input parameters such as current, gas flow rate, and root gap in TIG welding. Grey Relational Analysis is used to analyze output responses such as tensile strength and % elongation in TIG welding to obtain optimum values for the mechanical properties of the welded parts [Wahule,et al,(2018)].

The study examined the tensile strength of MIG and TIG welded dissimilar joints of mild steel and stainless steel. Four test samples were prepared, and it was found that TIG was more suitable for dissimilar metal welding due to its superior strength. Additionally, MIG welded dissimilar joints had a higher dilution percentage in stainless steel (Radha Mishra et al,)

The study examined the impact of TIG flux on the performance of dissimilar welds between mild steel G3131 and stainless steel 316L, focusing on the effects of CaO, Fe2O3, Cr2O3, and SiO2, finding that oxide flux produced residual slag (Cheng-Hsien Kuo et al,).

2.3 Tungsten Electrode Classifications

Tungsten is obtained by reducing tungsten trioxide with hydrogen to reach a purity level of 99.95%, followed by casting it into an ingot (Jeffus & Bower, 2009). This ingot is then heated to improve its ductility, allowing for the production of electrodes with diameters ranging from 0.5 to 6.4 mm and lengths from 75 to 610 mm. These electrodes typically have a thick black oxide layer that can be cleaned off (Jeffus, 2020). Owing to its high melting temperature and superior electrical conductivity, tungsten is well-suited for non-consumable electrodes, capable of reaching arc temperatures of 11,000°F (6000°C) (Jeffus, 2012). To enhance arc striking and durability, small quantities of cerium, lanthanum, thorium, or zirconium are incorporated (Bower, 2010).

Table 2.1. Identification and Types of Tungsten Electrodes (Jeffus & Baker, 2016)

No.	AWS Classification	Tungsten Compositions	TIP Color
1	EWP	Pure Tungsten	Green
2	EWTh-1	1% thorium added	Yellow
3	EWZr	0.25% to 0.5% zirconium added	Brown
4	EWTh-2	2% thorium added	Red
5	EWG	Alloy not specified	Grey
6	EWCe-2	2% cerium added	Orange
7	EWLa-2	2% lanthanum added	Blue
8	EWLa-1.5	1.5% lanthanum added	Gold
9	EWLa-1	1% lanthanum added	Black

Pure tungsten (EWP) electrodes exhibit strong resistance to heat and erosion, along with superior electron emission properties (Jeffus & Baker, 2016). They are especially effective for low-temperature AC welding because of the high melting points of aluminum and magnesium, providing stable arcs and balanced wave energy. To achieve the best arc stability, tungsten electrodes should be ground with their axis perpendicular to that of the grinding wheel (O'Brien, 1991; Minnick, 1996; Lancaster, 1997).

2.4 TIG welding parameters

In TIG welding, welders oversee multiple factors such as the type of electrode material, the shape of the grind, the filler material used, joint dimensions, base materials, gas cup size, torch angle, travel speed, arc length, type of inert gas, gas flow rate, welding current, and polarity. These parameters are essential in influencing both the welding process and the final quality of the weld (Thakur & Chapgaon, 2016).

2.4.1 TIG welding equipment

TIG welding machines consist of essential components: a TIG torch for welding, an electrode to create the arc, a power source for electrical energy, and shielding gas systems to prevent contamination. These elements collaborate to produce clean, precise welds, requiring skilled operators to adjust settings like amperage and gas flow for different materials.

I. Torch

TIG torches provide welding current and shielding gas and are available in both water-cooled and air-cooled models. Air-cooled torches that limit current to 200 amps help keep the welder cool. In contrast, water-cooled torches can handle larger continuous welding currents.

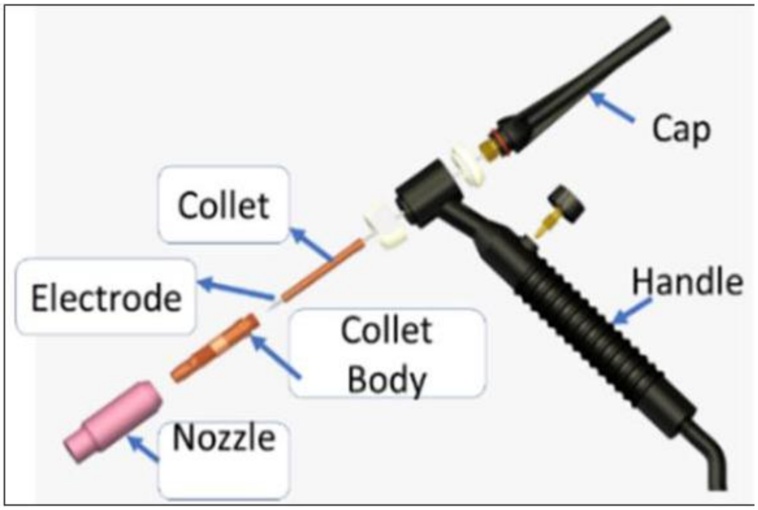

Figure2.3. TIG welding process torch schematic diagram [Rana et al., (2017)]

II. Power sources

TIG welding requires a power supply with an open-circuit voltage of 70-80 volts. In contrast, direct current welding necessitates a rectified power source from a 400V supply, allowing the welder to regulate the intensity as needed.

III. Shielding Gases

Shielding gases such as Ar, He, H, and N shield the weld pool, electrode tip, and filler metal from air contamination in TIG welding. Gas selection is determined by several criteria, including metal type, expense, temperature, arc stability, and penetration depth [Bhavsar & Patel, (2016); Jeffus and Baker, (2016)]. Effective shielding is essential for preserving ionization and cooling weld components [Parmar & Nair, (2019)].

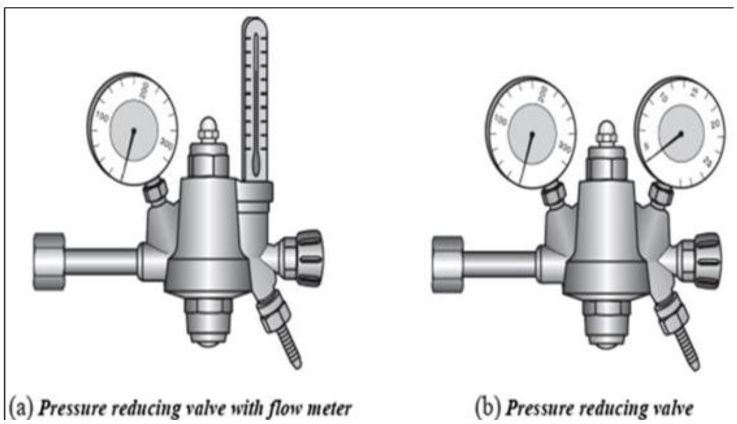

Figure2.4. Regulators [Parmar & Nair, (2019)]

Steel cylinder pressure ranges from 200 to 300 bar and must be reduced to a safe level using a pressure-reducing valve. Argon flow rates are 7-16 L/min, while nitrogen rates are 14-24 L/min [O'Brien, (2004); Jeyaprakash et al., (2015)]. Pre-flow time of 3-5 seconds clears air from nozzles before welding.

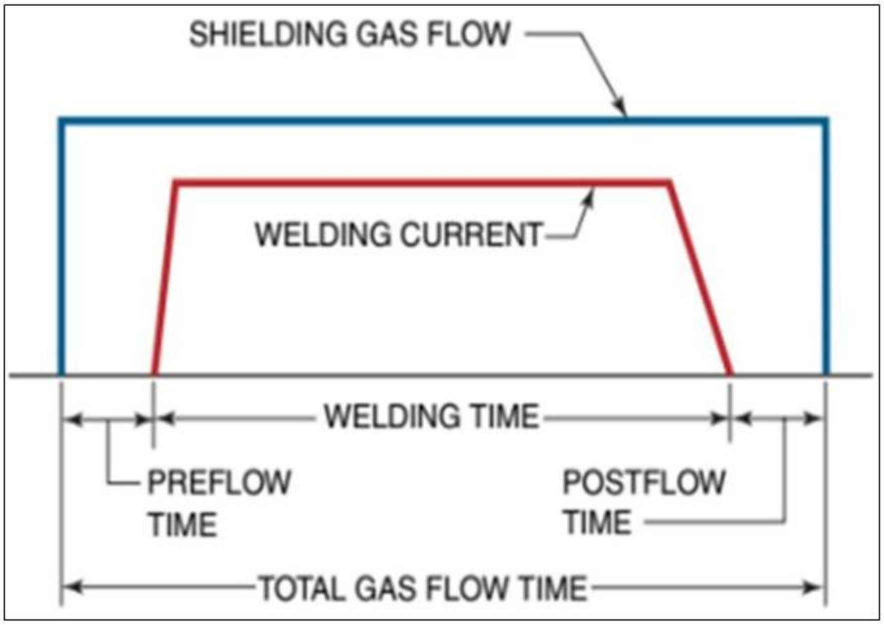

Figure2.5 Welding time against shielding flow of gas time [Bower et al., (2010)]

Subsequent flow duration is the amount of time gas continues to flow after welding stops, protecting the molten weld pool, filler material, and tungsten electrode from oxidation and contamination. It is determined by the welding current and electrode size [Bower et al., (2010)], as indicated in Table 2.2.

Table 2.2 Gas time for flow after welding [Bower et al., (2010)]

Electrode diameter within millimeters	**Time for Gas Flow After Welding**
6	30 sec
5	25 sec
4	20 sec
3	15 sec
2.4	10 sec
2	8 sec
1	5 sec
0.5	5 sec
0.25	5 sec

2.5 The Quality of Welding

Quality in fabrication and welding is essential since it is determined by the mechanical properties of the weld metal, as well as its metallurgical and chemical characteristics [Connor et al., (1987); American Welding Society, (1991)]. The study found that welded material dimensions and defect counts affect joint performance, often due to design and manufacturing errors. Factors like design, weld preparation, shielding, and cleanliness influence weld quality, with cracks being particularly challenging to repair [Becker et al (2002)], the investigator [Yamauchi et al., (1983); Abrha, (2015)] The study organized welding failures into the following causes: inadequate process conditions (45%), human error (32%), incorrect technique (10%), and unsuitable consumables (5%). These findings came from a research into welding failures and their underlying causes.

Controlling welding parameters such as current, voltage, and travel speed is critical for achieving optimal weld quality. A welding current of approximately 65 A can greatly increase the yield and tensile strength of mild steel joints [Rahui et al,(2024)].

Choosing the suitable filler material is critical to getting the desired mechanical qualities. For mild steel, filler that matches the base material's composition helps to minimize cracking and enables proper fusion between the weld and base metal [Rahui et al,(2024)].

Shielding gases are essential in Gas Tungsten Arc Welding (GTAW) because they protect the weld region from dangerous ambient gases and prevent flaws such as porosity and cracking. They also help transport heat from the tungsten electrode to the workpiece, resulting in a stable and successful welding arc [Minnick, W. H. (1996)].

A weld's microstructure has a significant impact on its mechanical qualities. TIG welding provides a fine-grained structure in the weld zone, which increases strength and toughness when compared to other welding processes [Rahui et al,(2024)].

To maintain a clean weld pool, it is essential that the shielding gas flow is sufficient and steady to effectively shield the weld from atmospheric contaminants. In windy or drafty environments, additional shielding gas is required, leading to increased costs and making GTAW less desirable for outdoor applications [Cary et al, (2005)].

2.6 Related Research Works on Welding Material

These study the effects of optimizing pulse TIG parameters on the tensile strength of AZ31B Mg alloy were investigated, and it was discovered that peak current 210A, base current 80A, and pulse frequency 6 Hz yielded a maximum tensile strength of 188 MPa (Karthikeyan, M. 2016).

This experiment the welding input parameters have been proven to have an important influence in defining the quality of a weld connection with minimal distortion (Karthikeyan, M. 2016).

These study the effect of TIG welding process factors such as weld current, gas flow rate, and work piece thickness on the bead shape of SS304 was examined. It was discovered that the process parameters evaluated had a significant impact on the mechanical properties (Sathish, R.2012).

The welding position and welding current have an effect on orbital pipe welding, according to a previous study. The peak current, base current, welding speed and gas flow rate all had an effect on tensile strength and elongation, according to Joseph's research on the optimization of GTAW welding parameters pulsing current using simulated annealing and a genetic algorithm. The Taguchi method can be used to determine the best parameters for increasing the tensile strength of S30430 steel plate and API (Baskoro, A. S. G. W. A. 2020).

The findings revealed that increasing the number of welding sequences at pipe connections reduced welding distortion, with 4A welding sequences exhibiting the most distortion.

The Taguchi method can be used to determine the best welding parameters that result in the least amount of distortion (Widyianto, et al. 2021).

TIG welding on AA6351 sheets with ER 6063 filler revealed that the depth of penetration decreases with increased bevel height, and tensile strength increases with lower weld speed. Bevel angles between 300- 450 are suitable for maximum strength, and strength increases with decreasing heat input rate in the heat-affected zone (Ahmed Khalid Hussain et. al).

The study examined the creep rupture behavior of 3mm thick 316L austenitic stainless steel weld joints made using single pass activated TIG and multi-pass conventional TIG welding processes. Results showed that the weld joints had lower creep rupture life than the base metal, and single pass activated TIG welding increased it over multi-pass TIG weld joints (Sakthivel et.al).

The study conducted TIG welding on AISI 304Lstainless steel, comparing the effects of welding current on tensile strength, hardness profiles, microstructure, and residual stress distribution. Pulsed current welding showed lower residual stress magnitude compared to constant current welding, and joint tensile and hardness properties were enhanced due to finer grain formation and dendrite breaking (Karunakaran et. al).

The study compares three welding processes: SAW submerged arc welding, SMAW (shield metal arc welding), and GMAW (gas metal arc welding) and recommends importing weld quality testing equipment, promoting training programs for welders and suppliers, and establishing industries to produce more locally produced weld quality testing equipment (Thakur and Gebrelibanos, 2019).

The study examined the impact of TIG arc welding process parameters on the microstructure, tensile property, and fracture of Ni-base super-alloy joints. The experiment used welding plate widths of 1.2-1.5 mm, 55-90 A welding current, and 2100-2900 mm/min welding speed. Results showed that heat input increased with increased current and speed (Wang et. al).

These study the influence of welding settings on the geometric properties and distortion of A36 mild steel was investigated. The welding settings had an effect on the degree of distortion at the end of the welding process, according to the findings (Baskoro, et al. 2021).

Done experiment Autogenous TIG welding was performed on 12-millimeter-thick mild steel with 200 A current, 19 V voltage and 100 mm/min welding speed. Finer grain size was obtained at weld metal and warmth affected zone (Patel, et al (2013).

This experiment was carried out to examine the microstructure and oxidation resistance of mild steel TIG welds in various regions. Due to the complex heat cycle and quick solidification, a dramatic change in the microstructure was noticed during the welding process. The mild steel weld's mechanical characteristics and oxidation resistance are also affected by this microstructure change. On 12 mm thick mild steel, Autogenous TIG welding was performed with 200 A current, 19 V voltages and a welding speed of 100 mm/min. At the weld metal and heat-affected zone, the grain size was finer (Ahirwar, P. 2015).

These study the effect of TIG welding process factors such as weld current, gas flow rate, and work piece thickness on the bead shape of SS304 was examined in this study. It was discovered that the process parameters evaluated had a significant impact on the mechanical properties (Sathish, 2012).

The TIG welding process on stainless steel AISI 316L involves various process parameters that have been systematically altered through experimentation. This study focuses on the optimization of these parameters and includes a comparison of both numerical simulations and experimental results from different welding techniques (Singh, et al. 2020).

The study optimizes parameters like current, voltage, and gas flow rate to improve tensile strength and hardness of Al-6061 T6 welds using statistical methodologies, transforming industrial practices (Serrano, M. 2024).

A prediction model is also developed using Artificial Neural Network (ANN). The analysis provides significance of said process parameters and its effect on the quality and strength of joint. It is a powerful statistical technique used to study and analyze the effect of various process parameters upon the response and the analysis starts with the implementation concept of Design of Experiment (DOE), ANOVA and optimized by using genetic algorithm (Abrha, 2017).

The study utilized grey relational analysis and the Taguchi method to determine optimal conditions for TIG-MIG hybrid welding parameters, identifying basic process parameters and machine working range (Tesfaye, F. K. 2023).

2.6.1 Influence on hardness

This part investigates the TIG welding process for AISI 1020 pipes, specifically analyzing how various welding variables influence the micro hardness of the weld bead. By understanding these effects, the study aims to improve mechanical performance, increase durability, and enhance quality control in industrial applications, ultimately leading to more reliable welded structures.

According to [Kumar, R., & Singh, N. K. (2023)], used a L9 orthogonal array to test TIG welding parameters for AISI 1020 mild steel pipe joints, including 120, 150, and 180 amps, various groove designs (V, U, V&U), and filler rods (ER304, ER308, ER309). The maximum hardness of 98 HRB was attained at 150A using U and V groove designs with ER304 filler metal.

Researchers from Saha and Dhami (2018) and Saha (2020) investigated the effect of TIG welding settings on 4.75 mm thick 316L stainless steel pipe connectors. They used a Taguchi technique with an L27 orthogonal array to investigate four welding parameters: current, gas flow rate, welding speed, and filler rod diameter. The best combinations, which included a gas flow rate of 12 lit/hr, a current of 150 amps, and a filler rod diameter of 3.2 mm, led in a 7.36% improvement in hardness, from 92 HV to 100 HV.

According to [Chaudhari et al., (2019)] The study focused on the parametric optimization of TIG-welded 150 x 150 x 6 mm SS 316L and mild steel pipes using Taguchi's technique with an L9 orthogonal array. This method resulted in the highest Rockwell hardness score of 88.7 HRB at an optimal variable configuration.

2.6.2 Tensile strength

This section digs into the TIG welding procedure as it applies to AISI 1020 pipes, exploring the delicate link between numerous welding parameters and their impact on the tensile strength of the weld beads. We hope to learn how welding current, gas flow rate, and filler material diameter affect the mechanical qualities of the weld by evaluating these parameters. Understanding these dynamics is critical for optimizing the welding process, improving joint integrity, and ensuring the dependability of welded structures in real settings.

Mild steel, with a carbon content of 0.05% to 0.25%, typically has a tensile strength of 370 to 700 MPa, making it suitable for structural applications like buildings and bridges. Its ductility allows significant deformation under stress, enhancing safety and reliability in a variety of engineering applications [Shane (2025)].

According to [Ghosh et al., (2016); Moi et al., (2018)] The study aimed to improve TIG welding by investigating variables such as weld current, groove angle, and filler rods. Using the L9 orthogonal array-based Taguchi technique and ANOVA, the scientists discovered that groove angle, filler metals, and weld current had a substantial impact on tensile strength. They reached an ideal tensile strength of 575.43 MPa using 100A, a specified groove angle, and a specific filler material.

According to [Saha & Dhami, (2018); Saha, (2020)], Experiments focused at how TIG welding settings affected 4.75 mm thick SS 304L pipe connections. The only variable that influenced optimal configurations for tensile strength and hardness was the current, which resulted in an increase in tensile strength from 515 MPa to 556 MPa and hardness from 92 to 100 HV.

According to [Anand et al., (2017)], the mechanical properties of weld joints were investigated in mild steel and 316L austenitic steel. Using the Taguchi method, researchers optimized factors such as arc current (100, 150, 200A), voltage (18, 22, 26V), and shielding gas flow rate (10, 12, 14L/min). The ideal conditions 100A current, 26V voltage, and 10L/min gas flow produced a maximum tensile strength of 560.5 MPa, with contributions of 47.50%, 24.55%, and 20.96% from each factor, respectively.

2.6.3 Bending Strength

This section examines the TIG welding process for AISI 1020 pipes, concentrating on how welding variables such as current, filler material, and gas flow influence the bending and flexural strength of the weld bead. Understanding these correlations is critical for optimizing procedures, improving weld quality, and increasing the longevity and dependability of welded structures.

According to [Huong et al (2024)], the study aimed to improve the mechanical properties of dissimilar stainless steel junctions mild steel by adjusting TIG welding conditions. Using the

Taguchi approach, researchers assessed numerous process factors to determine optimal settings that dramatically improved weld performance. This method not only exhibits the efficacy of parameter optimization, but it also provides useful insights for producing stronger and more dependable welds in applications involving various stainless steel grades.

2.6.4 Compressive Strength

The compressive strength of mild steel is influenced by various factors such as material composition, microstructure, heat treatment methods, steel section dimensions and shape, applied stress, and temperature effects, which all contribute to its strength and toughness [Du,et al, (2023)]

The size and geometric shape of a steel section have a considerable impact on stress distribution under load, with thicker sections providing greater strength and deformation resistance. The kind and magnitude of applied stress also influence compressive strength, whereas temperature influences brittleness and performance under compressive loads [Tong, et al (2022)]

2.7 Optimizations Techniques mild steel AISI 1020 Pipe Welding

The study addressed inconsistencies in MIG pipe welding by developing an automated orbital system to enhance the ultimate tensile strength (UTS) and Rockwell hardness (RH) of mild steel 1020 pipes. Using an L9 orthogonal array, maximum UTS of 411.2 MPa and RH of 95 HRB were achieved. A hybrid ANN-GA model predicted UTS of 417.857 MPa and RH of 96.5364 HRB with low error rates in confirmation tests, demonstrating its effectiveness [Mengistie et al. (2023)].

This research focused on optimizing TIG welding settings for relating AISI 1020 mild steel with 304 stainless steel, The researchers hoped to increase weld quality and mechanical qualities by fine-tuning variables such as welding current, arc voltage, welding speed, and gas flow rate. The use of an automated TIG welding fixture enabled uniform welding processes, reducing flaws associated with human procedures. Finally, the study found that the welded joints had significantly increased tensile strength, hardness, and bending strength [Yegnanesh et al. (2024)].

2.8 Identification of Gaps

- Excessive Research on TIG Welding Parameters: The insufficient comprehensive research has been observed into different parameters of the TIG welding, especially on orbital welding techniques used in mild steel 1020.
- Missed orbital welding aspects: The available literature misses important points regarding orbital welding of mild steel 1020 pipes.
- Lack of assessment of weld mechanical properties: The mechanical properties of the welded joints are sometimes not evaluated extensively on mild steel 1020 orbital pipes.
- Limited Cost Analysis: The literature rarely includes meaningful economic evaluations of the optimization methods, which is impractical for real industrial applications.
- Weak Examination of Welding Parameters: Although welding current, filler rod and shielding gas flow rate are taken into account in studies but their direct effects on weld joint strength is still unknown on mild steel 1020 orbital pipes

CHAPTER THREE
MATERIALS AND METHODOLOGY

3.1. Introduction

This study investigates the impact of TIG welding parameters on the orbital welding of AISI 1020 mild steel pipes, using a Taguchi-based hybrid grey relational analysis for optimization. It employs specified mild steel pipes, TIG welding equipment, and various filler materials. The Taguchi method designs experiments to vary key parameters, including welding current in ampere, Gas flow rate in liter, and Filler diameter in millimeter. Weld quality is assessed through tensile, hardness, bending, and compressive strength to enhance welding reliability and efficiency in industrial applications.

3.2 Research Methodology

The research methodology for the thesis titled "Investigation of the Effects of TIG Welding Parameters on Orbital Welding of Mild Steel Pipes Optimized Through Taguchi-Based Hybrid Grey Relational Analysis" employs a quantitative experimental design, in which AISI 1020 mild steel pipes will be subjected to varying TIG welding parameters, including Welding Current (A), Gas Flow Rate (L), and Filler Diameter (mm). A Taguchi L9 orthogonal array will facilitate systematic experimentation to assess the impact of these parameters on weld quality, measured through tensile strength, hardness, bending strength, and compressive strength. Data will be collected and analyzed using the Taguchi method to calculate signal-to-noise ratios, followed by hybrid grey relational analysis to rank the performance of different parameter combinations. Finally, the optimal settings will be validated through additional welding trials, ensuring the robustness of the findings and contributing to improved welding processes.

3.3. Data Collection Methods

The initial approach for collecting primary data involved direct observation through visual inspection to identify defects in TIG welding. This widely used, non-destructive method allows for immediate assessment of weld quality by examining the weld surface for visible imperfections. During this process, skilled welding technicians meticulously record essential variables such as welding current, voltage, gas flow rate, travel speed, and electrode type. By closely monitoring these parameters, they optimize welding procedures and maintain consistent weld quality. This method not only aids in detecting surface defects but also provides valuable insights into the relationships between various welding conditions and the resulting weld integrity, ultimately contributing to improved welding practices and outcomes (Becker, 2023).

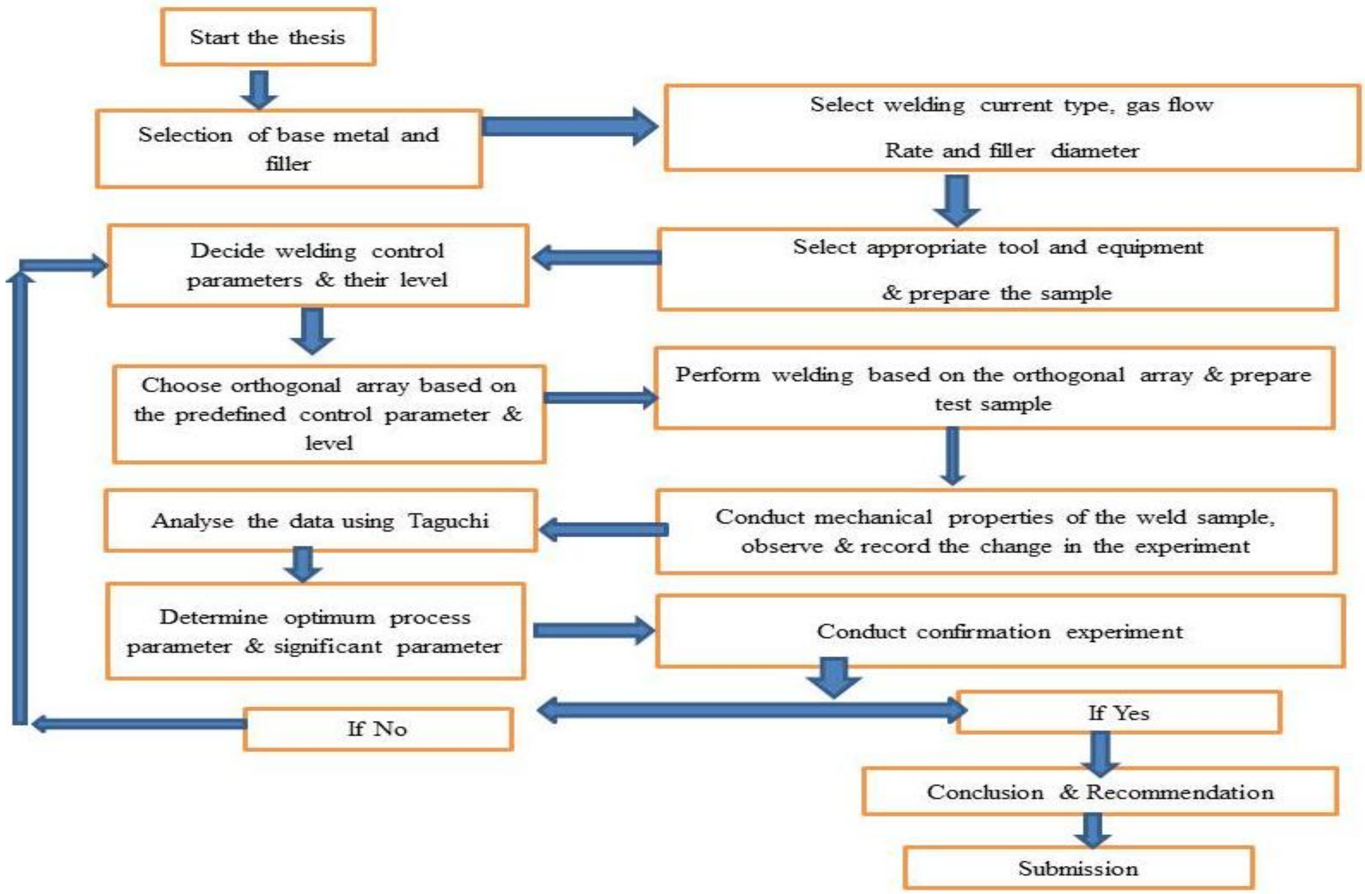

Figure3.1Thesis methodology flow chart

3.4. Method of Data Analysis

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

- ❖ Minitab software (for ANOVA and regression analysis). In addition, to this, the results have been verified using tools like, ANOVA, cause-and-effect diagram.
- ❖ The hybrid approach leverages the strengths of both methods to address multi-response optimization problems.

3.4.1 Design of experiment methods

Design of Experiments (DOE) is a systematic and efficient method that enables scientists and engineers to study the relationship between multiple input variables (factors) and key output variables (responses). This structured approach to data collection and discovery was first introduced in the 1920s by R. A. Fisher at the agricultural research station in Rothamsted, England (Moulon et al., 1985).

The Taguchi method employs a fractional factorial design of experiments alongside an orthogonal array to systematically identify the optimal combinations of process parameters. By analyzing sample quality through ANOVA (Analysis of Variance), this method effectively determines process limits and aims to minimize variation in outcomes. This approach is particularly advantageous as it is both cost-effective and straightforward, making it accessible for various applications. Its user-friendly nature allows researchers and practitioners to implement it easily, enhancing the efficiency and reliability of their experiments (Rajesh & Sumathi, 2020).

3.4.2 Steps of experiment

Prepare a detailed experimental plan in advance to ensure that the results of the experiment are both objective and valid (Design of Experiments, 2019).

1. Design an Experiment

Formulating an experiment involves developing a comprehensive framework to explore the correlation between variables by manipulating one or more independent variables and measuring their impact on one or more dependent variables.

- **Identify Variables:** Establish both independent (manipulated) and dependent (measured) variables.
- **Formulate Hypothesis:** Based on the chosen variables, create a precise and testable hypothesis.
- **Design Treatments:** Develop the experimental conditions where the independent variable(s) will be manipulated.
- **Measure Outcomes:** Strategize and implement procedures for collecting data on the dependent variable(s) in a reliable and accurate manner.

2. Perform the Experiment

Conduct the experiment according to the pre-planned design to test the hypothesis within the defined scope. This includes:

- Proper measurement and control of the variables.
- Consistent data collection.
- Uniform execution across trials.

The aim is to determine the results by observing the changes that occur after controlling other variables, particularly ensuring consistent manipulation of the independent variable.

3. Data Analysis

Data interpretation includes analyzing the observations made, understanding the significance of the collected data, and explaining the results. This analysis should be presented systematically, such as in graphs or tables.

It is crucial not to eliminate outliers that appear invalid or inaccurate based on preconceived notions, as significant scientific breakthroughs often arise from what may initially seem like 'incorrect' data. The analysis should include additional calculations to support or refute the hypothesis. This approach emphasizes that science remains unbiased, treating all data as valuable information, regardless of initial impressions (Being, 2019).

4. Draw Conclusions and Recommendations

In relation to the hypothesis, conclusions should be drawn without explicitly accepting or rejecting it, as both outcomes can provide valuable insights. The variability of results from repeated experiments can lead to new predictions for the hypothesis, thereby deepening subject matter knowledge.

Whether the hypothesis is accepted or rejected aids in understanding the analyzed subject. This process also prompts a re-evaluation of the hypothesis in light of planned further experiments, underscoring the importance of embracing scientific reasoning (Lammers and Babbie, 2005).

3.4.3 Statistical Analysis of Experimental Data

1. Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) is a statistical method used to detect differences between experimental trials. It is applicable in experimental designs that involve one dependent variable, which is a continuous parametric numerical measure, along with multiple experimental groups across one or more independent variables. ANOVA compares the variance among the experimental data to assess whether there are significant differences among group means. Additionally, it examines the variation within each sample; if the variation is significantly larger, this may indicate that the different samples are not equal, suggesting potential distinct effects among the groups (Sawyer, 2009).

2. Assumptions of ANOVA

- ✓ **Continuous Dependent Measure:** The dependent variable must be continuous, meaning it can take on any value within a wide range.
- ✓ **Normality:** The data for each group should come from a population that follows a normal distribution. For example, plotting the heights of individuals from different continents should resemble a bell-shaped curve.
- ✓ **Independence:** Data in one group must not influence data in another group, and data from all groups should be collected through random sampling.
- ✓ **Equal Variances:** The variances across all groups being compared should be approximately equal.

3.5. Materials and Experimental Procedure

For this thesis, the process parameters related to welding defects were analyzed to determine the TIG welding settings that would produce optimal weld bead quality. The welding process parameters included input variables, such as tensile stress, while the output variables of the TIG welding process were optimized. The base metal used was low carbon steel (AISI 1020), and a butt joint was prepared in a flat position using a single-pass welding method. In this study, a total of nine specimens were prepared, and a combination of Design of Experiments (DOE) was employed to optimize the welding control parameters in order to achieve the best welding quality.

3.5.1 Materials

For this study, AISI 1020 mild steel pipe was used, as it is a type of carbon steel. The specimens were mild steel pipes with dimensions of 100 mm in length, 100 mm in diameter, and 3 mm in thickness. This material was chosen for the experiments. The material composition was analyzed using a spectrometer at the Federal Democratic Republic of Ethiopia Technical and Vocational Training Institute.

AISI 1020 steel possesses excellent dimensional accuracy, good machinability, moderate hardness, weldability, and ductility. Carburizing can enhance its hardness and surface properties, making it a cost-effective material. Generally, the strengthening of this carbon steel is achieved through cold working, which provides relative stress relief and toughness, allowing for easy fabrication at a low production cost. The yield strength is 380 MPa, with ultimate tensile strengths ranging from 460 MPa, elongation between 17% and 28%, and a reduction in area between 50% and 57%.

The chemical composition of the welding pipes was analyzed to determine the optimal combinations of welding factors and parameters for this study. The specimens were cut using appropriate tools to meet standard dimensions for each test (tensile, hardness, compression, and bending).

3.5.1.1 Selection of Material

The selected material for this experiment is a mild steel pipe with a thickness of 3 mm. The carbon content of AISI 1020 ranges from 0.17% to 0.23% by weight and it has a Rockwell hardness of approximately 68 HRB (Rockwell B scale). As shown in Figure 3.2, the dimensions of the mild steel plate used for the experimental analysis are 100 mm in length, 100 mm in diameter, and 3 mm in thickness.

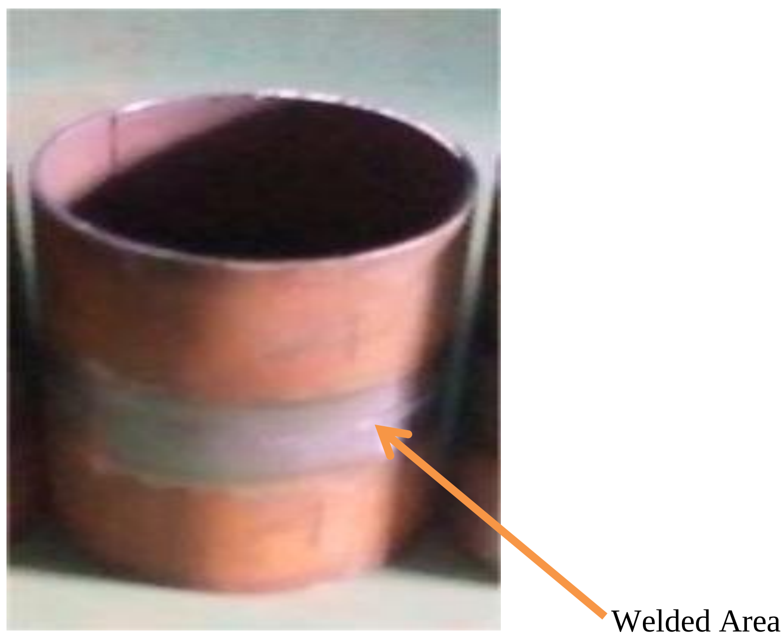

Figure 3.2 mild steel pipes

3.5.1.2 Materials Used:

AISI 1020 mild steel pipes with dimensions of 100 mm in length, 100 mm in diameter, and 3 mm in thickness were used for each pipe sample as the welding material for the Design of Experiments (DOE). During this welding experiment, ER70S-6 wire electrodes were employed.

3.5.1.3. Equipment's used

In this chapter, a Design of Experiments (DOE) was conducted for the optimization of TIG welding parameters. The equipment used included a welding machine, gloves, argon shielding gas bottle, protective helmets, appropriate clothing, pillars, a wire brush, a vice, a permanent marker, and a grinding machine. Figure 3.3 shows the TIG welding specimens during the welding operation aimed at optimizing product quality.

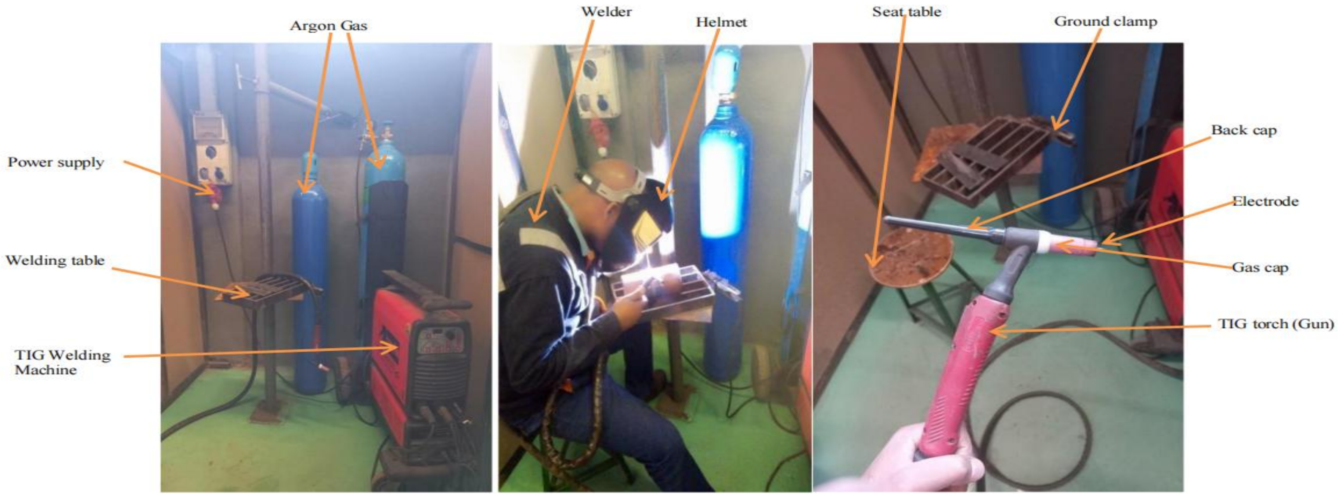

Figure 3.3 SUPERIOR TIG 322 AC/DC-HF/LIFT model machine and specimens for welding

3.5.1.4 Technical Specification for TIG Welding Machine

TIG welding, also known as Gas Tungsten Arc Welding (GTAW), is a welding process that utilizes a non-consumable tungsten electrode to create an arc and melt metal, often with inert gas shielding. This method results in high-quality precise welds. Table 3.1 provides a detailed discussion of the requirements for TIG welding.

Table 3.1 TIG Welding Technical Specification

Model	SUPERIOR TIG 322 AC/DC-HF/LIFT
Origin	Italy
Efficiency	85 V
Current range	5 - 270 A
Mains frequency	50 / 60 Hz
Dimensions	93,5 x 50 x 119,5 cm
DC current	215 A

3.5.2 TIG Welding Experimental Procedure

3.5.2.1 Cleaning the Welding Specimens:

Before conducting the welding experiment, the surfaces of the welding specimens must be thoroughly cleaned to achieve a better surface finish, properly unify the weld pool, and reduce the amount of porosity. Prepare the welding equipment and set the appropriate welding parameters. Ensure that protective safety equipment is worn. Then, proceed to weld the specimens. After welding, allow the specimens to cool down, grind the welded areas, and complete the welding process.

3.5.2.2 Design for Experimental Set up:

For this study, specimens were prepared using a welding process with specified materials to fabricate TIG welds of butt joints in a flat position. The welding experiments were conducted using the TIG welding process, employing a tungsten electrode with a diameter of 2 mm as a non-consumable electrode. Figure 3.4 illustrates the pipe butt joint in the flat position and the geometry of the welding specimen for the welding settings.

Table 3.2 setting the welding parameter

Welding Current (A)	Gas Flow Rate (L)	Filler Diameter (mm)
80	6	1.6
80	10	2
80	14	2.4
100	6	2
100	10	2.4
100	14	1.6
120	6	2.4
120	10	1.6
120	14	2

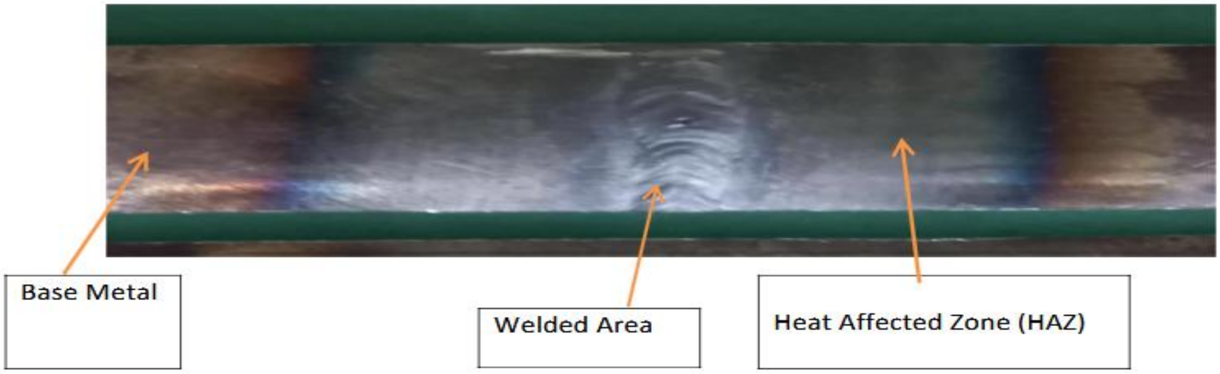

Figure 3.4 welded sample for study

3.6. Weld bed Geometry

The technique that addresses the challenges of TIG welding in the manufacturing industry is activated flux tungsten inert gas (A-TIG) welding. By applying flux to the workpiece surface prior to welding, A-TIG increases the aspect ratio by approximately 200% and the weld penetration depth by about three times. A-TIG welding achieves deeper penetration through two mechanisms: the arc constriction effect and the reversed Marangoni effect. The reversed Marangoni effect is caused by an inward surface fluid flow induced by the addition of sulfur or oxygen two surface-active elements to the molten pool, while the Marangoni effect involves an outward surface fluid flow. [Samarendra Acharya (October 2024)]

3.7 Mechanical Property testing for various mechanical tests

Mechanical property testing for AISI 1020 mild steel involves a variety of tests to evaluate its strength, ductility, hardness, and other characteristics. These tests including tensile, bending, hardness and compression tests provide crucial data for material selection, design, and manufacturing processes.

3.7.1 Tensile Strength

The principles of deformation and fracture can be described through the use of a uniaxial tension (or tensile) test. Thus, a concise description is provided to introduce the deformation and fracture mechanisms in metals. Generally, tensile tests are performed on AISI 1020 mild steel specimens with a thickness of 3 mm, as shown in Fig. 3.6. The samples are loaded uniaxial along the length of the specimen, and the applied load and the corresponding extension or change in length of the sample is measured simultaneously.

3.7.1.1. Specimen preparation and test procedures

A tensile specimen typically has a standardized cross-section, as shown in Table 3.3 and Figure 3.5. It features two necks and a gauge section in between; the shoulders and grip sections are usually 33% larger than the gauge section to facilitate easy gripping [Davis, 2004; Jiru et al., 2022]. The preparation of test specimens depends on the testing objectives as well as the governing test method or specification.

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

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

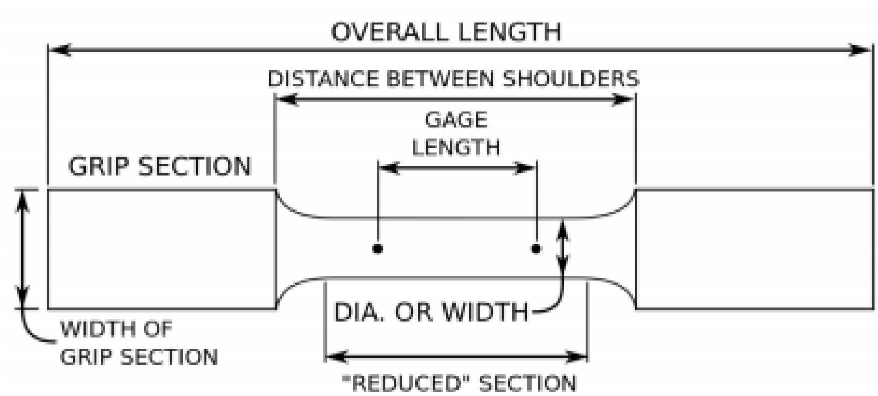

Figure 3.5 tensile test specimen standard dimension (Davis, 2004 and Jiru et al., 2022)

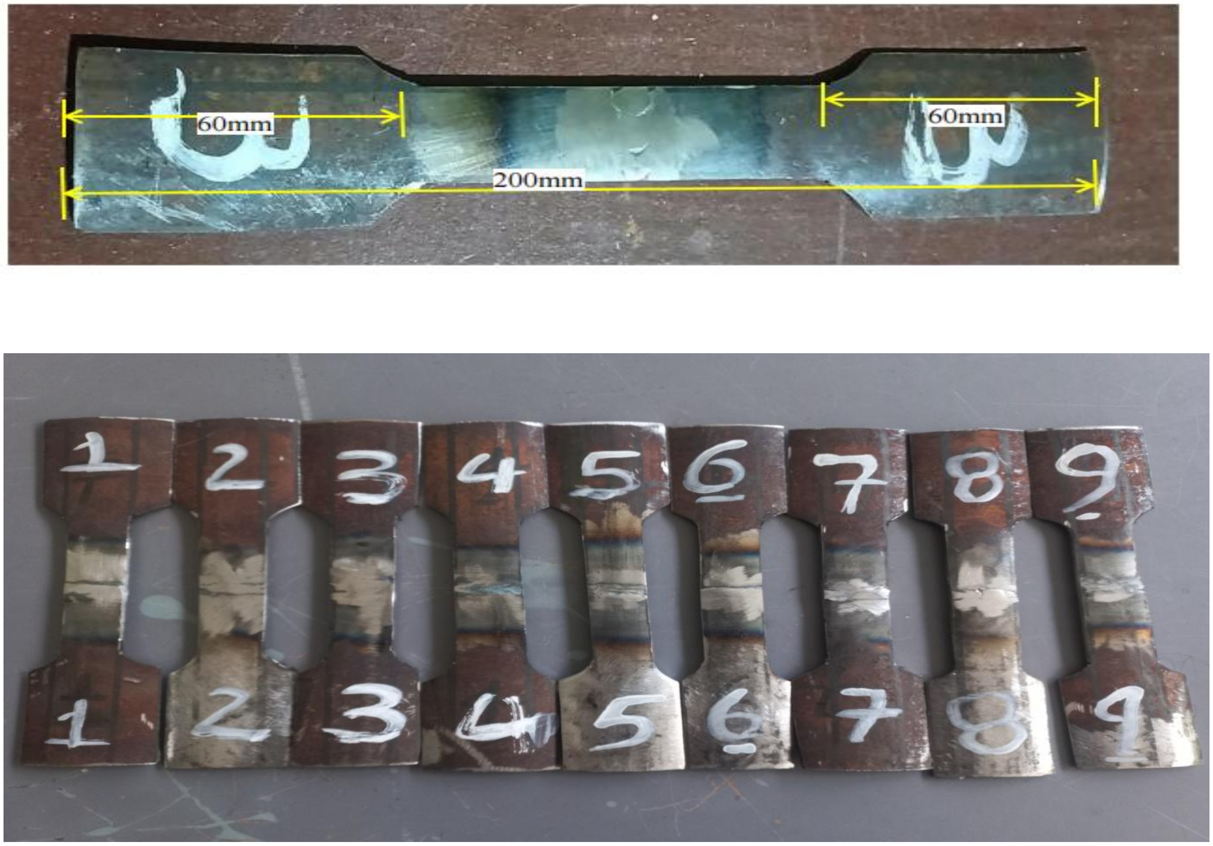

Figure 3.6 sample prepared for tensile strength from mild steel specimens

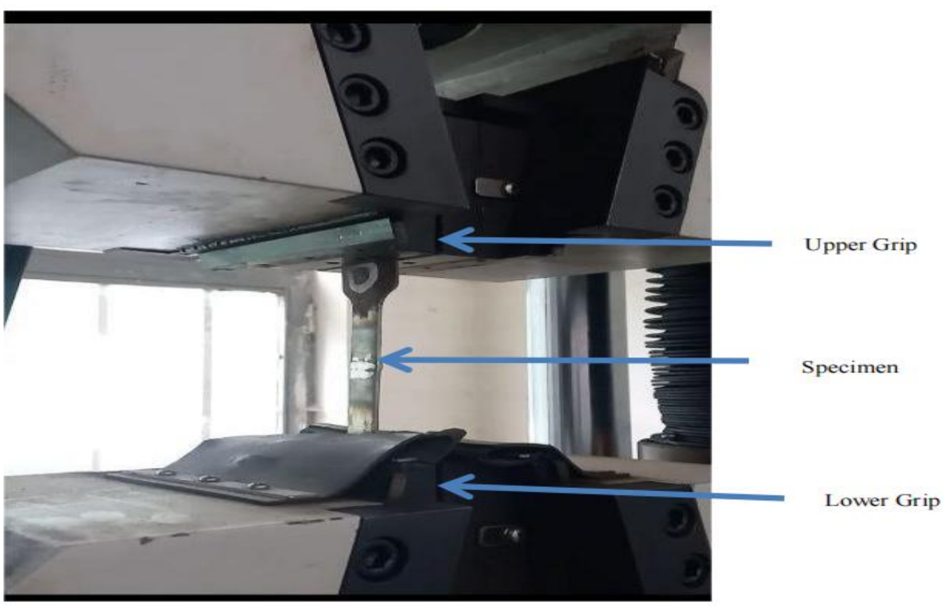

Figure 3.7 Universal tensile testing machines during specimen is test at FDRE Technical and Vocational Training Institute

Figure 3.8 the result after tensile test at FDRE Technical and Vocational Training Institute.

3.7.2 Hardness Testing

In hardness testing, a hardened steel ball or diamond point is pressed into the surface of a welded specimen under a specific load to create an indentation. The size of this indentation is then measured to assess the hardness of the weldment. The three most commonly used hardness tests are the Vickers, Brinell, and Rockwell tests (Jiru et al., 2022).

3.7.2.1 Rockwell Hardness

The Rockwell Hardness Test measures the depth of penetration of an indenter under specific loads, typically using a diamond cone or hardened steel ball. It establishes a zero reference point and then measures the penetration depth, which directly relates to the hardness value. The test analyzes indentation depth after applying minor and major loads, using a standardized scale that varies based on the type of indenter and load. The Rockwell Hardness Test is a versatile tool employed in various industries, including metallurgy, manufacturing, and quality control, to assess material hardness for product performance and durability.

Figure 3.9 Rockwell hardness testing machine

3.8. Bending Testing

A bending test, also known as a bending tensile test, evaluates materials for their bending strength and various other essential properties. By assessing a material's resistance to bending forces, this testing can reveal important details about its mechanical characteristics, including modulus, bending strength, and fracture behavior. It is crucial for understanding how materials behave under stress and determining their suitability for specific applications. Examples of bending test types include three-point, four-point, and cantilever bending tests. These tests, which are often standardized for consistency, provide insights into characteristics such as ductility, fracture resistance, and flexural strength.

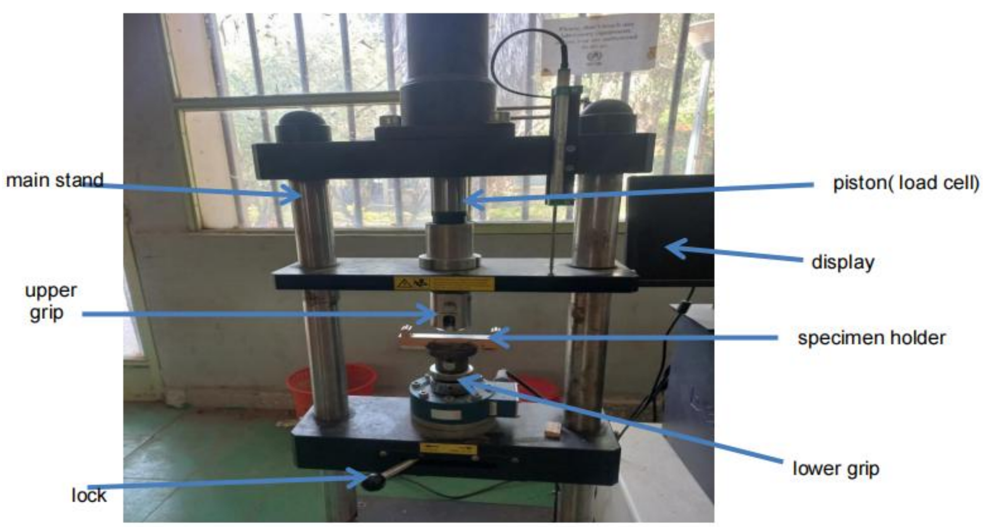

Figure 3.10 bending testing machine

3.9 TIG welding parameters

TIG welding is a type of precision arc welding that produces clean welds using an inert gas and a non-consumable tungsten electrode. It creates attractive welds on various metals and can be performed with or without filler material. Certain components are essential for TIG welding to operate effectively. Below is a detailed breakdown of the key components:

1. **Tungsten Electrode**: The tungsten electrode is the key element of the TIG welding process, responsible for transferring electricity and creating an arc with the workpiece. Tungsten's exceptionally high melting point (3422°C) makes it ideal for this application, as it does not melt during the welding process.
2. **Inert Gas Shielding**: An inert gas, typically argon, is used to shield the weld area from air contamination. This ensures a clean weld pool and prevents oxidation. The gas envelops the arc and flows through the torch, protecting it from contaminants in the air.
3. **Filler Material**: Although TIG welding can be performed without filler material by melting the base metals together, it often requires the addition of a separate filler rod to strengthen joints or close gaps. This filler is manually added to the molten weld pool by the welder.

3.10 Grey Relational Analysis

This study aims to optimize the mechanical parameters in TIG-welded mild steel AISI 1020 to enhance Rockwell hardness, compressive strength, and tensile strength. By adjusting welding conditions, it seeks to improve material durability and structural integrity for reliable use in demanding applications [Prakash et al., 2021].

Grey Relational Analysis (GRA) is a useful method for multi-response analysis, as it measures the absolute differences between sequences to determine their correlation. Taguchi-based Grey Relational Analysis (TGRA) examines the inter-functional correlations among several input parameters, including current, gas flow, and filler rod diameter. This study includes nine tests that optimize responses such as bending strength, tensile strength, hardness, and compressive strength by predicting the Grey Relational Grade (GRG). The highest GRG represents the most influential parameter combinations, helping to identify the ideal input levels for improved results. The results section includes detailed descriptions of the GRA application and conclusions.

The multiple response procedure is evaluated using the Grey Relational Grade (GRG), which simplifies the optimization of complex, multi-response processes into a single, comprehensive metric. By identifying the optimal parameter combination associated with the highest GRG, this approach facilitates significant improvements in overall performance and efficiency across various applications [Shaikh & Rao, 2015].

The Taguchi design employs an L9 orthogonal array to conduct nine tests while optimizing various parameters. This strategy not only provides consistent and reliable results but also allows for more efficient analysis by reducing experimental labor. By considering multiple elements and levels, the design offers a comprehensive framework for enhancing process performance and achieving significant outcomes.

3.11 Determine Parameter Design Using Orthogonal Array

First, identify the parameters you wish to vary, along with their levels and the desired strength of the design. Next, select an appropriate orthogonal array from established tables or specialized software, which provides a systematic arrangement of experiments. This structured approach enables efficient exploration of the parameter space, facilitating the identification of optimal settings.

The Taguchi L9 method is a powerful experimental design technique that utilizes an orthogonal array to systematically investigate the factors influencing a process's output. By reducing the number of trials needed, this method not only saves time and resources but also provides valuable insights into the significance of each factor. Additionally, it helps validate the optimality of a solution and highlights potential areas for improvement, ultimately enhancing overall process performance and reliability.

CHAPTER FOUR

RESULT AND DISCUSION

4.1 Experimentation Work

All pipes were cleaned with a polishing disk to remove impurities like rust, dust, and oil. Edges were prepared using a stainless-steel grinding wheel according to design requirements. The welding experiments adhered to the orthogonal array in Table 3.2, as illustrated in Figure 4.1, which shows the specimens being welded per the design of experiments (DOE).

Figure 4.1 Illustrates the welding experimental work carried out in this investigation, showcasing the welded specimens in order

4.2 Visual Examination of TIG Welded Samples

The weld surfaces were inspected for defects following the EN 970 standard. Table 4.1 shows that specimens 1–9 were minimal defect welded according to DOE developed in this investigation. Table 4.1 summarizes the visual test results for various samples, highlighting that Sample 3 featured well-formed beads with minimal spatter, while Sample 4 displayed excessive deposition with little spatter. Additionally, Sample 6 exhibited an excellent sound weld with excessive deposition and no spatter, demonstrating the quality of the welds assessed. Overall, deep penetration in the weld root enhanced the mechanical properties of the weld joint.

Table 4.1 Visual evaluation of weld specimens

Trials	Welding Current (Amp)	Gas Flow Rate (L/min)	Filler Rod (mm)	Result of Visual Inspection
1	80	6	1.6	Continuous deposition, with a slight undercut and no splatter.
2	80	10	2	Uneven bead caused by quick travel speed and no splatter.
3	80	14	2.4	The welding bead appears well-formed, with minimum spatter.
4	100	6	2	Sound weld with high deposition with minimal splatter.
5	100	10	2.4	There is no spatter and the weld beads are irregular.
6	100	14	1.6	Sound weld with high deposition and no spatter.
7	120	6	2.4	Uneven weld bead with a small undercut.
8	120	10	1.6	Impurities in the argon gas result in a uniform bead look and low porosity.
9	120	14	2	There are little defects or splatter evident.

4.3. Hardness Test Analysis

Hardness is the resistance to deformation, penetration, wear, and scratching, relevant in fields such as metallurgy, lubrication engineering, design, mineralogy, and machining (Parthasarathy, Ganesh, & Chellamuthu, 2018). Common scales for measuring hardness in welding include Brinell, Rockwell, and Vickers, with differential depth measurements taken using direct reading devices (Committee, 2000). The Rockwell Hardness method measures the permanent depth of an impression made by an indenter, utilizing steel ball and cone indenters, particularly the B scale with hardened steel balls at an initial load of 100 kg. Softer materials like fully annealed steels and nonferrous metals are tested with 1/16-inch hardened steel ball indenters. Figure 4.2 presents the Rockwell hardness results for experimental weld beads, featuring specimens prepared to a width of 20 mm and polished with 400, 800, and 1200 grit sandpaper.

Figure 4.2 Hardness sample prepared for test.

Table 4.2 the experimental Rockwell hardness value

S. N	Weld Bead Hardness Type "B" in HRB value			Average Hardness in HRB value
	Trial-1	Trial-2	Trial-3	
1	94.9	78.1	93.7	**88.9**
2	91.0	93.1	94.5	**92.9**
3	87.9	89.2	93.8	**90.3**
4	103.0	101.8	95.7	**100.2**
5	92.4	93.7	94.1	**93.4**
6	92.5	88.6	96.2	**92.4**
7	84.5	99.6	93.7	**92.6**
8	97.7	94.5	87.5	**93.2**
9	91.2	90.3	95.4	**92.3**

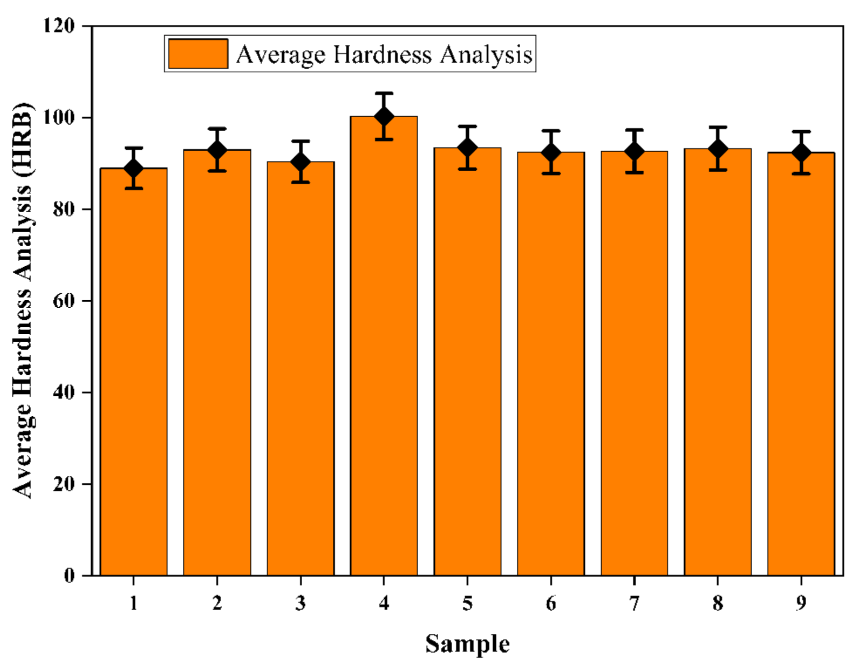

Figure 4.3 Graph hardness specimens for testing

Table 4.2 presents the Rockwell hardness results for the experimental weld beads, while figure 4.3 illustrates the hardness specimen used for testing. The study identified a substantial correlation between welding parameters and hardness levels in experimental weld beads. The highest hardness recorded was 100.2 HRB at a 100A welding current, a gas flow rate of 6 litres per minute, and a 2 mm filler metal thickness. This indicates that medium currents can enhance weld hardness by increasing heat input and facilitating metallurgical reactions. Conversely, a minimum hardness of 88.9HRB was observed at an 80A current, highlighting sensitivity to variations in welding conditions. The data, obtained using a 100 kgf HRB indenter according to ASTM E28 standards, ensure reliable measurements and establish a foundation for further research. Overall, the study emphasizes the importance of optimizing welding settings to achieve desired mechanical properties, thereby improving the quality and performance of welded joints. This study's findings align with previous research (Yadav et al., 2022). The micro hardness at 100A increased by 11.3% above the ASTM Rockwell type "B" values for AISI 1020. These values can improve based on proper processing factors setting and selecting like welding current, gas flow rate, and proper selection of filler material. This analysis aligns with ASTM standards such as ASTM A53 and ASTM A106, which define the mechanical property requirements for steel pipes. The "larger is better" signal-to-noise ratio can be found in Appendix III.

4.4 Tensile test Analysis

The assessment of the performance and design of engineered materials relies heavily on tensile testing. It supports material analysis, alloy development, quality control, and design by measuring Young's modulus and providing insights into strength and ductility under uniaxial loads [Joseph et al., (2016)]. Samples were created using a band saw and grinder, adhering to ASTM guidelines and conforming to ASTM E8-04 geometric specifications is shown in figure 4.4

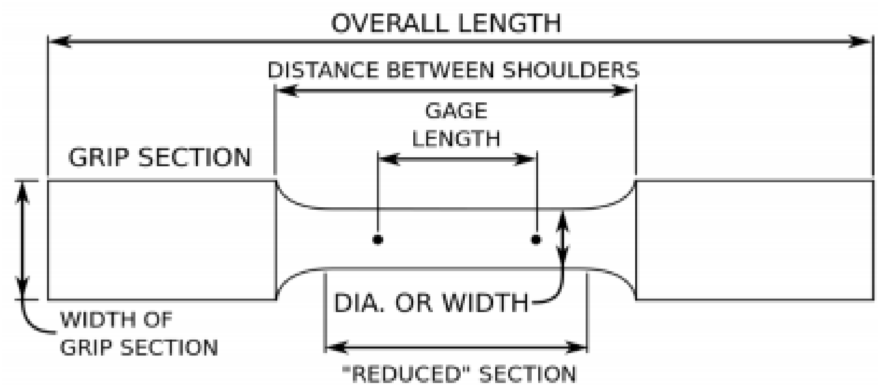

Figure 4.4 drawing of tensile test sample manufactured in compliance with ASTM-E8-04

Figure 4.4 presents a tensile test sample that complies with ASTM E8-04 standards. Its larger gripping ends enhance handling and secure attachment, reducing slippage during testing. The thinner central section focuses stress, allowing for controlled deformation and failure.

This design is essential for accurately measuring tensile strength, yield strength, and ductility, providing critical data for material characterization and engineering applications.

Figure 4.5 Tensile test samples prepared before testing and after testing

Tensile testing involves inserting a sample into a machine where tension is applied, resulting in an increase in both gauge length and force. As illustrated in Figure 4.5, this study involved preparing two specimens transverse to the weld bead, which were tested twice for reliability, with the average results presented in Table 4.3.

Table 4.3 Tensile test results

S. N	**Test -1**	**Initial dimensions**			**Fm**	**UTS**	**Test-2**	**Initial dimensions**			**Fm**	**UTS**	**Average UTS**
		W	**T**	**L**	**KN**	**MPa**		**W**	**T**	**L**	**KN**	**MPa**	**MPa**
1	1	20	3	200	34.0	**566**	1	20	3	200	33.7	**562**	**564**
2	2	20	3	200	34.1	**568**	2	20	3	200	33.8	**564**	**566**
3	3	20	3	200	38.0	**633**	3	20	3	200	38.3	**638**	**635.5**
4	4	20	3	200	34.8	**580**	4	20	3	200	34.7	**585**	**582.5**
5	5	20	3	200	34.0	**566**	5	20	3	200	34.2	**570**	**568**
6	**6**	**20**	**3**	**200**	**38.0**	**633**	**6**	**20**	**3**	**200**	**38.3**	**638**	**635.5**
7	7	20	3	200	36.8	**613**	7	20	3	200	36.9	**615**	**614**
8	8	20	3	200	34.7	**578**	8	20	3	200	34.8	**581**	**579.5**
9	9	20	3	200	35.3	**589**	9	20	3	200	34.9	**583**	**586**

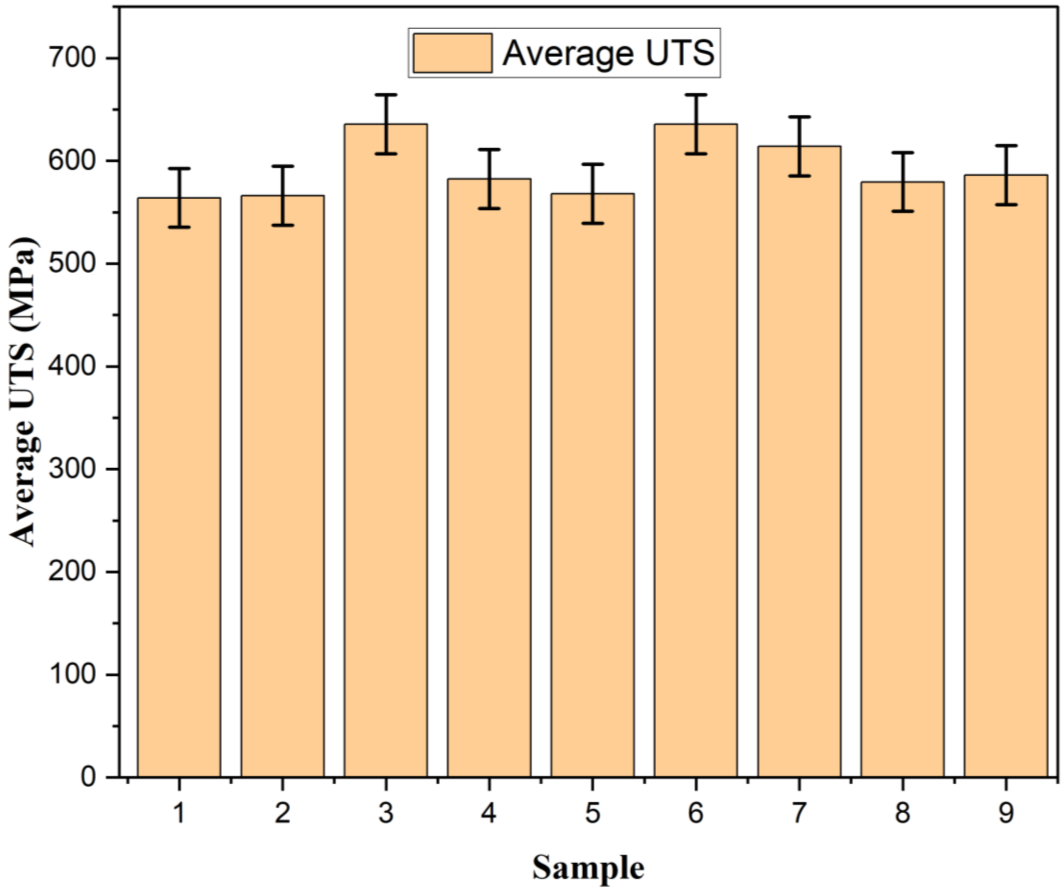

Figure 4.6 Graph tensile specimens for testing

In a single experiment, two tensile inspection specimens were tested at room temperature, as shown in figure 4.6, resulting in an average ultimate tensile strength of 635.5 MPa. This was achieved after 9 trials using a welding current of 100A, a gas flow rate of 14 L/min, and a filler material diameter of 2 mm. The lowest tensile strength recorded was 564MPa, obtained with an 80A welding current, a 6L/min gas flow rate, and a filer material diameter is 2 mm. The study indicates that increasing welding current and gas flow rates enhances tensile strength, influenced by the material's chemical composition, structure, and manufacturing process. These results align with prior research by [Anand et al., (2017); Ghosh et al., (2016); Linger & Bogale, (2023); Lugde and Deshmukh, (2015); Moi et al., (2018); Muluken, (2020);]. The highest tensile strength was achieved at maximum welding current, showing a direct correlation between tensile strength and current (Ramakrishnan et al., 2021). A tensile strength of 635.5 MPa was recorded at 100 A and 14 L/min shielding gas flow, which is a 5.9% increase over ASTM data for AISI 1020. The "larger is better" signal-to-noise ratio can be found in Appendix III.

4.5 Bending Strength

Bend testing is a useful method for determining a material's ductility and strength by bending it over a predetermined radius. It evaluates plastic deformation under stress and detects flaws, such as weld faults, to ensure structural integrity and safety. Figure 4.7 depicts two face bend samples that were bent 180° during welding tests using a 20 mm (4T) mandrel diameter ASME section IX mandrel [Joseph et al., (2016)]. High bend strength and no visible cracks are deemed acceptable, ensuring that materials perform consistently in their intended applications [Kumar et al., 2017].

Figure 4.7 Bending test specimens, showcasing their preparation before testing and their condition after testing

Table 4.4 Results of the bending examination

Test 1	**W (mm)**	**T (mm)**	**L (mm)**	**F (KN)**	**BS (MPa)**	**Test 2**	**W (mm)**	**T (mm)**	**L (mm)**	**F (KN)**	**BS (MPa)**	**Average Bending Strength (MPa)**
1	19.9	3	40	1.18	**395.5**	1	20.5	3	40	1.19	**386.7**	**391.1**

2	20.0	3	40	1.2	**400**	2	21	3	40	1.21	**384.2**	**392.1**
3	20.0	3	40	1.19	**396.7**	3	20.7	3	40	1.19	**383.4**	**390.05**
4	20.2	3	40	1.22	**406**	4	19.3	3	40	1.23	**423.3**	**414.65**
5	19.8	3	40	1.15	**387.5**	5	19.2	3	40	1.14	**396.4**	**391.95**
6	20.0	3	40	1.18	**393.3**	6	19.7	3	40	1.17	**394.2**	**393.75**
7	20.0	3	40	1.19	**396.6**	7	19.3	3	40	1.16	**399.4**	**398.0**
8	20.1	3	40	1.21	**400**	8	19.5	3	40	1.16	**396.0**	**398.0**
9	19.9	3	40	1.19	**398.7**	9	20.4	3	40	1.21	**395.3**	**397.0**

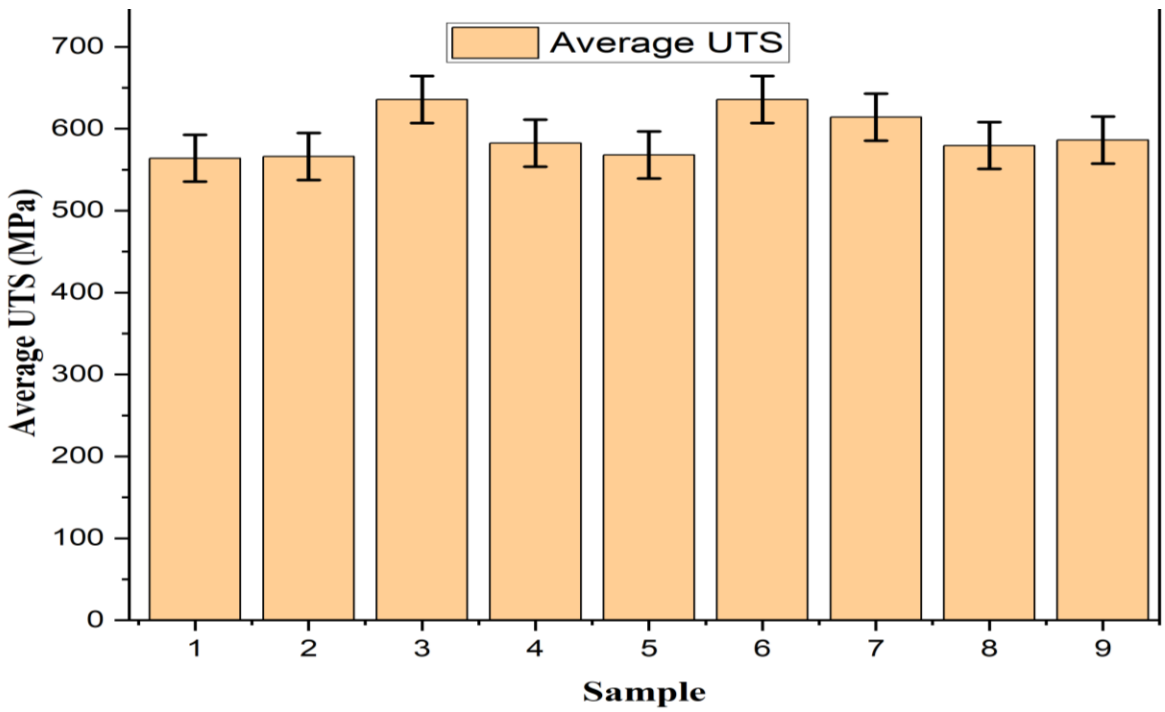

Figure 4.8 Graph Bending specimens for testing

Bending strength is a material's ability to withstand bending under stress, which is critical for structural design. As deformation rises, the crystalline structure strengthens, resulting in increased bending strength. Bend testing evaluates ductility and strength by bending specimens over a predetermined radius (Figure 4.7). Two specimens were created from each work piece, and the average findings are reported in table 4.4 and Figure 4.8.

The highest achievable bending strength reached 414.65MPa ninth experiments parameters with a maximum welding current of 100A, a gas flow rate of 6 lit/min, and filler material diameter 2 mm Similarly, a minimal bending strength measured to be 390.05MPa was observed using the settings parameters of 80A welding current, 14 lit/min gas flow rate, and filler material diameter 2 mm. This investigation was consistent with the conclusions of previous scholar investigation. [Kumar et al., (2017); Singh & Mittal, 2017); Linger & Bogale, (2023)]. As a consequence, the bending strength was 414.65MPa at 100A welding current and 6 lit/min shielding gas flow rate, a 9.6% increase over the ASTM values for AISI 1020. The "larger is better" signal-to-noise ratio can be found in Appendix VI.

4.6 Compressive Strength Analysis

The compressive strength of the samples was measured with Bairo hydraulic universal testing equipment (HUT-600, 600 kN capacity). A consistent compression force of 100 kN was used to account for the high hardness of the weld joints, which is critical for determining the structural integrity of the materials. This testing simulates real-world conditions, providing information on the weld joints' endurance and reliability in practical applications.

Table 4.5 Results of the Compressive strength examination

S. N	**Compressive Strength** MPa	**Trial-2**	**Compressive Strength** MPa	**Average Compressive Strength** MPa
1	960.7	1	965	**954**
2	959.2	2	962.6	**960.9**
3	949.4	3	958.6	**963.15**
4	970.1	4	974	**972.05**
5	963.6	5	961.9	**962.75**
6	980	6	982	**981**
7	972	7	970.3	**971.15**
8	976.1	8	978.9	**977.5**
9	956.9	9	955.9	**956.4**

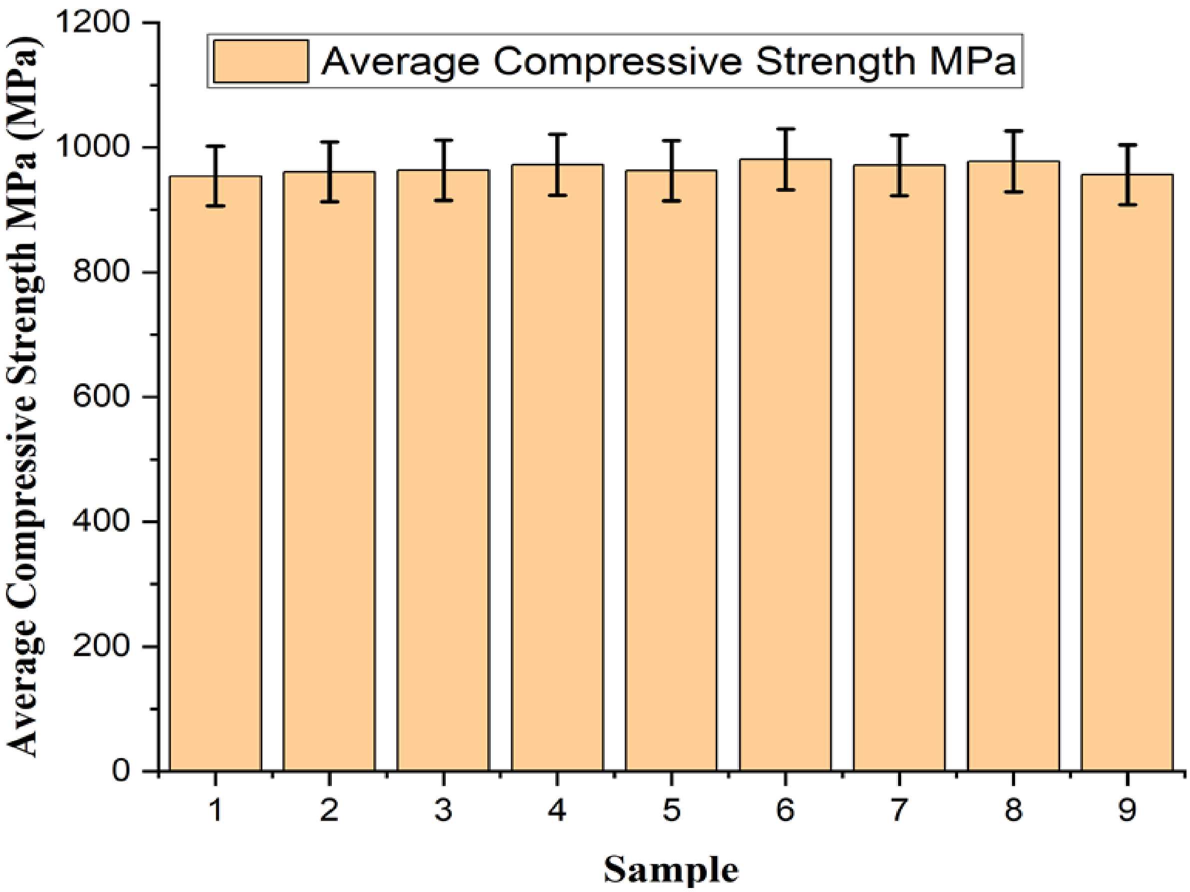

Figure 4.9 Graph Average compressive strength specimens for testing

Two specimens were prepared for each work piece, and the results were averaged. The highest compressive strength was 981 MPa in the ninth experiment, with a 100 A welding current, 14 L/min gas flow, and a 2 mm filler diameter. The lowest strength was 954 MPa in the first experiment, with 80 A and 6L/min gas flow. The strength at 100 A was 9% greater than ASTM AISI 1020 data. The "larger is better" signal-to-noise ratio can be found in Appendix VII.

4.7 Taguchi-based Grey Relational Analysis (TGRA)

Taguchi-based Grey Relational Analysis (TGRA) can effectively analyze experimental results by assessing multiple performance metrics simultaneously, such as hardness, tensile strength, compressive strength, and bending strength. The methodology involves conducting a series of controlled experiments, adhering to an orthogonal array that systematically varies welding parameters like current, gas flow rate, and filler diameter. By calculating the Grey Relational Grades (GRGs) for each test, TGRA identifies optimal parameter combinations that yield superior mechanical properties. This multi-response optimization technique minimizes variability and enhances the overall quality of the welded joints, providing insights for improved process control in industrial applications.

Grey Relational Analysis (GRA) assesses the signal-to-noise (S/N) ratio of performance attributes and explores relationships in limited data contexts. The Taguchi-based GRA addresses issues with multiple input variables and response factors. In this study, nine test sets were analysed, focusing on hardness, compressive strength, bending strength, and ultimate tensile strength. The highest Grey Relational Grade (GRG) value, calculated for each dataset, determines the optimal arrangement to enhance results. This approach is consistent with multi-response optimization principles, as highlighted by [Ashebir et al. (2022)].

4.8 Comparison of Experimental Results

The multi-response optimization technique employs Taguchi-based Grey Relational Analysis (TGRA) to systematically identify the most effective combinations of process variables. This approach enhances decision-making by optimizing multiple responses simultaneously, leading to improved performance and efficiency in various industrial processes [Abdullahu,et al,.(2024)]. The Taguchi technique was employed to systematically gather response data from AISI 1020 mild steel welded using TIG welding. The findings, presented in Table 4.6, highlight the critical importance of enhancing ultimate tensile strength, bending strength, compressive strength, and Rockwell hardness. Improving these parameters is essential for optimizing performance, refining product design, and enhancing manufacturing processes, ultimately leading to more durable and efficient welded structures in various industrial applications.

Table 4.6 the experimental results demonstrate that greater values are associated with improved quality attributes

S. N	Microhardness (RHB) (HRB)			Ultimate Tensile Strength (UTS) (MPa)		Compressive Strength (CS) (MPa)		Bending Strength (BS) (MPa)	
	H-1	**H-2**	**H-3**	**UTS-1**	**UTS-2**	**CS-1**	**CS-2**	**BS-1**	**BS-2**
1	94.9	78.1	93.7	566	562	960.7	965	395.5	386.7
2	91	93.1	94.5	568	564	959.2	962.6	400	384.2
3	87.9	89.2	93.8	633	638	949.4	958.6	396.7	383.4
4	103.2	101.8	95.7	580	585	970.1	974	406	423.3

5	92.4	93.7	94.1	566	570	963.6	961.9	387.5	396.4
6	92.5	88.6	96.2	633	638	980	982	393.3	394.2
7	84.5	99.6	93.7	613	615	972	970.3	396.6	399.4
8	97.7	94.5	87.5	578	581	976.1	978.9	400	396
9	91.2	90.3	95.4	589	583	956.9	955.9	398.7	395.3

4.8.1 Analysis based on the Taguchi technique

The Taguchi system is acclaimed as an effective methodology for producing high-quality AISI 316 materials using TIG welding, especially with L9 orthogonal arrays. It optimizes welding parameters to minimize variability and improve quality. By focusing on robust design principles, it identifies optimal conditions for superior mechanical properties, improving product consistency and reducing manufacturing costs, making it a valuable asset in the welding industry [Nobrega et al,. (2021)]. The L9 (or 3^3) orthogonal array tests welding current, shielding gas flow rate, and filler material diameter at three levels, total 9 trials. This structure allows for a full analysis of these components' interplay, which improves welding optimization and decision-making. Taguchi's strategy tries to reduce repeats while producing optimal outcomes quickly. It uses Minitab19 Statistical Software to effectively analyze and replicate experimental experiments. The Degree of Freedom (DOF) represents the minimal contrasts required for assessing process parameters. It quantifies the total number of experiments necessary to thoroughly investigate the observable variables, ensuring that the relationship and interactions among these parameters are accurately analyzed to optimize the overall process efficiency and effectiveness. The study uses signal-to-noise ratios for Rockwell Hardness (RH), Ultimate Tensile Strength (UTS), Compressive Strength (CS), and Bending Strength (BS) to evaluate and improve welding performance. To calculate the S/N ratio, use Equation (4.1). The study examines the relationship between TIG welding process parameters and mechanical qualities such as bending strength, hardness, compressive strength, and ultimate tensile strength. NOISE represents negative ratings, whereas SIGNAL represents positive outcomes in the assessment.

4.8.2 Multi-Response Optimized Performance within GRA

Taguchi’s technique is extremely effective for determining optimal combinations of process parameters to improve certain response characteristics, particularly when numerous quality attributes must be examined at the same time. To acquire the best results, approaches such as

Grey Relational Analysis (GRA) are recommended. GRA is particularly useful for dealing with partial or imprecise data, making it ideal for enhancing performance in operations like as machining and material manufacture (Osuchukwu, 2022).

The study on hybrid titanium metal matrix composites (H TMMCs) used Taguchi-based Grey Relational Analysis (TGRA) to optimize process parameters, achieving significant improvements in mechanical properties. Key parameters included 5-hour milling, 40MPa compaction, 1200 °C sintering, resulting in enhanced hardness, compressive strength, and reduced wear rate and porosity [Birhane A, et al, (2024)].

Phase 1: To show quality, experimental findings are transformed into S/N ratios using compression, tensile, bending strength, and Rockwell hardness tests, and ratios are compared to measure material performance.

$$\frac{S}{N}(\eta) = -10Log\left[\frac{1}{z}\sum_{i=1}^{z}\frac{1}{Yi^2}\right] \quad \text{Eq. 4.1}$$

Whereas z represents the number of replication tests conducted, while Y_i denotes the measured response values obtained from these tests.

Table 4.7 the ratio S/N (η) for the reported values larger is Better

S.N	Ratio of S/N of (HS)	Ratio of S/N of (UTS	Ratio of S/N of (CS)	Ratio of S/N of (BS)
1	38.978	55.0256	51.8458	59.591
2	39.3603	55.0563	51.8679	59.6536
3	39.1138	56.0623	51.8224	59.6739
4	40.0174	55.3059	52.3536	59.7538
5	39.4069	55.087	51.8646	59.6703
6	39.3134	56.0623	51.9044	59.8334
7	39.3322	55.7634	51.9977	59.7457
8	39.3883	55.2611	51.9977	59.8023
9	39.304	55.358	51.9758	59.6128

Phase 2: Use equations (4.1) and (4.2) to normalize ij as Zij (0 Zij 1) to normalize data using the Taguchi method, collect original data points and apply the formula Use a grey relational mechanism to create normalized signal-to-noise (S/N) ratios, ensuring values are between 0 and 1 for consistent comparisons and further analysis [Rojas, H et al, (2024)]. Higher values in

signal-to-noise (S/N) normalization enhance compression strength, ultimate tensile strength, and bending strength, making larger values preferable. This technique refines performance indicators and optimizes material properties for improved results [Borito, et al, (2025)]. Using equation (4.2), larger is best.

$$Zij = \frac{nij - \text{Min}(nij)}{Max(nij) - \text{Min}(nij)} \quad \text{Eq. 4.2}$$

Here, Zij: - denotes the normalized value for the iii-th experiment related to the jjj-th dependent factor or response. The variable ηij: - signifies the signal-to-noise (S/N) ratio that requires normalization. Additionally, **max (ηij)** and **min (ηij)** indicate the maximum and minimum values of the S/N ratio, respectively. This normalization process allows for the S/N ratios to be standardized, facilitating easier comparison and analysis across different experiments. The Goal Ratio Calculation (GRC) depicts the link between ideal results and actual examination outcomes. Higher normalized results indicate greater achievement, with an optimal outcome of one [Tronchin, et al, (2021)]. Table 4.8 figured out normalized S/N ratios of determined outcomes generated from table 4.8, calculated data using the above- mentioned equations.

Table 4.8 Computed Normalized S/N ratios of determined results

S/N ratios normalized (η) for higher is better				
SN	Ratio of S/N of (BS)	Ratio of S/N of (UTS)	Ratio of S/N of (H)	Ratio of S/N of (CS)
1	0	0	0	0
2	0.06740	0.02740	0.06086	0.55520
3	0.18876	0.38571	0.06957	0.71059
4	0.29663	0.59143	0.23478	0.85176
5	0.31011	0.65142	0.26087	0.88470
6	0.32360	0.66000	0.48695	0.89882
7	0.56629	0.78000	0.89565	0.78000
8	0.75505	0.78857	0.06957	0.96000
9	1	1	1	1

Phase 3: The deviation sequences ($\Delta_{ij}\Delta_{ij}$) for both quality criteria are calculated using the same approach. The absolute difference between $Z_{ij}^{0}Z_{ij}^{0}$and $Z_{ij}Z_{ij}$ indicates divergence from the desired level, resulting in quality loss. Table 4.9 shows deviation sequences for different normalized signal-to-noise ratios (ηη).

$$\Delta ij = Zij0 - Zij \quad \text{Eq. 4.3}$$

Whereas Δij denotes the deviation series and Zij^{0} is typically equal to one ($Zij^{0} = 1$).

Phase 4: Grey Relational Coefficients (GRCs) for normalized signal-to-noise ratio data are computed using a specific equation. This equation simplifies the determination of GRCs based on normalized values.

$$Zij = \frac{\Delta\text{Min} + \lambda\Delta\text{Max}}{\Delta\text{ij} + \lambda\Delta\text{Max}} \begin{cases} i = 1,2,3 \ldots 27 \\ j, = 1,2,3,4 \end{cases} \quad \text{Eq. 4.4}$$

The parameter λ, often known as the distinguishing or identifying coefficient, runs from 0 to 1. Its value can be modified to meet the system's specific requirements.

A value of λ = 0.5 is usually chosen because using 0 or 1 has no effect on parameter ranking in the sequence [Bantan et al, (2021)]. The GRC values derived from equation (4.4)

Phase 5: Calculate GRCij for each group, then aggregate to estimate overall risk, normalize as appropriate, then compute GRGi for a comprehensive assessment.

$$\boldsymbol{GRGi} = \frac{1}{m}\sum GRCij \quad \text{Eq. 4.5}$$

Whereas, m defines the total number of responses (or achievement characteristics) and equals 4 due to the four responses (H, UTS, CS, and BS). Table 4.9 shows the GRCs and GRGs for all experiments that were calculated in the same manner.

Table 4.9 Deviation Series progression for normalized S/N ratios (η)

S. N	Deviation Series (Δij have the exact same equation expression)			
	ΔBS	ΔH	ΔUTS	ΔCS
1	1	1	1	1
2	0.1325	0.1391	0.1725	0.6447
3	0.0112	0.1304	0.8142	0.4894
4	0.9033	0.9652	0.6085	0.3482
5	0.8898	0.9391	0.5485	0.3152

6	0.8764	0.713	0.54	0.3011
7	0.6337	0.3043	0.42	0.42
8	0.4449	0.1304	0.4114	0.24
9	0	0	0	0

Table 4.10 Grey relational grades (GRGs) and Grey relational coefficients (GRCs)

S.N	Grey Relational Coefficients (GRCs)				Grey Relational Grades (GRGs)
	BS	UTS	H	CS	
1	1	1	1	1	1
2	0.6173	0.6069	0.6156	0.7806	0.6551
3	0.6512	0.7148	0.6179	0.8523	0.709
4	0.6846	0.7962	0.665	0.9301	0.7689
5	0.689	0.8235	0.6731	0.9503	0.784
6	0.6935	0.8275	0.7527	0.959	0.8082
7	0.7852	0.8888	0.9572	0.8889	0.88
8	0.8754	0.8936	0.9921	0.9166	0.9628
9	1	1	1	1	1
Average mean of GRG					0.8853

Phase 6: Choose the most suitable variable and level settings. The greater the gray relationship grade, the higher the product's excellence attribute. This allows for exploration of variable influences and helps identify the optimal levels that satisfy all attributes effectively.

The Gray Relationship Grade (GRG) detects controllable components in two ways: (1) utilizing minitab software to optimize parameter setups and (2) manually calculating the average GRG scores [Abdullahu F, et al (2024)].

The process consists of three major steps: First, the Gray Relationship Grades (GRGs) are organized by variable level for each column in the orthogonal array (OA). Second, the average of the GRGs is calculated. Third, grade scores for each L9 OA examination are computed using the design of experiments (DOE). To assess the impact of variable iii, the average grade rating for each level jjj is calculated as AGV_{ij} and its impact is defined as E_i [Bodunrin et al., 2015].

$$Ei = max(AGVij) - Min\ (AGVij) \qquad \text{equation 4.6}$$

If the variable I can be controlled, the optimal level j* is calculated by (4.6)

Table 4.11 Average GRG response table

S.N	Factor of Control	GRG Average by Parameter Levels			Max-Min (Ei)	Rank
		L1	L2	L3		
1	Welding Current (WC)	2.3731	2.6241	**3.2082**	0.8351	1
2	Filler Road Diameter (FD)	2.6391	**2.849**	2.7173	0.2099	3
3	Gas Flow Rate (GRF)	2.5642	**3.0429**	2.3612	0.6817	2

This is the optimum parameters

Welding Current (WC) = 140

Filler Road Diameter (FD) = 2

Gas Flow Rate (GRF) = 16

4.8.3 Regression Analysis

Regression Analysis: HS, TS, BS, & CS versus WC, GFR and FD

In regression analysis, the dependent variable is hardness strength, and the independent variables are welding current, gas flow rate, and filler diameter. Welding current controls heat input during the welding process, which affects weld hardness. The gas flow rate determines the shielding gas protection from oxidation, as well as the weld cooling rate. Meanwhile, filler diameter influences the amount of material deposited as well as heat transmission characteristics, both of which contribute to the welded joint's hardness strength.

Table 4.12 Regression Analysis: HS versus WC, GFR, FD

Source	DF	Adj SS	Adj MS	F-Value	P-value
Regression	3	14.0217	4.6739	0.037	0.046
WC	1	6	6	0.048	0.048
GFR	1	7.4817	7.4817	0.049	0.046

FD	1	0.54	0.54	0.04	0.044
Error	5	63.0672	12.6134		
Total	8	77.0889			

This regression analysis aims to quantify how the independent variables welding current, gas flow rate, and filler diameter collectively influence the tensile strength of welded joints. By establishing a mathematical relationship between these factors and tensile strength, we can gain valuable insights into the welding process.

Table 4.13 Regression Analysis: TS versus WC, GFR, FD

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	1831.75	610.58	0.04	0.046
WC	1	32.67	32.67	0.03	0.036
GFR	1	1552.04	1552.04	0.043	0.027
FD	1	247.04	247.04	0.026	0.032
Error	5	4754.25	950.85		
Total	8	6586			

This regression analysis seeks to quantify how the independent variables welding current, gas flow rate, and filler diameter interact to determine the bending strength of welded joints. By creating a quantitative relationship between these variables and bending strength, we can gain useful information for the welding process.

Table 4.14 Regression Analysis: BS versus WC, GFR, FD

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	154.148	51.383	0.039	0.041
WC	1	65.01	65.01	0.029	0.034
GFR	1	87.784	87.784	0.047	0.029
FD	1	1.354	1.354	0.030	0.022
Error	5	298.011	59.602		
Total	8	452.159			

This regression analysis seeks to quantify how the independent variables welding current, gas flow rate, and filler diameter interact to determine the compressive strength of welded joints. By creating a quantitative relationship between these variables and compressive strength, we can gain useful information for the welding process.

Table 4.15 Regression Analysis: CS versus WC, GFR, FD

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	163.154	54.385	0.049	0.034
WC	1	121.5	121.5	0.043	0.035
GFR	1	1.87	1.87	0.02	0.045
FD	1	39.784	39.784	0.037	0.05
Error	5	535.408	107.082		
Total	8	698.562			

4.9 Comparative Discussion

Previous studies have explored welding parameter optimization and its impact on mechanical properties. Karthikeyan (2016) found that pulse TIG parameters enhance tensile strength in AZ31B Mg alloy, with a peak current of 210A yielding 188 MPa. Sathish (2012) noted significant effects of TIG welding parameters on SS304. Joseph (2020) demonstrated that welding position and current affect tensile strength and elongation in S30430 steel, utilizing the Taguchi method for optimization. Widyianto et al. (2021) minimized welding distortion through optimized sequences. Ahmed Khalid Hussain et al. studied AA6351 sheets, while Thakur and Gebrelibanos (2019) compared welding processes, and Tesfaye (2023) optimized TIG-MIG parameters using grey relational analysis.

The study investigates key areas in welding, focusing on weld bead geometry, statistical optimization methods like ANOVA and the Taguchi approach, and comparative analysis of welding techniques. Experimental work involved preparing AISI 1020 pipes and using an L9 orthogonal array for systematic testing of variables such as welding current and gas flow rate. Results showed a strong correlation between parameters and microhardness, achieving 100.2 HRB at 100A current. Tensile strength averaged 635.5 MPa, exceeding ASTM standards, while bending and compressive strengths reached 414.65 MPa and 981 MPa, respectively. Taguchi based Grey Relational Analysis was employed for multi-response optimization.

4.10 Verification Experimentation

Confirmation experiments affirm the findings by showcasing the efficacy of an optimization strategy. They verify improvements in performance at the expected maximum settings, ensuring that optimal performance levels are reached. Validation experiments are conducted using a welding current of 140A, a gas flow rate of 16 liters per minute, and a filler diameter of 2 mm, focusing on optimal process parameters. The ideal TIG welding parameters for managing the welding of AISI 1020 mild steel pipe involve controlling variables with three replications. As a result of the confirmation experiment, all variability is minimized, and the optimal outcomes achieved are deemed acceptable. Figure 4.10 displays the validation results for the Rockwell hardness type "B" parameters.

The internal surface quality of the welded area of AISI 1020 mild steel pipe is considered to be of nice quality during optical microscopy testing when it meets several key criteria. Firstly, the surface should be smooth and free from significant roughness, weld spatter, or irregularities, allowing for optimal light reflection and clarity in observation. Uniformity in texture and color is essential, indicating consistent weld penetration and filler material distribution without noticeable variations or defects.

Cleanliness is also critical; the internal surface should be free from contaminants such as oxides, dirt, or residues from the welding process, which can obscure microstructural features and hinder accurate analysis. The microstructure should exhibit a well-defined fusion zone with clear, distinct grain boundaries, reflecting proper welding techniques and heat treatment. Additionally, there should be no visible defects, such as cracks, porosity, or inclusions that could compromise the integrity of the weld and the overall performance of the pipe.

Finally, the heat-affected zone should be well-defined and show a gradual transition between the base material and the weld, indicating appropriate thermal management during the welding process. When these factors are present, the internal surface of the welded area can be deemed to have high quality for optical microscopy testing.

Table 4.16 Verification Experimentation Table

S. N	Micro hardness (H) (HRB)	Ultimate Tensile Strength (UTS) (MPa)	Compressive Strength (CS) (MPa)	Bending Strength (BS) (MPa)

	Test-1	Test-2	Test-3	Avg.	Test-1	Test-2	Avg.	Test -1	Test-2	Avg.	Test -1	Test -2	Avg.
1	94.7	95.2	99.7	**96.5**	630	641	**635.5**	984	978	**981**	404	416	**410**
2	92	96.1	96.7	**94.9**	579	611	**595**	950	955	**952.5**	402	427	**414.5**
3	99.6	99.5	101.5	**100.2**	564	560	**562**	970	950	**960**	410	392	**390.2**

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The experimentation on TIG welding of AISI 1020 mild steel has provided valuable insights into how various welding parameters affect the mechanical properties of welded joints. Utilizing a systematic Design of Experiments (DOE) approach, each specimen was carefully prepared and assessed for defects, hardness, tensile strength, bending strength, and compressive strength. Visual inspections revealed that most samples showed minimal defects, particularly Samples 3 and 6, which exhibited well-formed beads and sound welds. This suggests that the chosen welding parameters were effective in producing high-quality welds.

Key findings from the study highlighted the strong relationship between welding parameters and the mechanical properties of the welds. Hardness tests showed that the optimal hardness of 100.2 HRB was achieved at a welding current of 100A and a gas flow rate of 6 L/min, emphasizing the significance of medium currents. Tensile strength tests indicated that higher welding currents and gas flow rates led to increased tensile strength, with a maximum of 635.5 MPa tested. Additionally, bending tests revealed a peak bending strength of 414.65 MPa under optimized conditions, while compressive strength assessments showed a maximum of 981 MPa. The application of Taguchi-based Grey Analysis (GRA) helped identify optimal welding parameters, further verified by confirmation experiments that demonstrated consistent improvements across all tested mechanical properties.

This research underscores the significance of optimizing welding parameters to enhance the mechanical properties and performance of welded joints. The results provide important insights for the field of welding engineering and set the stage for future studies aimed at improving welding techniques. Furthermore, the effective application of the Taguchi method and grey Relational Analysis (GRA) illustrates their utility as valuable tools for systematic experimentation and optimization within welding technology.

5.2 RECOMMENDATION

In the experimentation work, standardizing all cleaning methods is essential to ensure consistency across trials, and thorough documentation of cleaning procedures along with polishing disk specifications is necessary for reproducibility. For the visual examination of TIG welded samples, implementing a detailed defect classification system is recommended to better categorize observed defects, which can aid in refining welding parameters for improved quality. Additionally, in hardness test analysis, incorporating methods like Vickers or Knoop would enhance the understanding of hardness variations and microstructural differences in welds. Increasing the number of tensile test trials is crucial for achieving statistical significance, and it is important to investigate how sample orientation relative to the weld bead affects tensile strength. For bending strength, testing at various angles can provide insights into material behaviour and ductility, while compressive strength analysis should explore the relationship between strength and microstructure through metallographic analysis to understand how welding parameters impact structural integrity.

Furthermore, utilizing a broader set of parameters in Taguchi-based Grey Relational Analysis (TGRA) will allow for the capture of additional variables influencing weld quality, leading to a more nuanced understanding of parameter interactions. Regularly updating comparison datasets with new experimental findings will help track trends over time, and employing machine learning algorithms could assist in predicting optimal welding parameters based on historical data. Finally, conducting verification experiments under real-world conditions such as field tests or simulations is crucial for validating the performance of welded joints and confirming lab findings, ensuring that the results are applicable in practical situations.

To enhance experimental robustness in welding and material science, maintain thorough documentation for reproducibility, use statistical software for robust data analysis, and collaborate with experts to refine methodologies, ensuring findings are meaningful and provide advanced insights into welding processes.

5.3 FUTURE WORK

Welding technology is advancing quickly, with an emphasis on creating improved methods that boost aesthetic appeal, cost-effectiveness, and productivity. These innovations are designed to enhance daily tasks for individuals. The following research gaps have been identified for further exploration by interested researchers:

- ✓ Utilization of tool s like gas clean that have effects on the AISI 1020 mild steel pipe metal will improve strength of bead and control the impact of heat during the GTAW (TIG) process.
- ✓ Optical Microscopy Enhancements: Utilizing advanced optical microscopy techniques to better analyze and evaluate surface texture and color uniformity.
- ✓ Defect Analysis: Conducting in-depth studies on the causes and effects of weld spatter and irregularities to develop strategies for minimizing these issues.
- ✓ Material Behavior: Analyzing the impact of various welding parameters on the quality of the internal surface to achieve optimal performance in real-world applications.

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APPENDIX

Appendix I

	Institution Name የኢፌዲሪ ቴ/ሙ/ስ ኢንስቲትዩት **FDRE TVT INSTITUTE**	Document No. OF/FTI/ALL/01		
	Title ወጭ ደብዳቤ **Outgoing Letter**	**Issue No.** **2**	**Page No.** **Page 1 of 1**	
Effective date **01/09/2016**				

ቁጥር/Ref. No: _________

ቀን/Date: August 27, 2025

To Whom it May Concern

This is to confirm that **Mr. Baharu Gadisa Hunde** has successfully conducted the experimental part of his/her research work in our Material Testing Laboratory. The experiments were carried out under proper supervision, using the facilities available in the laboratory.

The results obtained from the tests are attached herewith for your reference. Should you require any further clarification, please do not hesitate to contact us.

Regards

Tedros Alem Hadush

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Appendix II: F-value

Critical Values of the F-Distribution: $\alpha = 0.05$

Denom. d.f.	Numerator Degrees of Freedom 1	2	3	4	5	6	7	8	9	10
1	161.448	199.500	215.707	224.583	230.162	233.986	236.768	238.883	240.543	241.882
2	18.513	19.000	19.164	19.247	19.296	19.330	19.353	19.371	19.385	19.396
3	10.128	9.552	9.277	9.117	9.013	8.941	8.887	8.845	8.812	8.786
4	7.709	6.944	6.591	6.388	6.256	6.163	6.094	6.041	5.999	5.964
5	6.608	5.786	5.409	5.192	5.050	4.950	4.876	4.818	4.772	4.735
6	5.987	5.143	4.757	4.534	4.387	4.284	4.207	4.147	4.099	4.060
7	5.591	4.737	4.347	4.120	3.972	3.866	3.787	3.726	3.677	3.637
8	5.318	4.459	4.066	3.838	3.687	3.581	3.500	3.438	3.388	3.347
9	5.117	4.256	3.863	3.633	3.482	3.374	3.293	3.230	3.179	3.137
10	4.965	4.103	3.708	3.478	3.326	3.217	3.135	3.072	3.020	2.978
11	4.844	3.982	3.587	3.357	3.204	3.095	3.012	2.948	2.896	2.854
12	4.747	3.885	3.490	3.259	3.106	2.996	2.913	2.849	2.796	2.753
13	4.667	3.806	3.411	3.179	3.025	2.915	2.832	2.767	2.714	2.671
14	4.600	3.739	3.344	3.112	2.958	2.848	2.764	2.699	2.646	2.602
15	4.543	3.682	3.287	3.056	2.901	2.790	2.707	2.641	2.588	2.544
16	4.494	3.634	3.239	3.007	2.852	2.741	2.657	2.591	2.538	2.494
17	4.451	3.592	3.197	2.965	2.810	2.699	2.614	2.548	2.494	2.450
18	4.414	3.555	3.160	2.928	2.773	2.661	2.577	2.510	2.456	2.412
19	4.381	3.522	3.127	2.895	2.740	2.628	2.544	2.477	2.423	2.378
20	4.351	3.493	3.098	2.866	2.711	2.599	2.514	2.447	2.393	2.348
21	4.325	3.467	3.072	2.840	2.685	2.573	2.488	2.420	2.366	2.321
22	4.301	3.443	3.049	2.817	2.661	2.549	2.464	2.397	2.342	2.297
23	4.279	3.422	3.028	2.796	2.640	2.528	2.442	2.375	2.320	2.275
24	4.260	3.403	3.009	2.776	2.621	2.508	2.423	2.355	2.300	2.255
25	4.242	3.385	2.991	2.759	2.603	2.490	2.405	2.337	2.282	2.236
26	4.225	3.369	2.975	2.743	2.587	2.474	2.388	2.321	2.265	2.220
27	4.210	3.354	2.960	2.728	2.572	2.459	2.373	2.305	2.250	2.204
28	4.196	3.340	2.947	2.714	2.558	2.445	2.359	2.291	2.236	2.190
29	4.183	3.328	2.934	2.701	2.545	2.432	2.346	2.278	2.223	2.177
30	4.171	3.316	2.922	2.690	2.534	2.421	2.334	2.266	2.211	2.165
31	4.160	3.305	2.911	2.679	2.523	2.409	2.323	2.255	2.199	2.153
32	4.149	3.295	2.901	2.668	2.512	2.399	2.313	2.244	2.189	2.142
33	4.139	3.285	2.892	2.659	2.503	2.389	2.303	2.235	2.179	2.133
34	4.130	3.276	2.883	2.650	2.494	2.380	2.294	2.225	2.170	2.123
35	4.121	3.267	2.874	2.641	2.485	2.372	2.285	2.217	2.161	2.114
36	4.113	3.259	2.866	2.634	2.477	2.364	2.277	2.209	2.153	2.106
37	4.105	3.252	2.859	2.626	2.470	2.356	2.270	2.201	2.145	2.098
38	4.098	3.245	2.852	2.619	2.463	2.349	2.262	2.194	2.138	2.091
39	4.091	3.238	2.845	2.612	2.456	2.342	2.255	2.187	2.131	2.084
40	4.085	3.232	2.839	2.606	2.449	2.336	2.249	2.180	2.124	2.077
41	4.079	3.226	2.833	2.600	2.443	2.330	2.243	2.174	2.118	2.071
42	4.073	3.220	2.827	2.594	2.438	2.324	2.237	2.168	2.112	2.065
43	4.067	3.214	2.822	2.589	2.432	2.318	2.232	2.163	2.106	2.059
44	4.062	3.209	2.816	2.584	2.427	2.313	2.226	2.157	2.101	2.054
45	4.057	3.204	2.812	2.579	2.422	2.308	2.221	2.152	2.096	2.049
46	4.052	3.200	2.807	2.574	2.417	2.304	2.216	2.147	2.091	2.044
47	4.047	3.195	2.802	2.570	2.413	2.299	2.212	2.143	2.086	2.039
48	4.043	3.191	2.798	2.565	2.409	2.295	2.207	2.138	2.082	2.035
49	4.038	3.187	2.794	2.561	2.404	2.290	2.203	2.134	2.077	2.030
50	4.034	3.183	2.790	2.557	2.400	2.286	2.199	2.130	2.073	2.026
60	4.001	3.150	2.758	2.525	2.368	2.254	2.167	2.097	2.040	1.993
70	3.978	3.128	2.736	2.503	2.346	2.231	2.143	2.074	2.017	1.969
80	3.960	3.111	2.719	2.486	2.329	2.214	2.126	2.056	1.999	1.951
90	3.947	3.098	2.706	2.473	2.316	2.201	2.113	2.043	1.986	1.938
100	3.936	3.087	2.696	2.463	2.305	2.191	2.103	2.032	1.975	1.927
120	3.920	3.072	2.680	2.447	2.290	2.175	2.087	2.016	1.959	1.910
140	3.909	3.061	2.669	2.436	2.279	2.164	2.076	2.005	1.947	1.899
180	3.894	3.046	2.655	2.422	2.264	2.149	2.061	1.990	1.932	1.884
200	3.888	3.041	2.650	2.417	2.259	2.144	2.056	1.985	1.927	1.878
∞	3.841	2.996	2.605	2.372	2.214	2.099	2.010	1.938	1.880	1.831

Appendix III: Hardness and Ultimate Tensile Strength test

	Institution Name የኢፌዲሪ ቴ/ሙ/ስ ኢንስቲትዩት FDRE TVT INSTITUTE	Document No. OF/FTI/ALL/01		
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Weld Bead Hardness Type "B" in HRB Value Table

S. N	Weld Bead Hardness Type "B" in HRB value			Average Hardness in HRB value
	trial-1	trial-2	trial-3	
1	94.9	78.1	93.7	**88.9**
2	91.0	93.1	94.5	**92.9**
3	87.9	89.2	93.8	**90.3**
4	103.0	101.8	95.7	**100.2**
5	92.4	93.7	94.1	**93.4**
6	92.5	88.6	96.2	**92.4**
7	84.5	99.6	93.7	**92.6**
8	97.7	94.5	87.5	**93.2**
9	91.2	90.3	95.4	**92.3**

Weld Bead Ultimate Tensile Strength in MPa Table

S. N	Test -1	Initial dimensions			Fm	UTS	Test-2	Initial dimensions			Fm	UTS	Average UTS
		W	T	L	KN	MPa		W	T	L	KN	MPa	MPa
1	1	20	3	200	34.0	**566**	1	20	3	200	33.7	**562**	**564**
2	2	20	3	200	34.1	**568**	2	20	3	200	33.8	**564**	**566**
3	3	20	3	200	38.0	**633**	3	20	3	200	38.3	**638**	**635.5**
4	4	20	3	200	34.8	**580**	4	20	3	200	34.7	**585**	**582.5**
5	5	20	3	200	34.0	**566**	5	20	3	200	34.2	**570**	**568**
6	**6**	**20**	**3**	**200**	**38.0**	**633**	**6**	**20**	**3**	**200**	**38.3**	**638**	**635.5**
7	7	20	3	200	36.8	**613**	7	20	3	200	36.9	**615**	**614**

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Appendix IV: Verification Result Table

8	8	20	3	200	34.7	**578**	8	20	3	200	34.8	**581**	**579.5**
9	9	20	3	200	35.3	**589**	9	20	3	200	34.9	**583**	**586**

Verification Experimentation Result Table

S. N	Micro hardness (H) (HRC)				Ultimate Tensile Strength (UTS) (MPa)		
	Test-1	**Test -2**	**Test -3**	**Avg.**	**Test -1**	**Test -2**	**Avg.**
1	94.7	95.2	99.7	**96.5**	630	641	**635.5**
2	92	96.1	96.7	**94.9**	579	611	**595**
3	99.6	99.5	101.5	**100.2**	564	560	**562**

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Appendix V: Ultimate Tensile Strength Test Maximum and Minimum Graph

	Institution Name የኢፌዴሪ ቴ/ሙ/ስ ኢንስቲትዩት **FDRE TVT INSTITUTE**	Document No. OF/FTI/ALL/01	
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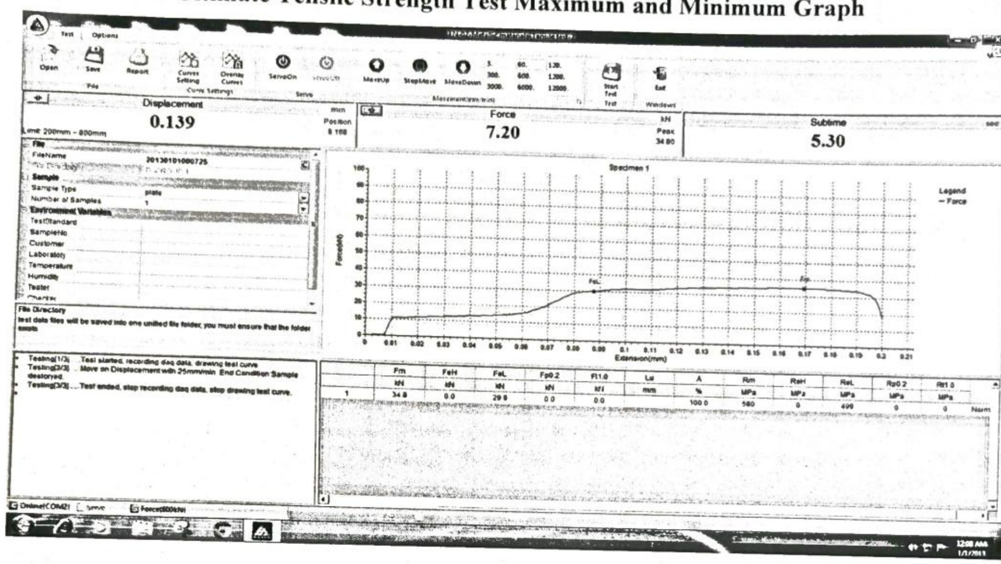
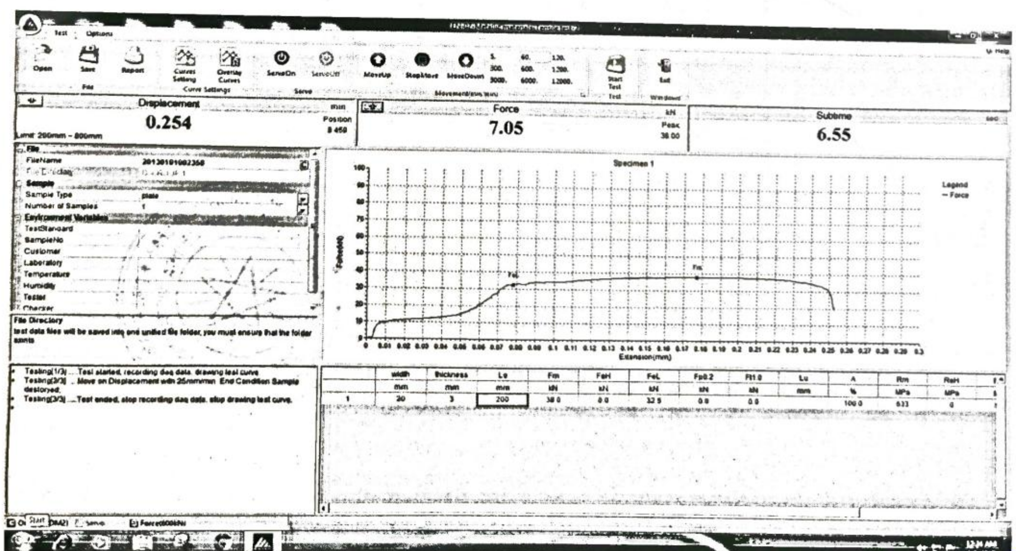
Ultimate Tensile Strength Test Maximum and Minimum Graph





Appendix VI: Verification Experimentation of Ultimate Strength Graph

	Institution Name የኢፌዴሪ ቴ/ሙ/ስ ኢንስቲትዩት **FDRE TVT INSTITUTE**	Document No. OF/FTI/ALL/01		
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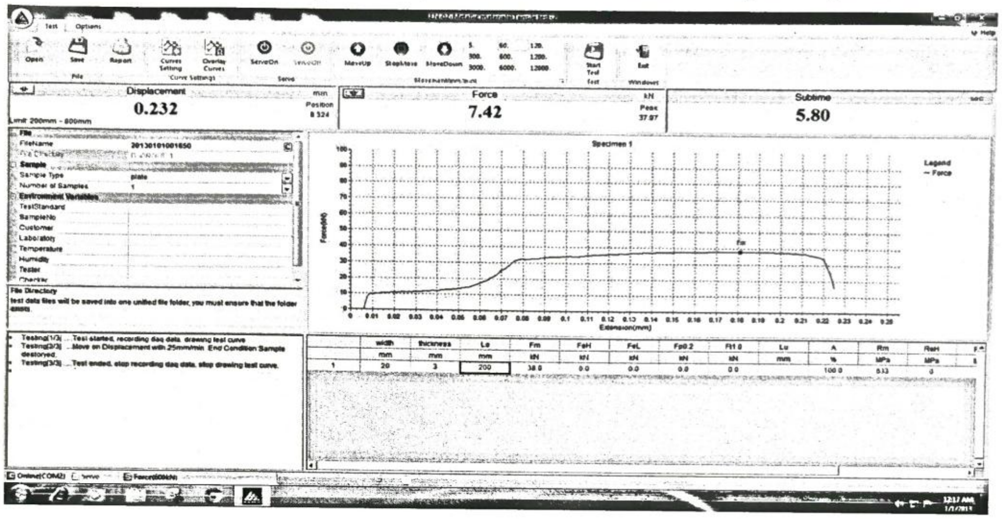
Verification Experimentation of Ultimate Tensile Strength Graph



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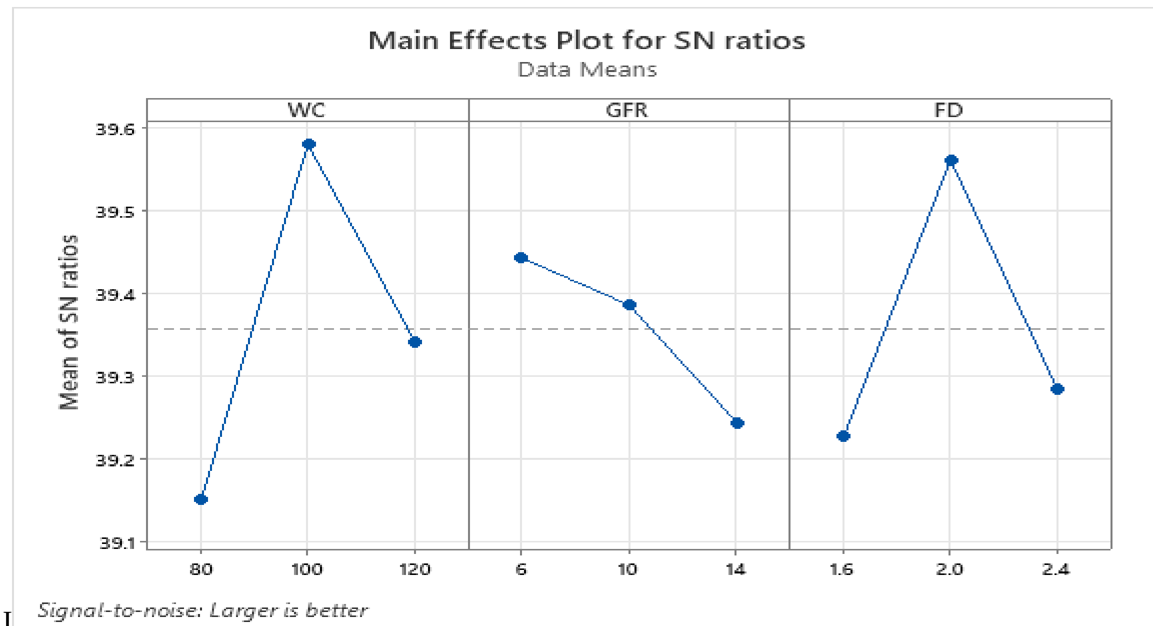
Appendix VII: Experimental Verification of Hardness

Appendix VIII: Signal to noise of Hardness



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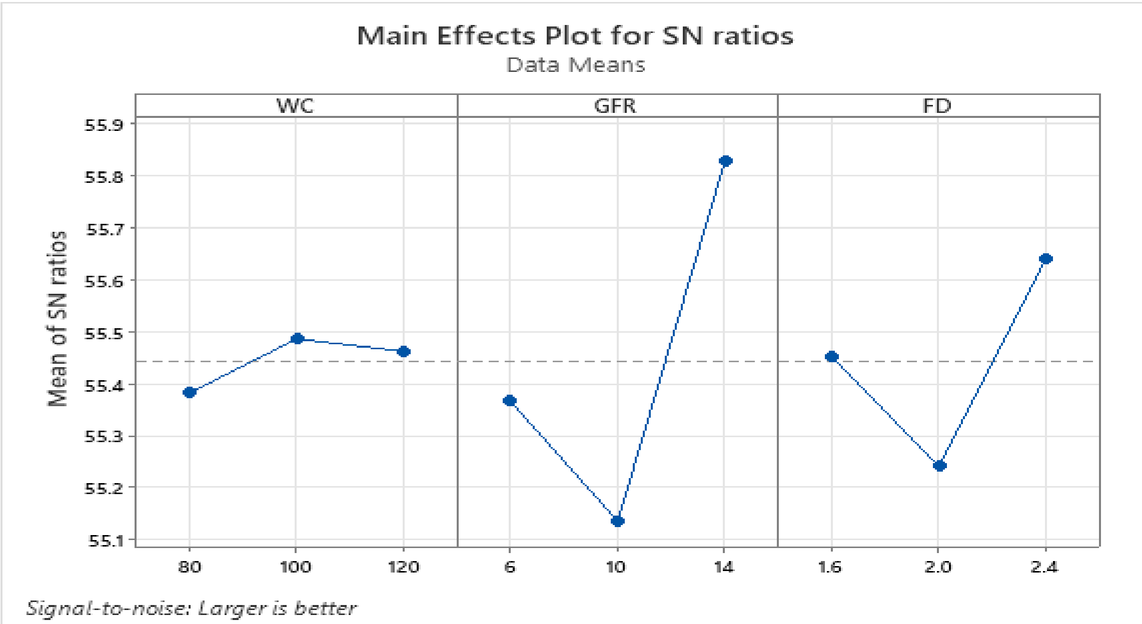
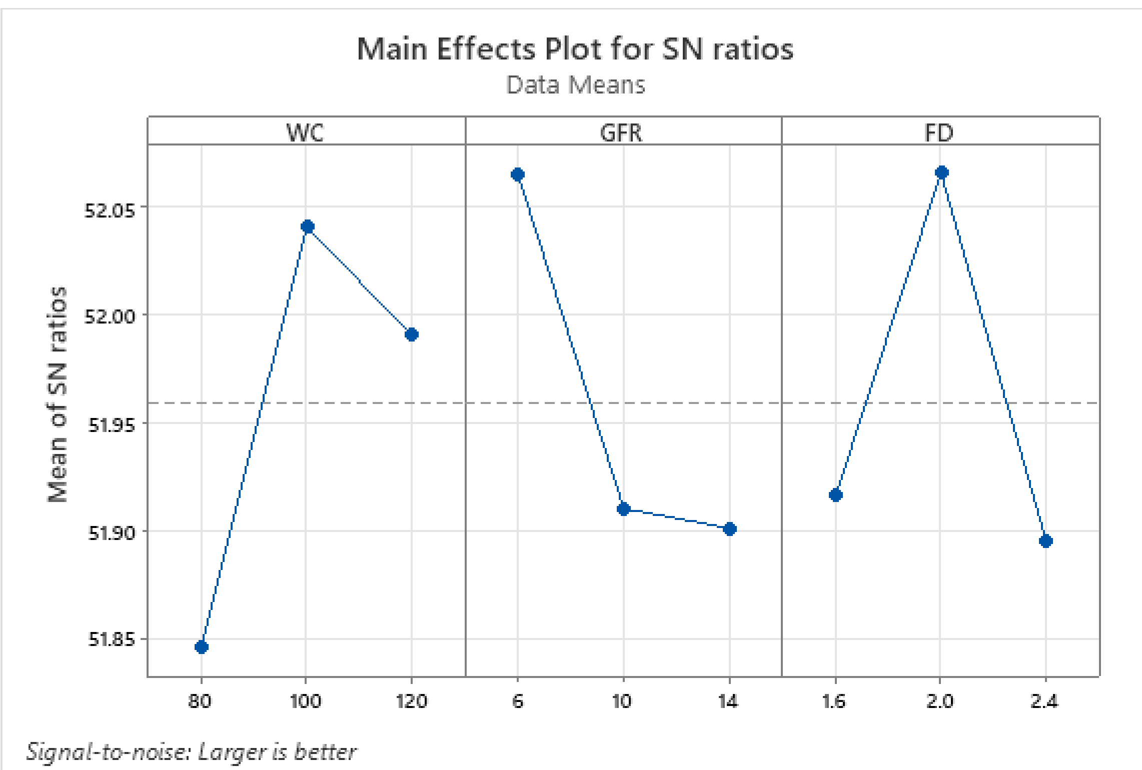
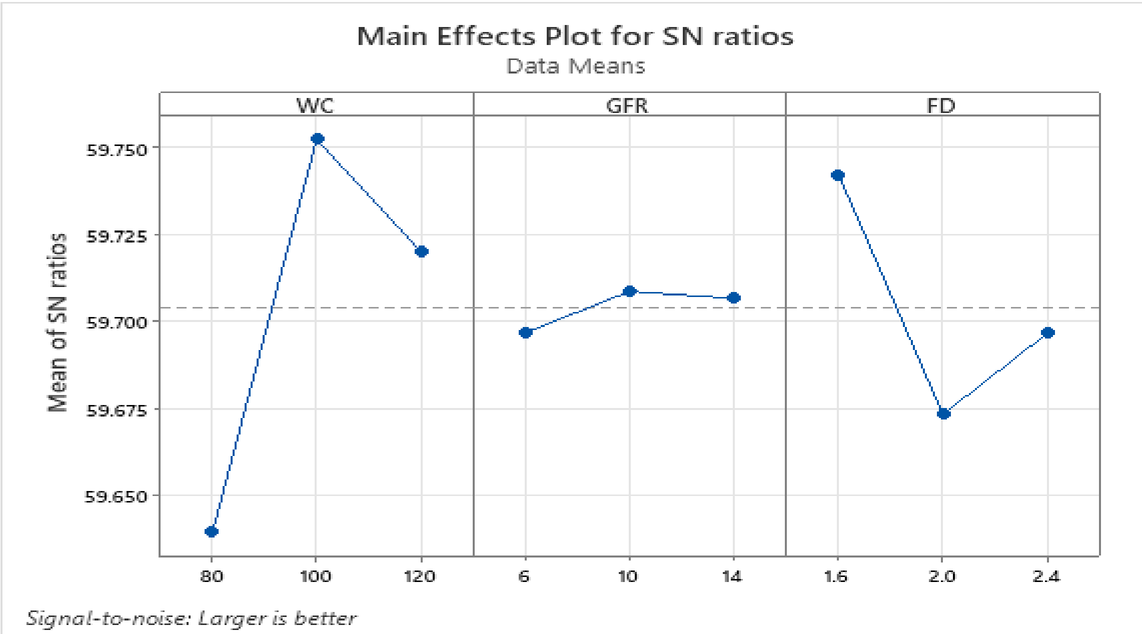
Appendix IX: Signal to noise of Ultimate tensile strength



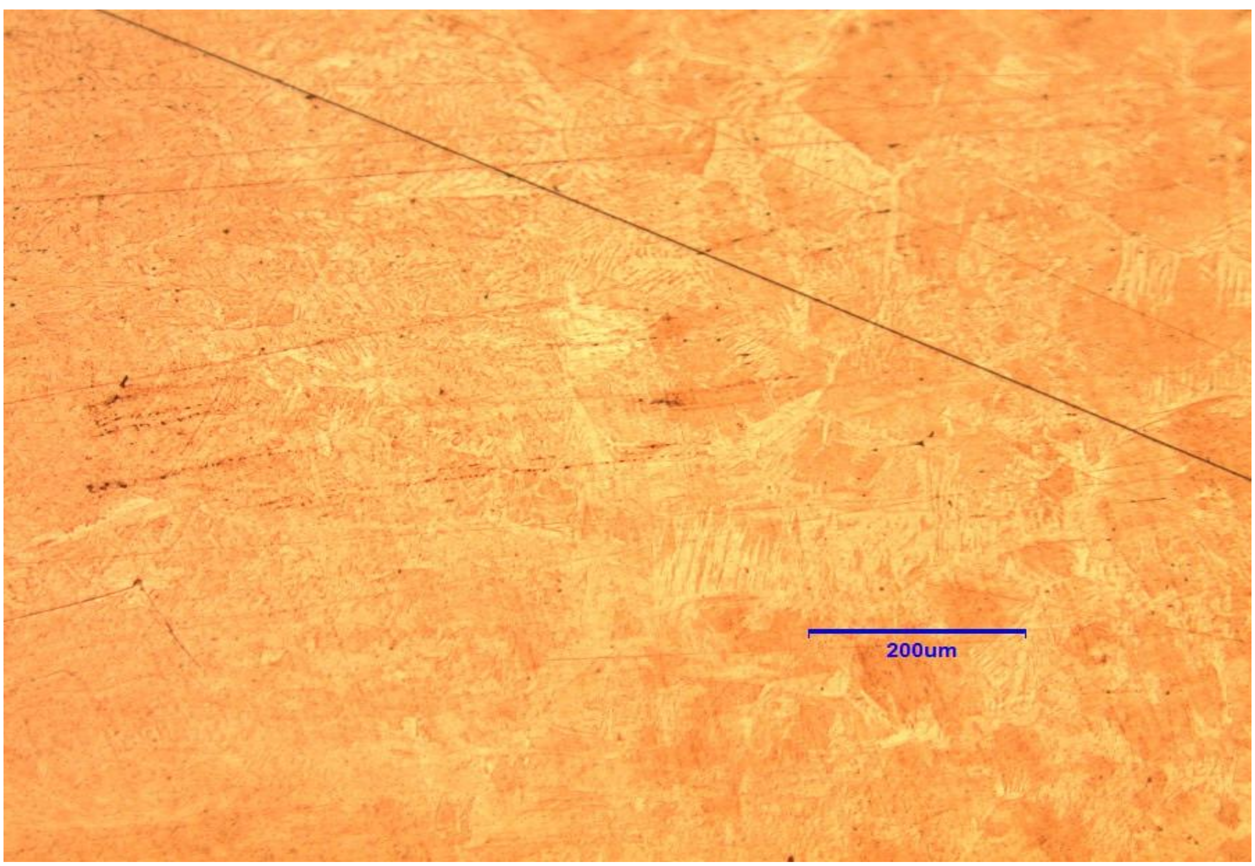
Appendix X: Signal to noise of bending strength

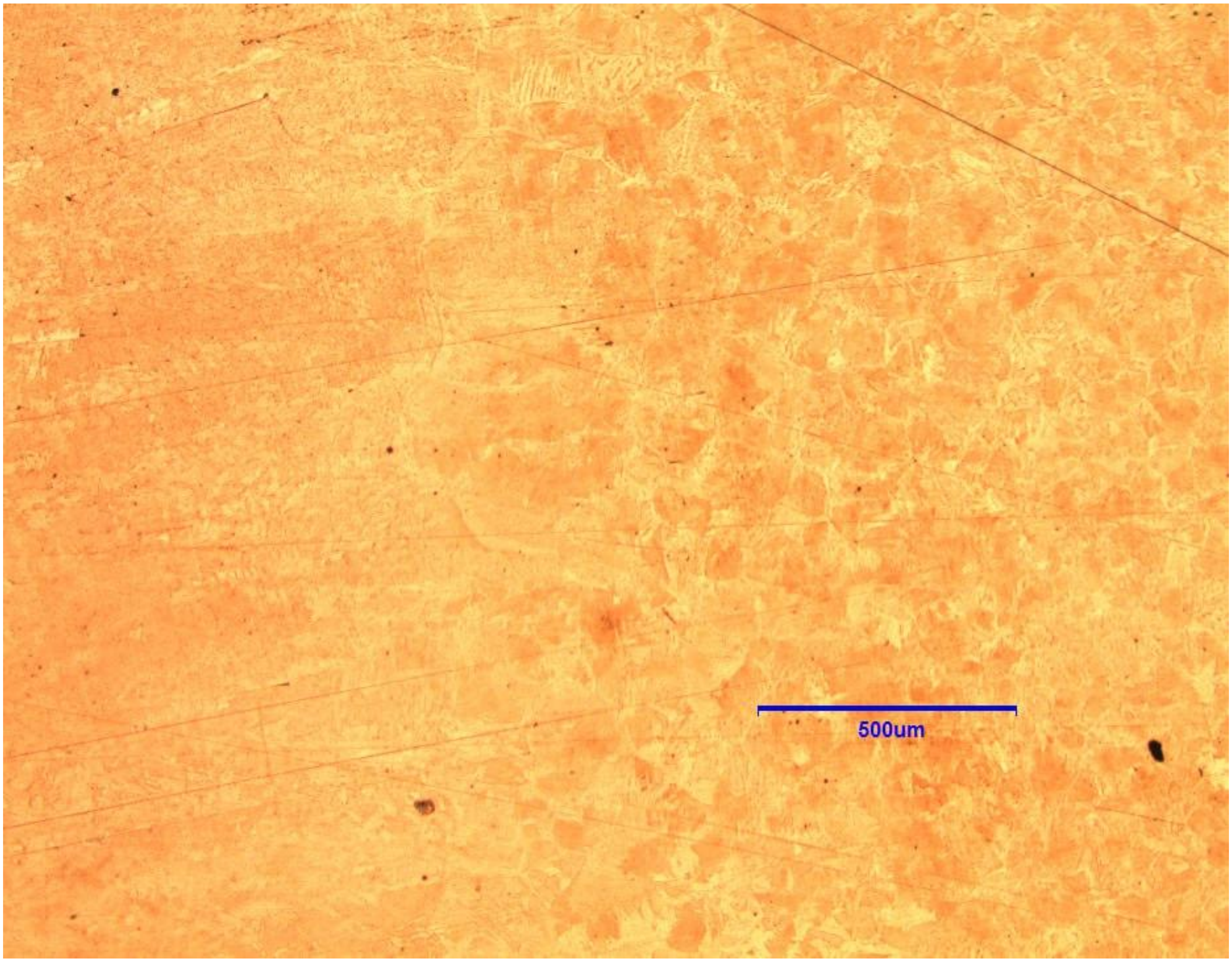


Appendix XI: Signal to noise of Compressive strength



Appendix XII: Surface Quality

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