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Optimization of Gas Metal Arc Welding Parameters on Austenitic Stainless Steel 304L Using Grey Based Taguchi Method

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BAHIR DAR UNIVERSITY

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Faculty of Mechanical and Industrial Engineering

Optimization of Gas Metal Arc Welding Parameters on Austenitic Stainless Steel 304L Using Grey Based Taguchi Method

M.Sc. Thesis

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THESIS APPROVAL SHEET

I hereby confirm that the changes required by the examiner have been carried out and incorporated in the final thesis

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Abstract

Weld quality mainly depends on features of bead geometry, mechanical-metallurgical characteristics of the weld. The most common problem in beverage and food Factories is faced with line breakage, leakage, minimal detrimental residual stresses and distortion that are due to the control of welding process input parameter to obtain a good welded joint with required quality and strength. This study investigated the optimization of three welding process parameters (welding Current, arc voltage and wire feed speed) of Gas Metal Arc Welding for SS 304L by using Taguchi based Grey relational analysis and Subsequently MINITAB software employed to analyze and optimize the experiments. Numbers of trials were performed as per L9 orthogonal array design and the mechanical Property such ultimate tensile strength (UTS) and Hardness (HRC) on Fusion and Heat affected zone. An optimal combined parameter of the welding operation was obtained via Grey relational analysis. By analyzing Grey relational grade matrix, the degree of influence for each controllable process factor onto individual quality targets were found. result shows that the optimal parameters combination were as i.e. welding current at 200 A, arc voltage at 26 V and wire feed speed at 8.5 m/min. Through analysis of variance (ANOVA) contribution and effect of individual parameter were investigated. It was observed that arc voltage with 38.27% contribution had the most significant effect followed by welding current with 37.04% contribution and wire feed speed as insignificant effect on the Tensile Strength and Hardness of the welded joint. Finally the conformations tests were carried out to compare the predicated values with the experimental values to confirm its effectiveness in the analysis of weld bead joint strength. The Grey Based Taguchi Method (GRG) for the Confirmation experiment test is 0.7735, which is in the range of the 95% confidence interval of the predicted optimal gray relational grade 0.6141 and 1.0415 and achieved tensile strength and hardness of 1520.87MPa, 25.40 HRC on FZ and 22.18 HRC on HAZ respectively. Hence, optimization of welding parameter can be a very useful technique for use to the industries to obtain significant improvements in welding strength and quality.

Keywords:

Gas Metal Arc welding, SS304L, Welding Parameter, GRG, mechanical Properties and ANOVA,

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Abbreviation

AC	Alternative current
Adj MS	Mean of Square of Variance
Adj SS	Sum of Square of Variance
ANOVA	Analysis of Variance
AISI	American Iron and Steel Institute
AWS	American Welding Society
DC	Direct Current
DCEP	Direct Current Electrode Positive
DF	Degree of Freedom
FZ	Fusion Zone
GMAW	Gas Metal Arc Welding
HAZ	Heat Affected Zone
HRC	Rockwell Hardness value at C constant scale
IJSRST	International Journal of Scientific Research in Science and Technology
MIG/MAG	Metal Inert Gas/ Metal Active Gas
PRR	number of pulses per second
TIG	Tungsten Inert Gas
UTS	Ultimate Tensile strength
304L	Extra Low carbon content than SS 304($C \leq 0.03\%$)
Seq SS	Sum of Square of Variance

Table of Equation

List of Symbols

Al	Aluminum
C	Carbon
Cu	Copper
Cr	Chromium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
Nb	Niobium
Ni	Nickel
Si	Silicon
S/N	Signal to Noise ratio
Ti	Titanium
Ta	Tantalum
V	Vanadium

List of Appendices

Chapter One

1. Introduction

A weld is defined by the AWS as “a localized coalescence (the fusion or growing together of the grain structure of the materials being welded) of metals or nonmetals produced either by heating the materials to the required welding temperatures, with or without the application of pressure, or by the application of pressure alone, and with or without the use of filler materials (Larry, 2012).

Gas Metal Arc welding uses a solid electrode wire that is continuously fed from a spool, through the welding cable assembly, and out through the gun. A shielding gas flows through a separate tube in the cable assembly, out of the welding gun nozzle, and around the electrode wire. The welding power flows through a cable in the cable assembly and is transferred to the electrode wire at the welding gun. The GMA welding produced as the arc melts the end of the continuously fed filler electrode wire and the surface of the base metal. The molten electrode metal transfers across the arc and becomes part of the weld. The gas shield flows out of the welding gun nozzle to protect the molten weld from atmospheric contamination (Larry, 2012).

Gas Metal Arc welding is extremely fast and economical because it can produce long welds rapidly that require very little post weld cleanup. This process can be used to weld metal ranging in thickness from thin-gauge sheet metal to heavy plate by making only a few changes in the welding setup. The process can be semi-automatic or automatic. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as AC, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray.

Conditions for obtaining satisfactory weld sit is desirable to have: (Khan, 2007)

- A sources of energy to create union by Fusion or Pressure
- A method for removing surface Contaminants
- A method for protecting metal from atmosphere Contamination
- Control of weld Metallurgy

1.1. Background GMA welding process

GMAW process was successfully developed at the Battle Memorial Institute in 1948 under the sponsorship of the Air Reduction Company. This development utilized the gas shielded arc, similar to the gas tungsten arc, but replaced the tungsten electrode with a continuously fed electrode wire. One of the basic changes that made the process more usable was the small-diameter electrode wires and the constant-voltage power source (a principle patented earlier by H.E. Kennedy). The initial introduction of GMAW was for welding non-ferrous metals. The high deposition rate led users to try the process on steel, but since the cost of inert gas was relatively high at the time, the cost savings were not immediately evident.

In 1953, Lyubavskii and Novoshilov announced the use of welding with consumable electrodes in an atmosphere of CO_2 gas. The CO_2 welding process immediately gained favor since it utilized equipment developed for inert gas metal arc welding, but could now be used to perform more economical welds with steels. Since the CO_2 arc is a hot arc requiring fairly high currents for larger electrodes, the process only became widely used with the introduction of smaller-diameter electrode wires and more efficient power supplies. Those power supplies used the short-circuit arc variation, also known as Micro-wire®, short-arc, or dip transfer welding, all of which appeared late in 1958 and early in 1959. This variation allowed welding on thin materials and every position, and soon became the most popular of the gas metal arc welding process variations. Another variation was the use of inert gas with small amounts of oxygen that provided the spray-type arc transfer. It became popular in the early 1960s.With the onset of the manufacturing in the 1960's and 1970's the types of wire electrodes have been upgraded to give wire electrodes with higher deposition rates, better finishes and wires more suitable for more modern steel types (WELDING, December 2010).

The welding gases have also evolved in the same way to make MIG welding faster, more efficient and with a better finish. One of the major changes has also been with power sources and feeders. MIG welding power sources have, over the years, gone from basic transformer types to the highly electronic power sources of the world today (Kamaleshwar Dhar Dwivedi, 2017).

1.1.1. Classification of welding

Various welding processes differ in the manner in which temperature and pressure are combined and achieved. Welding process can be classified on the basic source of heat of mentioned below:

1. Electric Arc Welding: A welding power supply is used to create and maintain an electric arc between an electrode and the base material to melt metals at the welding point. In such welding processes the power supply could be AC or DC, the electrode could be consumable or non-consumable and a filler material may or may not be added
2. Gas Welding: In this method a focused high temperature flame generated by gas combustion is used to melt the work pieces (and filler) together. The most common type of gas welding is Oxy-fuel welding where acetylene is combusted in oxygen.
3. Resistance Welding: Resistance welding involves the generation of heat by passing a high current (1000–100,000 A) through the resistance caused by the contact between two or more metal surfaces where that causes pools of molten metal to be formed at the weld area. Spot, Seam, Projection, Butt welding, Induction Welding
4. Thermo-Chemical Reaction Welding: (Thermit welding, Atomic H_2 welding).
5. Radiant Energy Welding: In this method a focused high-energy beam is used to melt the work pieces and thus join them together

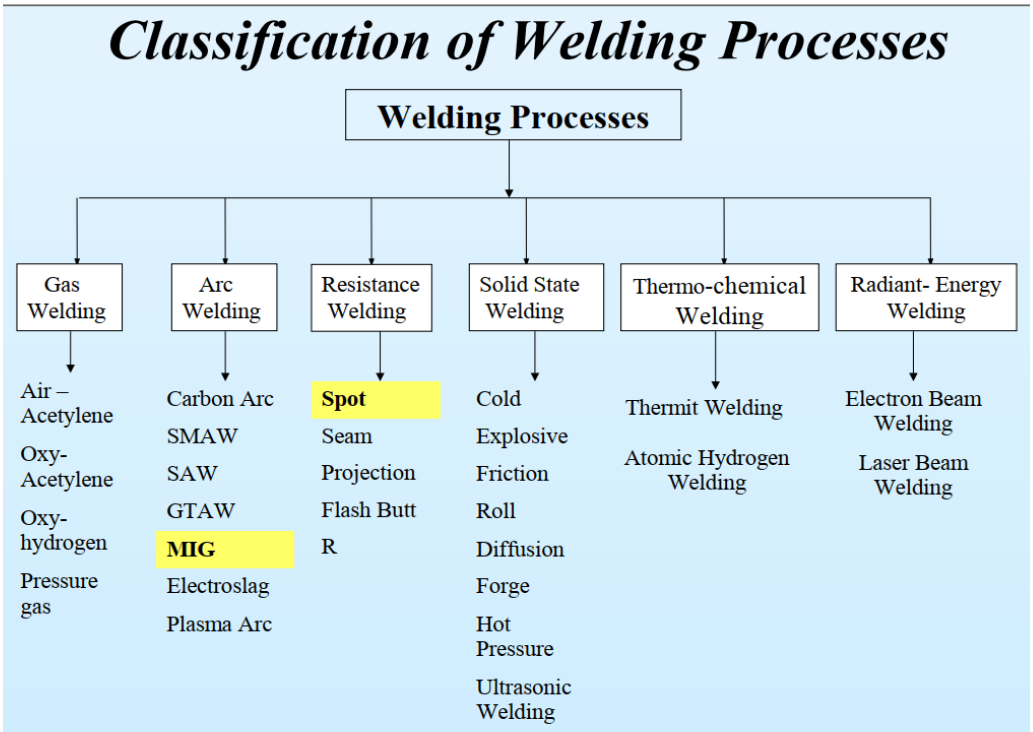


Figure 1.1. Classification of welding processes (slideshare.net, 2012)

1.1.2. Working principle of GMA welding

GMAW process as the name suggests, is a process in which the source of heat is an arc formed between a consumable metal electrode and the work piece, and the arc and the molten puddle are protected from contamination by the atmosphere (i.e. oxygen and nitrogen) with an externally supplied gaseous shield of inert and active gas such as argon, carbon dioxide, helium or an argon-helium mixture and argon-CO_2 mixture. No external filler metal is necessary, because the metallic electrode provides the arc as well as the filler metal.

A gas metal arc welding process consists of heating, melting and solidification of parent metals and a filler material in localized fusion zone by a transient heat source to form a joint between the parent metals. Gas metal arc welding is a gas shielded process that can be effectively used in all positions. The GMA welding process is based on the principle that a consumable metal electrode is used to produce an arc in between the metal electrode and the work piece. The arc so produced creates a large amount of heat and this heat is used to join the two metal pieces together. The whole process takes place under a shielding gas to prevent the weld from atmospheric contamination (K. VENKAT RAMANA R. T., 2019).

Working Principle

In GMAW process, the electrode wire from wire feed unit and shielding gas supply is attached with the welding gun. The positive terminal of DC power source is connected to the welding gun and the negative terminal is connected to a clamp. The clamp is connected to the work piece to be joined. The welding gun is bring near the work piece and as the trigger is pressed, arc is produced at the tip of the welding gun. The arc produced melts the electrode wire and it gets deposited in between the two metal pieces to be joined and form a slag free weld. A shielding gas also starts to spread as the arc is produced. It protects the weld from reacting with atmospheric air and prevents weld from contamination. The weld formed in gas metal arc welding is free from slag. It is a clean and efficient process. This is the working of GMA welding process (K. VENKAT RAMANA R. T., 2019).

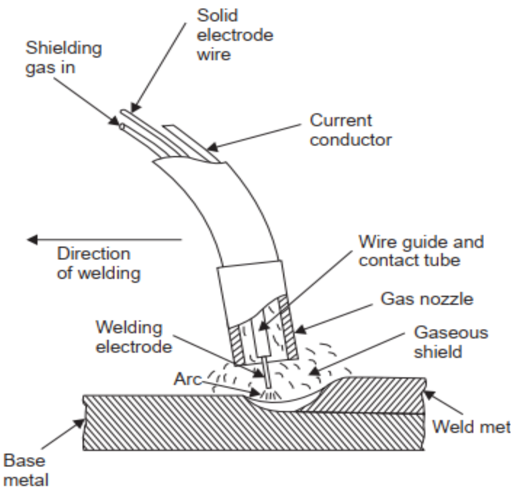


Figure 1.2. Working principles of GMAW (Khan, 2007)

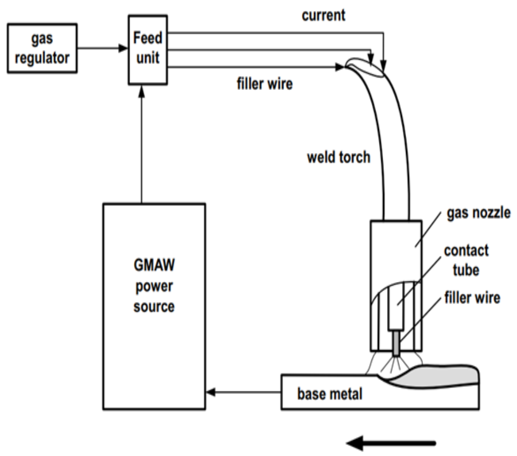


Figure 1.3. Schematic representation of gas metal arc welding process (GMAW) (J. Norberto Pires, 2006)

1.1.3. GMAW equipment and specifications

Basic equipment for conventional GMAW is consists of the power source, the electrode feed unit, the welding torch and the shielding gas regulator, as represented schematically in Figure 1.3. GMA welding components is shown in the figure 1.4 below on which we have performed the experiment.

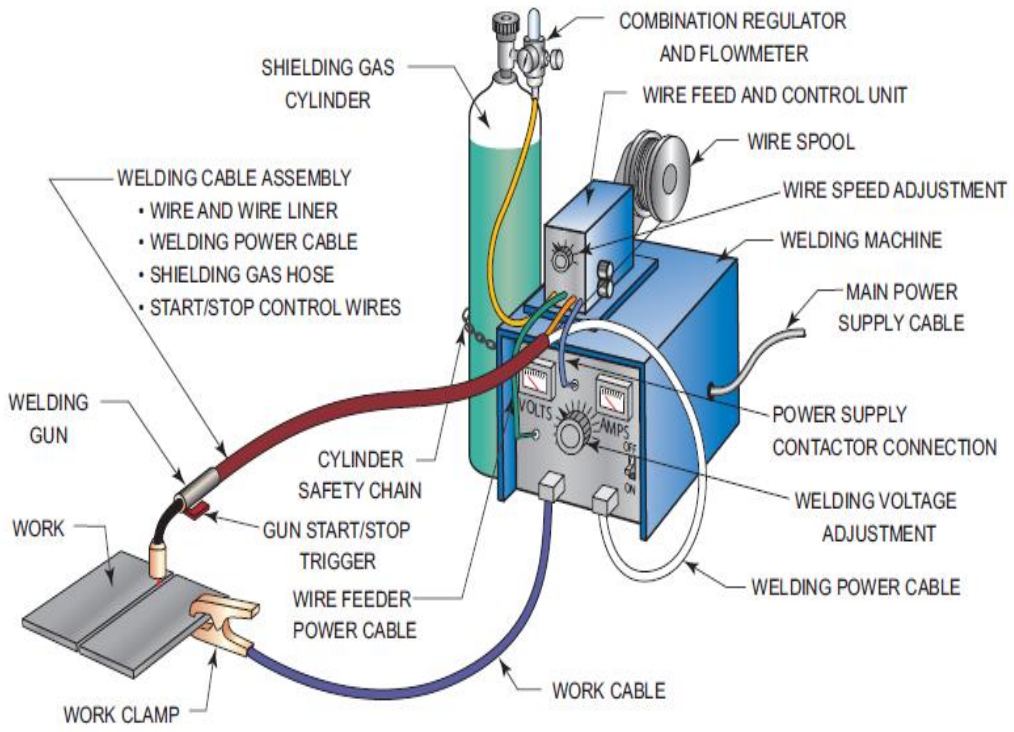


Figure 1.4. Welding Components of GMAW (Larry, 2012)

A. Power Source

Most common GMAW power sources are of the inverter type, but providing a constant-voltage output. A constant-voltage power source used in conjunction with a constant speed wire feeder can provide self-adjustment and stabilization of the arc length, in order to compensate for the variations in the torch to work-piece distance that occur mainly during manual welding operations. In a power source with approximately constant voltage characteristics any change in the arc length is compensated by the modification of the weld current and consequently of the burn-off behavior of the electrode. Figure 1.5 illustrates the effect of increasing the arc length from L1 to L2, which corresponds to an increase of the torch to work-piece distance. This increase of arc length produces an increase of the arc voltage and consequently a decrease of the weld current from I1 to I2 and of the burn-off rate from B1 to B2.

As the wire feed speed is constant and burn-off decreases the arc tends to assume the initial length. In addition these machines provide slope control of the power source characteristics and of the inductance in order to control spatter in short-circuiting transfer. GMAW inverters are also used to generate pulsed current with pulsed repetition rates typically between 100& 200 PRRs. Pulsed parameters are defined by algorithms in the controller. New synergic pulsed GMAW inverters can control melting rate through the modulation of the pulse shape and of the pulse frequency, being the process managed by a microprocessor.

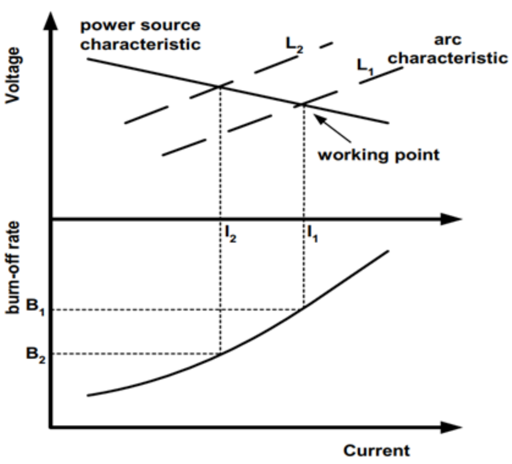


Figure 1.5. Self-adjustment mechanism with a constant-voltage power source Arc length L1> L2 (J. Norberto Pires, 2006)

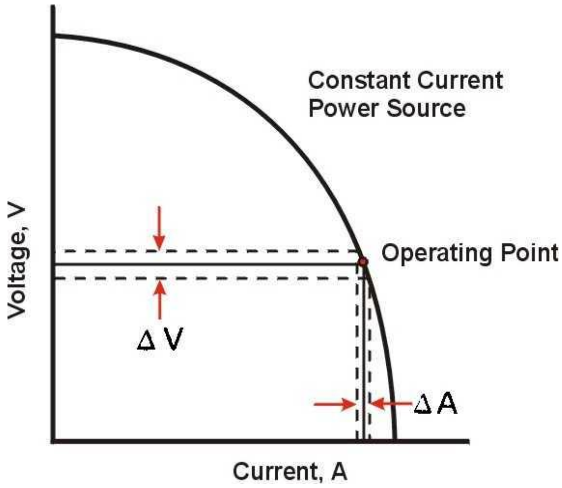


Figure 1.6. Constant Current power source (Current Remains Constant Even for Changes in Voltage Due to Changes in Arc Length) (Nadzam, 2014)

B. Electrode Feed Unit

The electrode feed unit and the welding control mechanism are generally furnished in one integrated package. The electrode feed unit pulls the electrode from the reel and pushes it through a conduit to the welding torch. This unit is composed of a direct-current motor, that varies the motor speed over a large range, a gear box and two pairs of rolls with a pressure adjusting screw and wire guides, that transmit mechanical energy, straighten and guide the electrode. (J. Norberto Pires, 2006).

C. Welding Torch (Gun)

Main functions of the welding torch are to furnish the electrode with electrical current and direct the electrode and gas flow to the work-piece. Main components of the welding torch are the contact tube, where the current is transmitted to the electrode, the nozzle, which provides a laminar gas flow to the weld pool, the torch switch, which sends signals to the feed unit, and the handle. The handle supports the gas and water (if necessary) tubes, the electrode guide tube and cables for current and signals. MIG torches for low current and light duty cycle (up to 60%) are gas cooled and torches for heavy duty cycle (up to 100%) and high current are water cooled. Robotic torches are in general water cooled, but if gas cooled torches are used they must be larger than manual torches.

1.1.4. GMAW affecting process parameters

Welding parameters affect the way the electrode is transferred to the work-piece, the arc stability, spatter generation, weld bead geometry and overall weld quality. The main parameters of the process are Welding Current, Arc voltage, Arc travel speed, Electrode extension, Electrode Diameter/size, electrode composition, Welding position, Gas Flow rate and shielding gas, also have direct influence on the metal transfer mechanisms.

A. Welding Current

Direct current electrode positive (DCEP) is the most used current in GMAW because it gives stable electric arc, low spatter, good weld bead geometry and the greatest penetration depth. For low currents and voltages in combination with active shielding gases or mixtures containing active gases, dip or short-circuiting transfer is obtained. Metal is transferred to the work-piece by bridging at frequencies usually above 100 Hz. This metal transfer mode gives low heat input, being suited for welding thin sections and for positional welding.

B. Welding Voltage

The arc length (arc voltage) is one of the most important variables in MIG that must be held under control. When all the variables such as the electrode composition and sizes, the type of shielding gas and the welding technique are held constant, the arc length is directly related to the arc voltage. Constant-voltage power source, the welding current increase when the electrode feeding rate is increased and decreased as the electrode speed is decreased, other factors remaining constant. This is a very important variable in MIG welding, mainly because it determines the type of metal transfer by influencing the rate of droplet transfer across the arc. The arc voltage to be used depends on base metal thickness, type of joint, electrode composition and size, shielding gas composition, welding position, type of weld and other factors.

C. Arc Travel Speed

The travel speed is the rate at which the arc travels along the work- piece. It is controlled by the welder in semiautomatic welding and by the machine in automatic welding. The effects of the travel speed are just about similar to the effects of the arc voltage. The penetration is increase at a certain value and decreases as the arc speed is varied. For a constant given current, slower travel speeds proportionally provide larger bead and higher heat input to the base metal because of the longer heating time.

D. Electrode Diameter/Size

The electrode diameter influences the weld bead configuration such as the size, the depth of penetration, bead width and has a consequent effect on the travel speed of welding. The choice of the wire electrode diameter depends on the thickness of the work piece to be welded, the required weld penetration, the desired weld profile and deposition rate, the position of welding and the cost of electrode wire. Commonly used electrode sizes are: 0.8, 1.0, 1.2, 1.6 and 2.4. Electrodes of 1.6 mm diameter are not recommended for positional applications. Each size has a usable current range depending on wire composition and spray- type arc or short- circuiting arc is used.

Table 1.1. Sizes of electrodes (K. VENKAT RAMANA R. T., 2019)

Wire diameter (mm)	Dip transfer		Spray transfer	
	Current (A)	Voltage (V)	Current (A)	Voltage (V)
0.6	30 – 80	15 – 18	120-210	24 –32
0.8	45 - 180	16 – 21	150 - 250	25 – 33
1.0	70 - 180	17 – 22	230 - 300	26 – 35
1.2	100 - 200	17 – 22	250 - 400	27 – 35
1.6	120 - 200	18 – 22	250 - 500	30 – 40

E. Shielding Gas

The primary function of shielding gas is to protect the arc and molten weld, pool from atmosphere oxygen and nitrogen. If not properly protected it forms oxides and nitrites and result in weld deficiencies such as porosity, slag inclusion and weld embrittlement. Gases used in GMAW can be pure gases, binary, ternary and exceptionally quaternary mixtures. Argon, helium and argon-helium mixtures are used in many applications for welding non-ferrous metals and alloys.

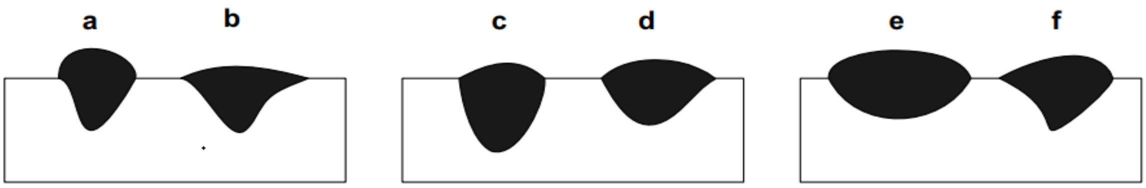


Figure 1.7. Effect of shielding gas on weld geometry. a - Argon; b -Argon+oxygen; c- CO_2 ; d-Argon+ CO_2 ; e-helium; f- Argon+helium (J. Norberto Pires, 2006)

The primary shielding gasses used are: Argon; Argon - 1 to 5% Oxygen; Argon - 3 to 25% CO_2 and Argon/Helium. Binary mixtures are commonly argon/carbon dioxide (up to 20% CO_2), argon/oxygen (up to 5% O_2) and argon/helium (up to 75% He). The first is used in the welding of carbon and low alloy steels, the second of stainless steels and the third of nonferrous materials. The addition of oxygen or carbon dioxide to argon stabilizes the welding arc and changes the bead shape, as illustrated in Figure 1.7. Welding current and arc voltage ranges for selected wire diameters operating with dip and spray metal transfer.

Table 1.2. Selection of shielding gas for GMAW process (Appendices 2)

GMAW process	98%Ar + 2% O_2
	97% Ar + 2% CO_2
	83% Ar + 15% He+ 2% CO_2
	69% Ar + 30% He+ 1% O_2
	90% He + 7.5% Ar + 2.5% CO_2

F. Wire Feed System

The performance of the wire feed system can be crucial to the stability and reproducibility of GMAW. As the system must be capable of feeding the wire smoothly, attention should be paid to the feed rolls and liners. There are three types of feeding systems: pinch rolls, push-pull and spool on gun. The conventional wire feeding system normally has a set of rolls where one is grooved and the other has a flat surface. Roll pressure must not be too high otherwise the wire will deform and cause poor current pick up in the contact tip.

G. Electrode Extension

The electrode extension is the electrode length that is out of the contact tube. The increase of electrode extension, produced by the increase of the torch distance to the work-piece for a specific parameters set, increases electrode melting rate because of the Joule effect. Electrode extension ranges from 5 to 15 mm for dip transfer, being higher (up to 25 mm) for the other transfer modes.

1.1.5. Uses and importance of welding

- Modern welding techniques are employed in the construction of numerous products, Ships, buildings, bridges, and recreational rides are fabricated by welding processes.
- Welding has made it possible for airplane manufacturers to meet the design demands of strength-to-weight ratios for both commercial and military aircraft.
- From the very beginning of early rockets to today's aerospace industry, welding has played an important role on the exploration of space would not be possible without modern welding techniques.
- Many experiments aboard the space shuttle have involved welding and metal joining. We are currently building a permanent space station. Someday welders will be required to build such a large structure in the vacuum of space.
- Items ranging from dental braces to telecommunication satellites are assembled by welding. Very little in our modern world is not produced using some type of this versatile process to improve our world.
- Welding is used extensively in the manufacture of automobiles, farm equipment, home appliances, computer components, mining equipment, and construction equipment, Railway equipment, furnaces, boilers, air conditioning units and hundreds of other products.
- Suppose the purpose is to join to plates in butt joint configuration, at this point riveted joint, bolted joint are of no use, even if you joined them backing strap is required and still required strength will not be there, at this stage welding is optimal way for joining.

1.1.6. Stainless steel

Stainless steels are defined as iron base alloys which contain at least 10.5% chromium. The thin but dense chromium oxide film which forms on the surface of a stainless steel provides corrosion resistance and prevents further oxidation.

Type of Stainless Steels: There are 5 types of stainless steels depending on the other alloying additions present, and they range from fully austenitic to fully ferritic types.

A. Austenitic Stainless Steels

The austenitic stainless steels contain 16 - 26% Cr, 8 - 24% Ni + Mn, up to 0.40% C and small amounts of Mo, Ti, Nb and Ta. The balance between the Cr and Ni + Mn is normally adjusted to provide a microstructure of 90 - 100% austenite.

These alloys are characterized by good strength and high toughness over a wide temperature range and oxidation resistance to over 1000°F (538°C). This group includes Types 302, 304, 310, 316, 321 and 347. Type 308 is used for Type 302 and 304 and Type 347 for Type 321. The others should be welded with matching filler. Type 347 can also be welded with Type 308H filler.

B. Ferritic Stainless Steels

The ferrite stainless steels contain 10.5 - 30% Cr, up to 0.20% C and sometimes ferrite promoters Al, Nb, Ti and Mo. They are ferrite at all temperatures and, therefore, do not transform to austenite and are not harden able by heat treatment. This group includes the more common types 405, 409, 430, 442 and 446. They are characterized by weld and heat affected zoned (HAZ) grain growth which can result in low toughness of welds. To weld the ferrite stainless steels, filler metals should be used which match or exceed the chromium level of the base alloy.

C. Martensitic Stainless Steels

The martensitic stainless steels contain 11- 18% Cr, up to 1.20% C and small amounts of Mn and Ni and, sometimes, Mo. These steels will transform to austenite on heating and, therefore, can be hardened by formation of martensite on cooling. This group includes Types 403, 410, 414, 416, 420, 422, 431 and 440. They have a tendency toward weld cracking on cooling when hard brittle martensite is formed. Chromium and carbon content of the filler metal should generally match these elements in the base metal. Type 410 filler is available as covered electrode, solid wire and cored wire and can be used to weld types 402, 410, 414 and 420 steel.

D. Precipitation Hardening Stainless Steels

There are three categories of precipitation hardening stainless steels – martensitic, semi-austenitic and austenitic.

- The martensitic stainless steels can be hardened by quenching from the austenitizing temperature [around 1900°F (1038°C)] then aging between 900 - 1150°F (482 - 621°C).
- The semi-austenitic stainless steels must be given a conditioning treatment which consists of heating in the range of 1350 - 1750°F (732 - 954°C) to precipitate carbon and/or alloy elements as carbides or inter-metallic compounds.
- The austenitic precipitation hardening stainless steels remain austenitic after quenching from the solution temperature even after substantial amounts of cold work. They are hardened only by the aging reaction. This would include solution treating between 1800 and 2050°F (982 - 1121°C), oil or water quenching and aging at 1300-1350°F (704 - 732°C) for up to 24 hours.

E. Duplex Stainless Steels (Duplex Ferritic – Austenitic Stainless Steels)

Duplex stainless steels solidify as 100% ferrite, but about half of the ferrite transforms to austenite during cooling through temperatures above approximately 1900°F (1040°C). This behavior is accomplished by increasing chromium and decreasing nickel as compared to austenitic grades. Nitrogen is deliberately added to speed up the rate of austenite formation during cooling. Duplex stainless steels are ferromagnetic. They combine both the higher strength and fabrication properties of austenitics with the resistance to chloride stress corrosion cracking of ferritic stainless steels. The most common grade is 2205 (UNS S32205), consisting of 22%Cr, 5%Ni, 3%Mo and 0.15% N.

Weld ability of Stainless Steels

Most stainless steels are considered to have good weld ability and may be welded by several welding processes including the arc welding processes, resistance welding, electron and laser beam welding, friction welding and brazing. For any of these processes, joint surfaces and any filler metal must be clean. The coefficient of thermal expansion for the austenitic types is 50% greater than that of carbon steel and this must be considered to minimize distortion. The low thermal and electrical conductivity of austenitic stainless steel is generally helpful. Less welding heat is required to make a weld because the heat is not conducted away from a joint as rapidly as in carbon steel

1.2. Statement of the Problem

In some Ethiopian industries specially related to food and beverage Factories, like beer industries, pasta and biscuit factory, Oil factory, Coca-Cola factory, water and gaseous (ambo) water factories. Those companies' mostly used austenitic stainless steel especially SS 304 and SS 304L because of its excellent corrosion resistance and excellent low-temperature performance in a wide variety of environments and good resistance to oxidation.

Type of beverage factories that I have seen and terms of production process, such as Dashen Brewery, most of the pipelines and tanks are made of stainless steel. When the factories are installed, the pipe lines and various tanks are joined by various types of welding process. Due to the high pressure through the pipelines and long-term inputs on the tanks, the welding process at the joints takes into account the proper material selection, type of welding process, critical skill on welding process parameter and material joint preparation. The risks due to that to health and occupational safety and the loss of resources are high. Therefore, due to the quality and strength of the weldment and associated occupational safety hazards, a high degree of professional welding skills and scientific knowledge on the welding process parameters are required in the welding areas. That is why the research has to be done on the Optimization of Gas Metal Arc Welding Parameters on Austenitic Stainless Steel SS304L.

So that most common problem is faced due to the control of welding process input parameter to obtain a good welded joint with required quality and strength with minimal detrimental residual stresses, distortion and line breakage. The process required sufficient control of welding parameter to provide electric current to melt both the electrode and a proper amount of base metal. In order to optimum quality of weld joint, it is necessary to predict the suitable amount of combination of welding parameter using Taguchi optimization method. By optimized and having the best welding process parameters combination the quality of welds can be produce consistently at high production rates and lowest costs.

1.3. Objective

1.3.1. General objective

This research intends on Optimization of Gas Metal Arc Welding (GMAW) Parameters on Austenitic Stainless Steel SS304L material for improving the tensile and hardness strength of the weld joint that have significant effect on weld quality and strength

1.3.2. Specific objectives

Specifically the objectives of the study were identified as:

- Prepare and Perform butt weld joint using GMA welding process,
- Investigate the effect of process parameters on the responses of the weldment, like tensile strength, and hardness on fusion and HAZ section.
- Determine the optimal level settings of welding parameters using grey based Taguchi method.
- Determine the most significant welding parameters using ANOVA, and
- Conduct confirmation test using the optimal welding parameters.

1.4. Scope of the Research

The research is subjected to the following scope:

- The welding joint experiment is based on butt weld using manual Gas Metal Arc welding (GMAW) model Manual Taurus 301 Synergic KGE and the material selection is Austenitic Stainless Steel (SS304L)
- The welding parameter selection in this study is welding voltage, welding current and wire feed speed.
- A Tensile Strength and Hardness on Fusion & HAZ of a weld are selected as a function variable in the experiment.
- The optimization of the welding process parameters are done by Gray based-Taguchi technique

1.5. Significant of the Research

Gas Metal Arc welding is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation. It is also an extremely important arc welding process when a high level of weld quality or considerable precision welding operation is required.

Grade Type 304/304L is the modern evolution of the original “18-8” austenitic stainless steel. It is very economical, most versatile, high corrosion resistant stainless steel suitable for a wide range of general purpose applications.

To overcome the problem stated above, this study will show the gap between the market and the demand. This study will provide information to the reader to know the effect of each welding process parameters, to know how to validate experimental data using grey relational analysis and ANOVA and which is optimum process parameters. and also this study will contribute to minimize the technical skill and knowledge gap by conducting GMAW processes for the industry and welding training institute trainers. When the industry can get internationally qualified welder with in the country incurring additional foreign exchange will be minimized and the industries have a chance to produce quality product and service within minimum cost.

For me this study will give an opportunity to dig out additional skill, knowledge and attitude on the profession and have chance to convince the official to expand the MIG/MAG welding training institutionally and creating job opportunities.

1.6. Limitation of the Study

The study was targeted only 304L stainless steel materials with horizontal position and butt joint configurations. Experimental testing was limited on the mechanical properties of the weld bead with the shortage of SEM (Scanning Electron Microscope) in the Ethiopia.

Chapter Two

2. Literature Review

2.1. Introduction

Welding of austenitic stainless steel in general, and GMAW process of such steel in particular, can well be considered as one of the areas where more extensive research may contribute, in a significant way, to the precise control of welding procedure for better and acceptable quality of weldment. Researchers had done investigations on joining the 304L austenitic stainless steel materials with use of MIG welding technique, those are discussed below:

2.2. Literature Review

(Dinesh Mohan arya, Vedanshchaturvedi and JyotiVimal, 2018)**.** Performed the optimization process parameters for Metal Inert Gas (MIG) Welding. This paper presented the influence of welding parameters like wire diameter, welding current, arc voltage, welding speed and gas flow rate optimization based on bead geometry of welding joint. The objective function have been chosen in relation to parameters of MIG welding bead geometry, Tensile strength, Bead width, Bead height, Penetration and Heat Affected Zone (HAZ) for quality target. Analysis Of Variance (ANOVA) has also applied to identify the welding current is the most significant factor. Experiment with the optimized parameter setting, which have been obtained from the analysis.

(D.Bahar1 M. N., May,2018). Presented paper on Optimization of MIG welding process parameters for hardness and strength of welding joint using Grey relational analysis. This paper deals with Gas Metal Arc Welding (GMAW) process is generally used in industry for high productivity and better quality. In this paper, the effects of various parameters on Voltage, Weld speed, Gas flow rate, Wire feed rate in SS 316 base metal. In this process, for hardness, in optimization of UTS contribution of gas flow rate is higher. It is also observed that welding voltage and gas flow rate should be lower but wire feed rate and welding speed should be higher to optimize UTS. In multi response optimization i.e. optimization of hardness as well as UTS contribution of welding speed is higher and welding voltage should be high.

(Abhishek D. Dhonde, May 2019)**.** Presented the effect of different welding parameters like welding current, stick out length and gas flow rate on the hardness of the weld and tensile strength of the weld joint. These all parameters have different effect on welding quality. In order to optimize these parameters for better weld quality Taguchi method has been used. The stainless steel plate has been used as welding material. The ANOVA is also employed to predict the percentage effect of each parameter on results.

(Jadoun, 2015) studied the joining of two dissimilar metals SS304 & Low Carbon Steel by GMAW and they optimized the process parameter by using Taguchi Method and finally they informed that the effect of welding parameters on the ultimate tensile strength can be ranked in decreasing order as follows: voltage >speed > current.

(S. Vani 1, 2018) Studied about how to predict and optimize the Metal Inert Gas welding of AISI 304 Stainless Steel (AISI 304 SS) work pieces, which are most widely in used in many industrial applications. The powerful tool known as Design of Experiments was used to optimize the welding process parameters for effective welding joint of the work pieces. The following welding voltage, welding current and welding speed were considered as input parameters and similarly tensile strength, percentage of elongation, and hardness were considered as performance characteristics for DOE application. The values after experimental measurements, compared with corresponding predicted results of tensile strength, percentage of elongation, and hardness. Moreover, the Taguchi Method was also used for DOE and considered L_{27} orthogonal array matrix and Signal-to-Noise Ratio, the tensile strength, percentage of elongation, and hardness of the predicted values have been creditably acquired via Fuzzy representation

(Diganta Kalita, 2015) investigated the effect of the process parameters of Metal Inert Gas Welding such as welding current, arc voltage and shielding gas flow rate on tensile strength of welded joints by the Taguchi Optimization method and they concluded that welding voltage has significant effect, both on mean and variation of the Tensile strength of the weld having 87.019% and 85.398% contribution respectively, whereas welding current has significant effect on mean only (10.807% contribution) whereas Shielding gas flow rate as insignificant effect on the tensile strength of the welded joint.

(Lalit S. Patel, 2014) Analyzed and experimentally investigated the TIG welding process parameters for purpose of maximizing tensile strength and minimizing distortion with the requirements of maximizing of weld strength of thin walled structures of stainless steel respectively. TIG welding parameters were analyzed to determine their significance on thin plates of 304L stainless steel of 4 mm thicknesses by design of experiments (DOE) with employing Taguchi method designs to have response (tensile strength &distortion). The effects of following two parameters: welding current, Root gap have investigated upon following two performance measures: tensile strength and distortions for 4 mm thickness of 304L stainless steel. The experimental results were analyzed using ANOVA and significance of effects for all the tested parameters upon performance measures was determined. Empirical models for tensile strength and distortion, in terms of significant parameters were developed and numerical optimization was performed according to the desirability for the maximization of tensile strength and minimization of distortion.

(Pawan Kumar, Aug 2013) worked carried out on plate welds AISI 304 & Low Carbon Steel plates using gas metal arc welding (GMAW) process. Taguchi method is used to formulate the experimental design. Design of experiments using orthogonal array is employed to develop the weldments. The input process variables considered here include welding current, welding voltage & gas flow rate. A total no of 9 experimental runs were conducted using an L9 orthogonal array and the ideal combination of controllable factor levels was determined for the hardness to calculate the signal-to-noise ratio. After collecting the data signal-to-noise (S/N) ratios were calculated and used in order to obtain optimum levels for every input parameter. The Nominal-the-better quality characteristic is considered in the hardness prediction. The Taguchi method is adopted to solve this problem. Subsequently, using analysis of variance the significant coefficients for each input parameter on tensile strength & Hardness (WZ & HAZ) were determined and validated**.**

(Tewari S. A., 2018) investigated the optimization of three welding parameters (wire feed speed, arc voltage, and shielding gas flow rate) for SS 304H by using Taguchi based Grey relational analysis. In this research work, pure argon was used as shielding gas. Numbers of trials were performed as per L16 orthogonal array design and the mechanical quality such ultimate tensile strength, micro-hardness, Toughness, and microstructure of SS304H optimized by Grey-based Taguchi analysis and result shows that the optimal parameters combination were as A4B4C3 i.e. flow rate at 23L/min, voltage at 25 V and welding speed at 350IPM and it was observed that wire feed speed had the most significant effect followed by voltage and gas flow rate. An optimal combined parameter of the welding operation was obtained via Grey relational analysis. By analyzing Grey relational grade matrix, the degree of influence for each controllable process factor onto individual quality targets can be found.

(Sarpate, 2019) Studied the MIG welding parameters optimization with the help of Taguchi. In this study, stainless steel 136 are joined by using MIG welding. Two parameters of MIG welding such as Current, Voltage are taken as input parameters. By varying these parameters, the tensile strength will be checked. The tensile strength was checked with the help of UTM. MINITAB software is used to get the optimization results. The analysis of signal to noise ratio will be done with the help of MINITAB software for higher the better characteristics. Finally, the confirmation tests will be performed to compare the predicted values with the experimental values which will confirm its effectiveness in the analysis of tensile strength of the joint & then the result & conclusion will be drawn.

(Nabendu Ghosh P. K., 2016) In the present work, X-ray radiographic test has been conducted in order to detect surface and sub-surface defects of weld specimens made of Ferritic stainless steel. The quality of the weld has been evaluated in terms of yield strength, ultimate tensile strength and percentage of elongation of the welded specimens. The observed data have been interpreted, discussed and analyzed by considering ultimate tensile strength ,yield strength and percentage elongation combined with use of Grey-Taguchi methodology.

(I. M. B. Omiogbemi, July 2017) The present study is to investigate the effects of metal inert gas (MIG) welding parameters on the mechanical properties (hardness, tensile and impact) of type 304 austenitic stainless steel (ASS) immersed in 0.5M hydrochloric acid at ambient temperature. The MIG welding was applied to 3mm thick ASS. The dimensions of the samples were 50mm x 15mm x 3mm and 120mm x 15mm x 3mm rectangular bars each for impact, hardness and tensile tests and for immersion in the medium. Design Expert Software, Scanning Electron Microscopy (SEM), Rockwell Hardness Test, Monsanto Tenso-meter and Izod Impact Test were used to determine the interactions of parameters, micro-structural analysis and optimal performances of the parameters respectively. Experimental results indicate that tensile strength increased with increase in welding parameters from 120MN/m2 to 133MN/m2 at speed of 40cm/min and current of 110. when the properties are compared with varying weld parameters adopted in joint's weld operations, there was a pattern displayed among the weld parameters with C3 (19.7HRA, 203N/mm2 and 19.7J)and C4 (14.9 HRA, 189N/mm2 and 14.9J) consistently coming out as the parameter producing an ASS weld joint with the best mechanical properties of hardness, tensile and impact strength.

(Kapil B. Pipavat, May 2014)This paper presents the influence of welding parameters like welding current, welding voltage, welding speed etc. on mechanical properties like tensile strength, hardness etc. on austenitic stainless steel AISI 316. By using DOE method, the parameters can be optimize and having the best parameters combination for target quality. The analysis from DOE method can give the significance of the parameters as it give effect to change of the quality and strength of product or does not. A plan of experiments based on Taguchi technique has been used to acquire the data. An Orthogonal array and analysis of variance (ANOVA) are employed to investigate the welding characteristics of austenitic stainless steel AISI 316 material and optimize the welding parameters. The techniques used for obtaining optimal process parameters with the use of experimental data have been reviewed. The success of MIG welding process in terms of providing weld joints of good quality and high strength depends on the process conditions used in the setup. This research aims to identifying the main factors that have significant effect on weld joint strength

(Raj Kumar Yadav, July-December, 2016) The study of the welding parameter's effect on residual stresses and hardness of weld specimen were carried out by statistical technique i.e. analysis of variance (ANOVA) and Signal to Noise (S/N) ratio. The optimum parametric conditions were found out by Taguchi method. Confirmatory test was performed to achieve the validity of the results. By performing investigation procedure, it was found by the analysis based on S/N ratio and ANOVA that the welding voltage contributes 57.3% towards the total variation observed in residual stresses. The welding current contributes 26.14% of the total variation observed in residual stresses. The welding voltage contributes 61.59% towards the total variation observed in hardness. The variable travel speed contributes 32.28% of the total variation observed in hardness.

(Nabendu Ghosh P. K., 2017) In present work, effect of current, gas flow rate and nozzle to plate distance on quality of weld in metal gas arc welding of Austenitic stainless steel AISI 316L has been studied through experiment and analyses. Butt welded joints have been made by several levels of current, gas flow rate and nozzle to plate distance. A plan of experiments based on Taguchi technique has been used. An Orthogonal array, Signal to Noise (S/N) ratio and analysis of variance (ANOVA) are employed to study the welding characteristics of material & optimize the welding parameters. The result computed is in form of contribution from each parameter, through which optimal parameters are identified for maximum tensile strength and percentage elongation.

(S.R. Meshram, (2013)) has done a research on optimization of process parameters of gas metal arc welding to improve the quality of weld bead geometry. In their work, a grey- based Taguchi method was adopted to optimize the gas metal arc welding process parameters. Many quality characteristic parameters were combined into one integrated quality parameter by using grey relational grade or rank. The welding parameters considered in their research were arc voltage, wire feed rate, welding speed, nozzle to plate distance and gas flow. The quality characteristics consider were penetration, reinforcement and bead width. Analysis of variance has performed to find the effect of individual process parameter on quality parameters. The Taguchi L_{25} array was adopted to conduct the experiments. The stainless steel (AISI410) was used as welding specimen.

(S.R. Patil, 2013) presented their work on optimization of MIG welding parameters for improving welding strength. They presents the influence of welding parameters welding current, welding voltage, welding speed on ultimate strength of welded joints of AISI mild steel materials. A plan of experiments using Taguchi has decided. Experiments were performed and result was confirmed. From this study they concluded that the welding current and welding speed are the major factors affecting tensile strength of welded joints.

(Saadat Ali Rizvia, 2017)**.**This study focuses on optimizing different welding parameters which affect the mechanical properties such as YS, UTS, Toughness, and Vickers hardness (VHN) of SS304H, Taguchi technique was employed to optimize the welding parameters, and fracture mode characterization was studied. A series of experiments have been carried out. L9 orthogonal array applied for it. Statistical methods of signal to a noise ratio (SNR) and the analysis of variance (ANOVA) was applied to determine the effects of different welding parameters such as wire feed speed, welding current and gas flow rate on Mechanical properties. Tensile strength, toughness, Vickers hardness (VHN), and mode of fracture were examined to investigate the weld quality of SS304H, and it was observed from the results that the welding voltage has significant effect whereas gas flow rate has insignificant effect on tensile strength of the weldment, and optimum process parameters were found to be 23 V, 350 IPM travel speed of wire and 20 l/min gas flow rate for tensile strength and mode of fracture was ductile fracture for tensile test specimen.

(Yilmaz, (2002)) Compared the results obtained from destructive tests for mechanical properties of austenitic stainless steel. (AISI 304L and AISI 316L plates of 5 mm thickness) joints welded by GMAW and GTAW process. The joints were made by GMAW process using ER 316 LSi filler metal and by GTAW process using ER 308L and ER 316L filler metals. In the present work the effects of current, gas flow rate and nozzle to plate distance on ultimate tensile strength. Yield strength and percentage of elongation of butt-welded joints of austenitic stainless steel have been experimented and analyzed through grey base Taguchi method.

(Pawn Kumar, 2013) The experiment was designed with L9 orthogonal array which is for very small values and investigated on effect of process parameters on tensile strength of SS 3Cr12 specimen after MIG welding. Reported that, the tensile strength was increasing by increasing of welding speed and flow rate, but it was remains increasing with decreasing of voltage and wire feed rate. It was revealed through central composite matrix using Minitab software.

(L. Suresh Kumar, 2011) Investigate for welding aspects of AISI 304 & 316 by Taguchi technique for the process of TIG & MIG welding. Mechanical properties of austenitic stainless steel for the process of TIG and MIG welding have discussed here. The voltage has taken constant and various characteristics such as strength, hardness, ductility, grain structure, tensile strength breaking point, HAZ have observed in these two processes.

(Radha Raman Mishra, 2014) Studied on dissimilar metal joint as a structural material for various industrial applications which provided good combination of mechanical properties like strength, corrosion resistance with lower cost. In the present study, stainless steel of grades 202, 304, 310 and 316 were welded with mild steel by Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding processes. The percentage dilutions of joints were calculated and tensile strength of dissimilar metal joints was investigated. The results were compared for different joints made by TIG and MIG welding processes and it was observed that TIG welded dissimilar metal joints have better physical properties than MIG welded joints.

Generally different researchers state a lot about the GMAW process and their work also have different input process variables and performance characteristics and those can use different methods, experiments measurement, mathematical Model, and other different optimization mechanism. According to their investigation the report also says a lot that they studied. The report shows that each research has its own idea and conclusion but in some cases some researchers have studied on the same material using different method had obtained different effects on welding quality on the same study. Because of these and other reasons this work wants to put its own value by analyzing on the effects of welding parameters on the mechanical property of SS304L stainless steel joint using Gas Metal Arc Welding process.

2.3. Summary of Literature Review

In the present work, it is planned to analyze the optimal levels from the weld voltage [V], weld current [Amp] and wire feed speed [m/min] in Pulsed Gas Metal Arc Welding to improve the ultimate tensile weld strength [MPa] and Hardness of the welding fusion zone and Heat Affected Zone. Thus, the experiment was designed by the Gray-based Taguchi method where the group of parameters was organized into the L9 orthogonal array. Those welding parameter combinations were performed and tested with Hardness test and tensile strength test. With the tests results, the signal-to-noise ratios calculation provided the optimum levels and an analysis of variance (ANOVA) showed the most influent input parameter on the output (response) parameters.

Chapter three

3. Materials and Methods

This chapter provides detailed information on materials and methods used for gas metal arc welding and testing of the specimen. The methodology of this research is experimental analysis. The work flow charts which are used for the accomplishment of this study are as follows:

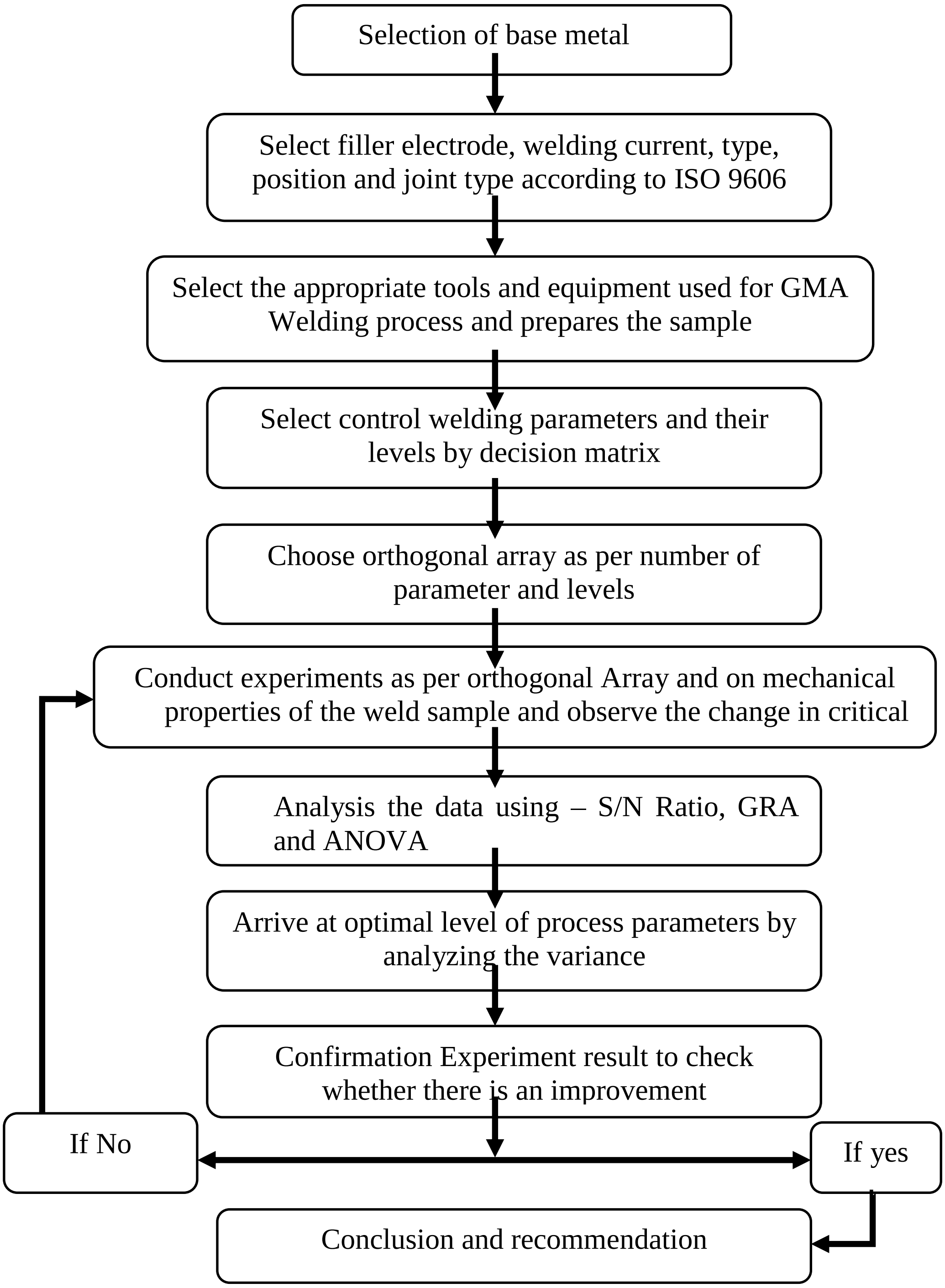


Figure 3.1. Work flow chart

3.1. Materials and Equipment

3.1.1. Materials

The raw material used to conduct this experiment is SS304L stainless steel (200mm x 100mm x 5mm) based on ISO 9606. It needs a V-groove with 30 degree and horizontal position. For the base metal of 304L stainless steel work piece the recommended Wire Electrode is Stainless Steel MAG Wire 308LSi.

Figure 3.2. Specimen for welding SS304L and Wire Electrode SS308LSi

The composition of SS304L and the wire electrode SS308LSi is mentioned in table 3.1 Stainless steel 304L cannot be hardened by heat treatment. It is widely used because of its property due to which it can be formed into various shapes.

The typical physical properties of 304L stainless steel and the recommended Wire Electrode Stainless Steel MAG Wire 308LSi.is shown in table 3.2.

The selection criteria of 304L stainless steel is based on corrosion resistance, availability, mechanical properties in specific temperature ranges, fabrication characteristics, and product cost. However, corrosion resistance and mechanical properties are usually the most important factors in selecting 304L grade stainless steel for a given experiments.

Table 3.1.Chemical compositions of base metal SS 304L and Wire Electrode SS308LSi (Appendices 3)

	Element								
	Carbon (C)	Manganese Mn)	Phosphorus (P)	Sulfur (S)	Silicon (Si)	Chromium (Cr)	Nickel (Ni)	Nitrogen	Iron
SS 304L	0.03	2.0	0.045	0.030	1.00	18 - 20	18 - 20	0.1	Balance
SS308LSi	0.014	1.78	0.015	0.001	0.85	19.67	10.4		Balance

Table 3.2. Physical Properties (Appendices 4)

Type #	SS304L
Density (lb/in^3)	0.29
Specific Heat BTU (^{o}F/lb) 0-100 ^{o}C	0.12
Thermal Conductivity BTU/Ft2/Ft/Hr/^{o}F 100 ^{o}C	9.4
Coefficient of Thermal Expansion Per ^{o}F x 10^{-6} 0-100 ^{o}C	9.6
Electrical Resistivity Microhm-cm 21 ^{o}C	70.0
Magnetic Permeability (Annealed) µ	1.008

The Mechanical properties for the recommended Wire Electrode of Stainless Steel MIG Wire 308LSi is shown in table 3.3.

Table 3.3. Mechanical Properties of Wire electrode SS308LSi and SS304L (Appendices 5)

No	Mechanical properties	Amount Wire (Typical as welded)	Amount base metal (Typical as welded)	
			Annealed	Cold rolled
1	Yield Strength (MPa)	415	275.8	1206.6
2	Tensile Strength (MPa)	570	689.5	1344.5
3	Elongation (%)	35	40	2
4	Reduction of area	40	65	
5	Impact Levels J @ 20°C	140		
	J @ -110°C	84		
	J @ -196°C	52		
6	Ferrite No.	FN 14		
7	Welding current	DC+	--	

3.1.2. Equipment and Instruments used

Welding has been done on EWM TAURUS 301 SYNERGIC S MM MIG/MAG welding machine. Hardness tests are conducted for all the samples by Rockwell hardness testing machine. Tensile tests are also carried out on Instron universal testing machine at Ethiopian Technical University laboratory, Addis Ababa, Ethiopia using a hydraulic chuck. The photographic vie w of the EWM TAURUS 301 SYNERGIC S MM MIG/MAG welding machine is shown in Fig. 3.3.

Figure 3.3. Welding setup of GMAW machine

The following machines and equipment have been used for MAG welding on SS 304L.

Table 3.4. Machines, Materials and Equipment List

Machines	Materials	Tools and Equipment	Safety materials
MAG welding Machine (water cooled) EWM TAURUS 301 SYNERGIC S MM MIG/MAG WELDER	SS 304L stainless plate	Regulator	Goggle
Bench type grinding machine	Stainless Steel MIG Wire 308LSi	Gas Cylinder Gas mixer	Helmet

Machines	Materials	Tools and Equipment	Safety materials
Rockwell hardness testing machine	Argon gas and CO_2	Bench Vice	Hand Gloves
Universal Testing Machine	Stainless steel type Cutter disc	File	Apron
Power hacksaw cutting machine	Grinding disc	Wire cutter	Mouth mask
Shearing Machine	Polisher disc	Gas mixer	Ear mask
Portable Grinder		Spark lighter	

Grinding Machine

A grinding machine often shortened to grinder is any of various power tool or machine tool used for grinding which is a type of machining using an Stainless Steel abrasive wheel as the cutting tools. Each grains of abrasive on the wheel's surface cuts a small chip from the work piece via shear deformation.

Grinding is used to finished work pieces that must shows high surface quality (e.g., low surface roughness) and high accuracy of shape and dimension. As the accuracy in dimensions in grinding is of the order of 0.000025 mm in most application it tends to be a finishing operation and removes comparatively little metal, about 0.25 to 0.50 mm depth. However, there are some roughing applications in which grinding removes high volumes of metal quite rapidly. With the help of grinding machine we form the V- groove on the materials.

Gas purge or back gas is an essential welding device that used to control the presence of oxidation in welding process, which is prepared and made ready as shown in figure 3.4.

Figure 3.4. Gas purge or back gas device

Experimental Procedure

The specimen of Austenitic stainless steel; grade SS304L as a base metal was taken and prepared to the required dimensions of 200 mm length, 100 mm width and 5 mm thickness. The work piece surface and edge were properly cleaned and prepared for welding using stainless steel type wire brush. Band saw and grinder were used to prepare the edge of the sample. To produce good quality welds, the surfaces of the weld joint should be clean of rust, scale, dirt, oil and grease. In this experimental study, Grinding is used for removing rust part and other impurities. The edge of the weld joint was prepared like V-grooves joint type which was done by using special techniques, and grinding machine. Fixtures and jigs are devices that were used to hold the parts to be welded in proper relation to each other.

In this experimental work horizontal welding position was used to join the specimen. The researcher takes the experiment on single ‘V’ type-Butt joint and horizontal welding position. Welding table and Gas purge are used to move the work piece into a position so that welding can be done more conveniently. Positioning is sometimes needed simply to make the weld joint accessible. The main objective of positioning is to put the joint in the horizontal or other more favorable position which increases the efficiency of the welder because higher welding speeds can be used. Horizontal position welding usually increases the quality of the weld because it makes the welding easier. The initial joint configuration was obtained by securing the plates in position using tack welding. The welding process was done using EWM TAURUS

301 GMAW machine. The welding conditions and process parameters such as different welding currents and welding voltage were selected according to the welding condition. Stainless Steel MAG Wire 308LSi.electrode was used as filler material. The welding joint was done at root opening of 2 mm and at a bevel angle 30^0 and groove angle of 60^0.

1. Root opening (RO): the separation between the members to be joined at the root of the joint (2 mm).
2. Root face (RF): Groove face adjacent to the root of the joint (1mm).
3. Groove face: The surface of a member included in the groove (4 mm).
4. Bevel angle (A): the angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member (30^0).

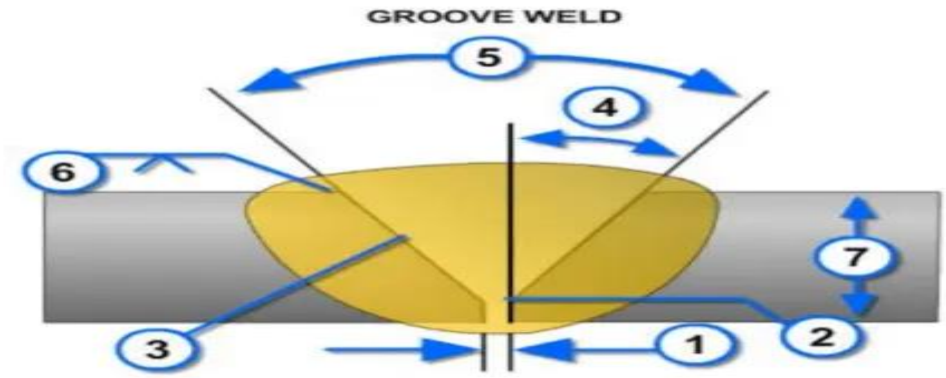


Figure 3.5. Groove welding nomenclature representation of horizontal position

5. Groove angle (A): the total included angle of the groove between parts to be joined by a groove weld (60^0).
6. Size of weld (S): the joint penetration (depth of bevel plus the root penetration when specified). The size of a groove weld and its effective throat are one in the same (5 mm).
7. Plate thickness (T): Thickness of plate welded (5 mm).

After preparing the welding sample in the second step the welding set-up prepared, checked and made ready for doing welding.

In this work there were three process parameters or variables. The welding procedure variables are those that control the welding process and the quality of the welds that are produced. In this work there were three major types of welding variables used for welding. These were the fixed or pre-selected, primary adjustable, and the secondary adjustable variables.

The fixed or preselected welding variables were those that were set before the actual welding takes. These were items such as wire electrode type (308LSi.), Filler wire electrode (1.0 mm diameter), type of current (DCEP), gas flow rate and shielding gas (95% of Argon and 5% of Co_2) and etc. These variables cannot be changed after welding starts.

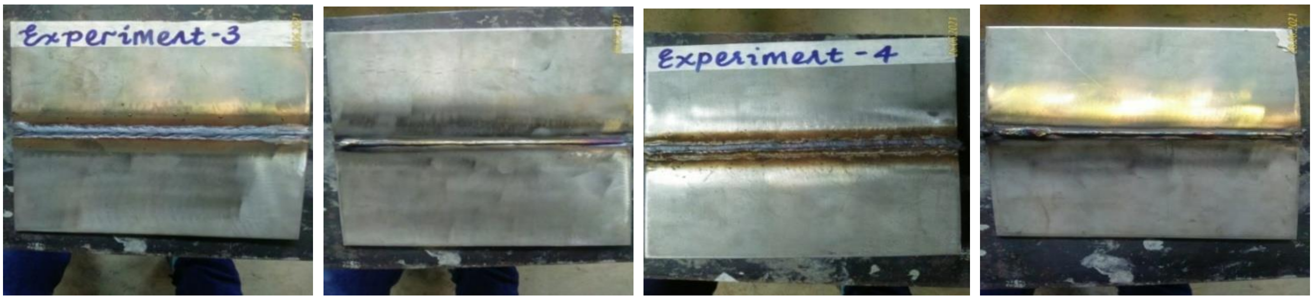
The primary adjustable variables were the major variables used to control the welding process once the fixed variables have been selected. The primary variables control the formation of the weld bead by affecting the bead width, bead height, penetration, arc stability etc. The primary welding variables those were considered in this study includes: welding current (A), arc voltage (V), and wire feed speed (WFS). These can be easily adjusted and measured so they can be used effectively to control the welding process.

Therefore this research welds the sample by varying and adjusting these primary adjustable variables. These variables had a great effect on mechanical property change of the welded sample. The secondary adjustable variables were the minor adjustable variables that were used to control the welding process. These variables were usually more difficult to measure.

Secondary adjustable variables those were considered in this experimental work includes: the work angle and the travel angle of the electrode. The electrode angles are called the travel angle and the work angle**.** The travel angle of the electrode is the angle between the joint and the electrode in the longitudinal plane. The work angle is the angle between the electrode and the perpendicular plane to the direction of travel.

Nine welded samples are thus made, by carrying out welding at different levels of Welding current, voltage and wire feed speed, as per Taguchi design of experiments, given in Table 3.8. Filler wire of 1.0 mm diameter was used in this experimental work. Photographic view of a welded specimen is shown in Fig. 3.6.

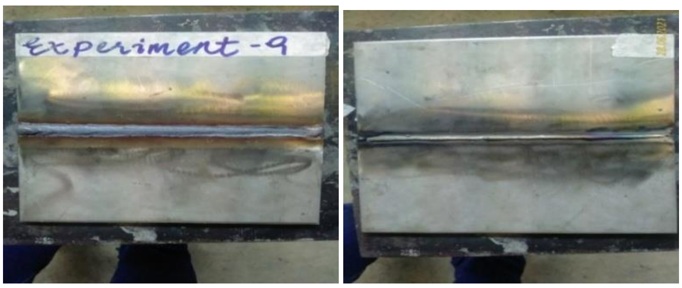
a. Cover face b. Root face a. Cover face b. Root face



a. Cover face b. Root face a. Cover face b. Root face

a. Cover face b. Root face a. Cover face b. Root face

a. Cover face b. Root face a. Cover face b. Root face



a. Cover face b. Root face

Figure 3.6. Photographic view of a specimen just after welding

3.1.3. Optimization Techniques

To determine the appropriate welding procedure for a given set of properties, the welding engineer tries to select welding parameters based on prior experience, but a number of experimental trials may be carried out, particularly for new projects, eventually leading to a definition of the optimal welding parameters. This process consumes more time and expensive. There are a lot of determination of process parameter techniques or methods, but the below depicted methods are suitable and scholars habitually used to study the process parameters optimization of GMA Welding on SS 304L materials.

Table 3.5. Selection of Optimization technique

No	Input Parameter	Output parameter	Optimizing Method	Material	Reference
1	Current, Voltage and Welding Speed	weld Quality and strength	Taguchi Technique	A312tp316l stainless	Singh and Dhami
2	Wire Feed Speed, Arc Voltage, and Shielding Gas Flow Rate	Tensile Strength, Micro hardness, Toughness, And Microstructure	Grey based Taguchi relational analysis.	SS 304H	Saadat Ali Rizvi Satya prakash Tewari January 2018
3	Welding Current, Stick out Length and Gas Flow Rate	Hardness and Tensile Strength of the weld	Taguchi's Method	SS304	Abhishek D. Dhonde1, Subhash S. Mane2
4	Current, Gas Flow Rate and Flux	Hardness	Taguchi's Method	Stainless Steel 316.	Akshay Harkal, Saili Kulkarni, 2019
5	Welding Voltage, Welding Current and Welding Speed	Tensile strength, percentage of elongation, and hardness.	Taguchi Method and Fuzzy Logic	(AISI SS 304)	S. Vani J. Venumurali, N. Swapna, B. Prasad kumar 2018
6	Arc Voltage, Wire Feed Speed and Shielding Gas Flow Rate	Tensile Strength, Micro Hardness and Percentage Elongation.	Taguchi Based Grey Relational Analysis	IS2062 Structural Stee	Saadat Ali Rizvi Satya prakash Tewari ,June 2017
7	Voltage, Wire Feed Rate, Speed, Nozzle To Plate Distance & Gas Flow	Penetration, Reinforcement and Bead Width.	Grey-based Taguchi method	stainless steel (AISI410)	S.R. Meshram et al.
8	Welding Current, Voltage and Speed	Optimum Bead Width and Bead Height	Grey based Taguchi Method	EN10025 S 235	K.Vinayagar1, A. Senthil Kumar, 2020
9	Current, Gas Flow Rate& Voltage	Hardness of HAZ and Weld bead.	Taguchi Method	SS304 (AISI 304)	Mohit Singhmar, 2015

No	Input Parameter	Output parameter	Optimizing Method	Material	Reference
10	Current, Gas Flow Rate and Number Of Passes	Deposition Rate and Hardness of Weld Bead	Grey based Taguchi technique	Stainless Steel (SS 304)	Surender Singh, Mandeep Singh, Vinod Kumar, 2016
11	Current, Gas Flow Rate and Nozzle to Plate Distance	Yield Strength, Ultimate Tensile Strength and Percentage of Elongation	Grey -based Taguchi methodology.	AISI 316L	Nabendu Ghosh Pradip Kumar Pal, Goutam Nandi, 2016
12	Arc Voltage, Welding Speed, Gas Flow Rate and Wire Feed Rate	Hardness and Ultimate Tensile Strength	Taguchi, Grey Relational analysis	MS 1020, and SS 316	D.Bahar1, Md. Nawaz Sharif2, K. Shravan Kumar3 D. Reddy4 2018
13	Speed , Current, Voltage, and Depth of Penetration	Tensile Strength	Grey- Based Taguchi Method	Stainless steel (S30430)	Asif Ahmad1 and S. Alam2 2018
14	Current, Wire Feed and Travel Speed	Ultimate Tensile Strength (UTS)	Response Surface Methodology,	SS 304L and SS430	G. Navaneeswar Reddy, M. Venkata Ramana 2017
15	Welding Current, Welding Voltage, Gas Flow Rate	Hardness, Yield Strength and Ultimate Strength	Taguchi Method	stainless steel 316L	M.Shailaja A.Yakann
16	Gas flow, voltage and welding current	Tensile Strength Hardness	Taguchi method	Stainless Steel-304,	Vijay Gohel, Jatin Makwana, Riteshkumar Ranjan
17	Welding Current and Root Gap	Welding strength, Distortion	Taguchi method	SS304L	Lalit S. Patel, Tejas C. Patel
18	Current, Voltage, and Gas Flow Rate	Tensile Strength, Hardness	Taguchi Orthogonal array	Stainless Steel 304	Vishal Chaudhari, Vaibhav Bodkhe, Shubham Deokate, 2019
19	Welding Voltage, Welding Current and Welding Speed	Tensile strength, Percentage elongation and Hardness	Taguchi Method & Fuzzy Logic	304 AISI Stainless Steel	N. Hyma Vathi, R. Vijaya Prakash
20	Welding current, gas flow rate and nozzle to plate distance	Yield strength, tensile strength & percentage elongation	Grey-Taguchi methodology	AISI 409 Ferritic stainless steel	Nabendu Ghosh, Pradip Kumar Pal, Goutam Nandi

Based on the above table 3.5, Gas Metal Arc welding parameters and welding material of SS304L, 20 journal articles were reviewed to select the best Optimization techniques in present studies.

From these reviews, ten articles were optimized for their parameters using Gray-Based Taguchi Method, seven articles are used a Taguchi method, two articles have also used a combination of Taguchi and Fuzzy logic and one articles have used Response Surface Methodology as shown below on figure

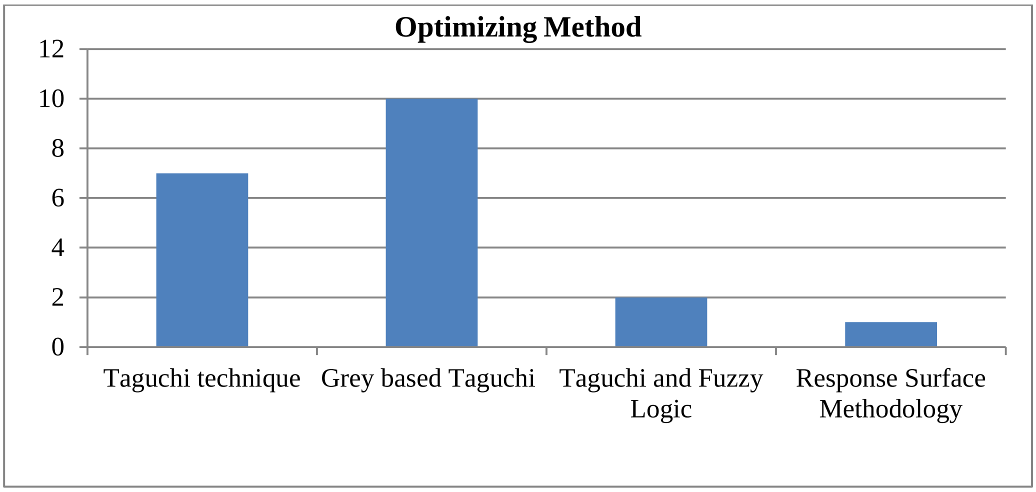


Figure 3.7. Selected optimization techniques

3.2. Methods

3.2.1. Selection of Input Parameters

Some of literature or studies or reasons for taking the input parameter selection by making decision are shown below

Table 3.6. Decision Matrix for selecting welding process parameters

Significant parameter / Author Title	Out put Result	welding current	Arc voltage	welding speed	Wire feed speed	shielding gas	gas flow rate	filler wire diameter
Ghosh et al. optimized the GMAW process parameters on 316L steel	strength of the welded joints	X			X			
Rizvi et al. optimized process parameters that affect the weldability of IS2062	strength of the welded joint	X	X					
Singh and Dhami analysed the defects in MIG Welding Of A312 TP 316L stainless steel pipe	Quality of weld bead.	X	X	X	X			

Significant parameter / Author Title	Out put Result	welding current	Arc voltage	welding speed	Wire feed speed	shielding gas	gas flow rate	filler wire diameter
Sheik and Achwal studied the effect of MIG welding on Galvanize steel.	weldability	X	X	X				
Mishra , Panda and Mohanta Optimized the process parameters in MIG welding.	depth of penetration	X	X	X				
Arya and Chaturvedi studied the influence of welding parameters	strength Penetration quality	X	X	X	X			X
Rizvi and Tewari performed parametric optimization of welding parameters for IS 2062 structural steel	strength		X		X	X	X	
Chavda et al. Observed the influence of Medium Carbon Steel material during welding.	weld strength, Quality	X	X		X		X	
Kumar and Brar investigated to find the best process parameters:	hardness and residual stresses	X	X					
Gangadhar et al. performed MIG welding on mild steel pieces	strength of the joint	X						
Contribution out of 10 literature studies		9	8	4	5	1	3	1
Contribution by percentage		90	80	40	50	10	20	10

Note: X = more significant parameter or have major contribution than other parameter

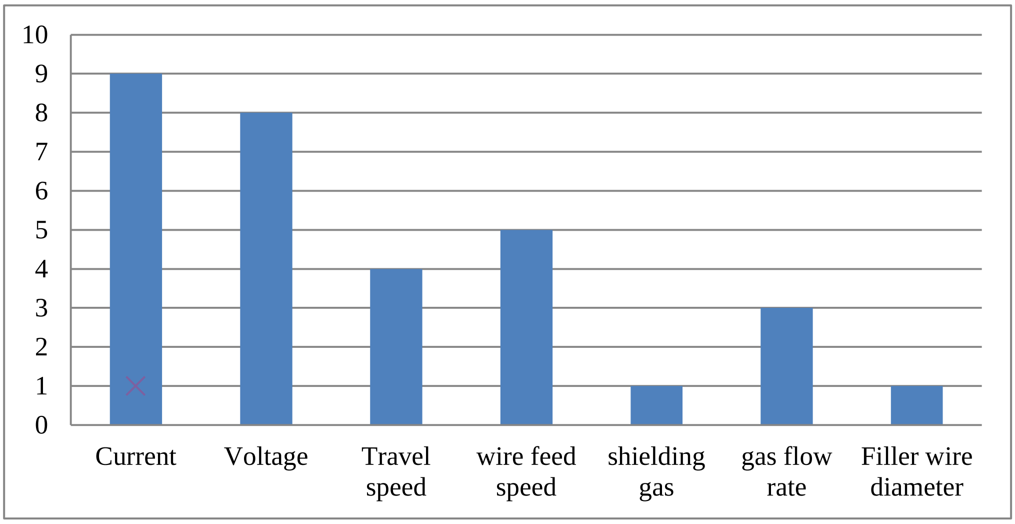


Figure 3.8. Selected welding process parameters

From the table above 3.6 And Figure 3.8, based on the design matrix of selected welding process parameters, were evaluated in ten literature studies comparing the welding process parameter with the output result, and the welding process parameters such as welding current, arc voltage and wire feed velocity were selected as special and priority parameters.

3.2.2. Determination of working parameters level values

Based on the following experimental design relationship, to determine working parameter level values

$$(\text{Level} - 1)\times\text{factor} + 1 \leq \text{Orthogonal Array} \leq (\text{level})^{\text{factor}}$$

3.2.3. Experimental Plan and Design

A. Experimental Plan

In the present research article, three-level gas metal arc welding process parameters i.e. welding current, welding voltage and wire feed speed are considered. The Values of process parameters are shown in Table 3.6. The ranges and levels are fixed based on the screening experiments and AWS handbook. Optimum welding process parameters, which considered the multiple performance characteristics, were acquired. The initial values of the welding parameters welding voltage of 22 volt, welding current of Amp 160, and wire speed of 8.5 m/min. Welding experiments for determining the optimal welding parameters were carried out by setting on each level.

Table 3.7. Welding Process Parameters and Their Levels (domain of experimentation)

Parameters	Welding current(A)	Welding Voltage(V)	Wire Feed Speed(S)
Units	Amp	Volt	m/min
Level 1	160	22	8.5
Level 2	180	24	9.5
Level 3	200	26	10.5

B. Design of Experiment

The design of experiments (DOE) is a technique that is used for the planning, conducting and analyzing the experiments to have the efficient and economical conclusions. The orthogonal array (OA) provides a set of well balanced (minimum experimental runs) experiments plan. Welding process input parameters play a very significant role in determining the quality of a weld joint. The joint quality can be defined in terms of tensile strength. Selection of experimental design is based on the following relationship.

$$(\text{Level} - 1)\times\text{factor} + 1 \leq \text{Orthogonal Array} \leq (\text{level})^{\text{factor}}$$

In the present case, $(3\text{-}1) \times 3+1 \leq$ Orthogonal Array $\leq 3^3$ or, $8 \leq$ Orthogonal Array ≤ 27

So, the L_9 orthogonal array has been selected.

Table 3.8. Experimental layout using L9 orthogonal array

Factors level			
Ex. no.	Welding current	Welding voltage	Wire feed speed
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Butt welding of AISI 304L austenitic stainless steel 200mm x 100mm x 5mm thick, have been done using the MIG welding machine make: EWM TAURUS 301 SYNERGIC S MM MIG/MAG WELDER. Taguchi design is adopted in order to identify optimal parametric combination for desired quality of weld. Total of 9 butt welded specimens have been obtained using 3 levels of current, 3 levels of voltage rate and 3 level of welding speed based on L9 Taguchi's Orthogonal Array Design of experiment.

The designs of experiments are done by Taguchi method in Minitab19 software. L9 orthogonal array is selected for the study. The Taguchi method is a systematic application of design and analysis of the experiments for the purpose of designing and improving quality. Table 3.9 shows the array of the design of experiments.

Table 3.9. Design of Experiments Orthogonal Array by Taguchi Method

Exp.No	Welding Current	Arc Voltage	Wire feed Speed
1	160	22	8.5
2	160	24	9.5
3	160	26	10.5
4	180	22	9.5
5	180	24	10.5
6	180	26	8.5
7	200	22	10.5
8	200	24	8.5
9	200	26	9.5

In this thesis proposal, am try to look through a lot of journal and articles that are written and prepared by different authors. The authors generally utilize different methods and materials for achieve their own goals. Those are:

- ✓ Taguchi's design method
- ✓ Grey Relation Analysis
- ✓ Analysis of Variance (ANOVA), and
- ✓ MINITAB analysis software.

A. Taguchi's design method

The Taguchi method developed by Genuchi Taguchi is a statistical method used to improve the product quality and identifies proper control factors to obtain the optimum results of the process. Optimization of process parameters is the key step in the Taguchi method for provides an efficient and systematic way to optimize designs for performance, achieving high quality without increasing cost. This is because optimization of process parameters can improve quality characteristics and the optimal process parameters obtained from the Taguchi method are in sensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. A large number of experiments have to be carried out when the number of process parameters increases. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting and the levels at which they should be varies. “Orthogonal Arrays” (OA) provide a set of well balanced (minimum) experiments and Dr.Taguchi’s Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the loss function is further transformed into signal-to-noise (S/N) ratio.

Processes Steps of Taguchi method

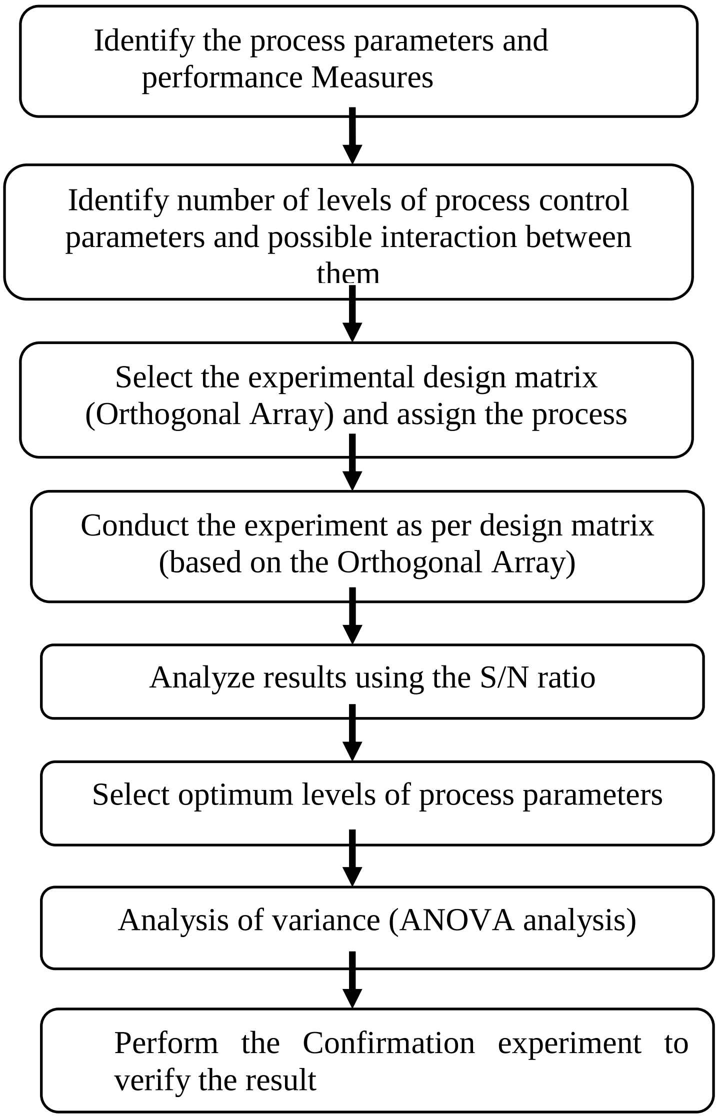


Figure 3.9. Processes in Taguchi methodology

B. Grey relational analysis

In grey relational analysis, experimental data that measured features of quality characteristics of the product are first normalized ranging from zero to one. This process is known as grey relational generation. Next, based on normalized experimental data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall grey relational grade determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. This approach converts a multiple-response- process optimization problem into a single response optimization situation, with the objective function in overall grey relational grade. The optimal parametric combination is then evaluated by maximizing the overall grey relational grade.

In grey relational generation, the normalized data corresponding to Lower-the-Better (LB) criterion can be expressed as:

$$\boldsymbol{x_i\ (k) = \frac{max y_i(k) - y_i(k)}{max y_i(k) - min y_i(k)}} \qquad (1)$$

For Higher-the-Better (HB) criterion, the normalized data can be expressed as:

$$\boldsymbol{x_i\ (k) = \frac{y_i(k) - min y_i(k)}{max y_i(k) - min y_i(k)}} \qquad (2)$$

Where xi (k) is the value after the grey relational generation, min yi(k) is the smallest value of yi(k) for the kth response, and max yi(k) is the largest value of yi(k) for the kth response. Normalizing of the experimental data according to Larger -the- Better (LB) by using the equation (2),

GRA provides the following steps to analyze the system or process. (Ramesh Rudrapati, 2016)

- Normalization of set of experimental results between 0 &1
- Calculation of grey relational coefficient from the normalized data
- Calculation of grey relational grade by averaging the grey relational coefficients. The grey relational grade is treated as overall response of the process instead of multiple attributes or response(s) i.e. ultimate load and breaking load in the present work
- Analyze the experimental results using the grey relational grade, statistical analysis of variance and signal noise ratio

- ❖ Selection of optimal levels of process parameters
- ❖ Verification of the optimal parametric condition by conducting confirmation experiments.

C. Analysis of S/N Ratio

In the Taguchi Method the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (standard Deviation) for the output characteristic. Therefore, the S/N ratio to the mean to the S. D. S/N ratio used to measure the quality characteristic deviating from the desired value. The S/N ratio S is defined as

$$S = -10\, log(M.S.D.)$$

Where, M.S.D. is the mean square deviation for the output characteristic.

To obtain optimal welding performance, higher-the better quality characteristic for Tensile strength must be taken. The M.S.D. for higher-the-better quality characteristic can be expressed

$$MSD = \frac{1}{R} + \sum_{j=1}^{R} (y_j - y_o)^2 \qquad (3)$$

Where R = Number of repetitions

In Taguchi technique, there are 3 Signal-to-Noise ratios of common interest for optimization

Nominal-The-Best: n = 10 Log10 [Square of mean/ variance]

$$S/N = 10\ log_{10}\left(\frac{\bar{Y}}{{S_y}^2}\right) \qquad (4)$$

Smaller-The-Better: n = -10 Log10 [mean of sum of squares of measured data]

$$S/N = -10\ log_{10}\left(\frac{\sum y^2}{n}\right) \qquad (5)$$

Larger-The-Better: n = -10 Log10 [mean of sum squares of reciprocal of measured data]

$$S/N = -10\ log_{10}\left(\frac{1}{n}\sum \frac{1}{y^2}\right) \qquad (6)$$

Where, n = Number of trials or measurement, y_i= measured value

$\bar{Y}$ = mean of the measured value and S_y = standard deviation

In current study, responses are associated with the strength of the weld joint, which should be high as possible so the larger-the-better criteria have been chosen.

The strength of the weld joint which is generally expected to be high is examined by equation 2 (D.Bahar, May 2018)

D. Analysis of variance (ANOVA)

The Taguchi method also provides a better feel for the relative effect of the different parameters/factors that can be analyzed by the analysis of the variance (ANOVA). It is a statistical method to estimate quantitatively the relative significance factors on quality characteristics (Technol, (2015)).

The purpose of the ANOVA is to investigate which process parameters significantly affect the quality characteristic. It is a statistical technique evaluated for percentage of contributions for variance by each input factor. ANOVA is a collection of statistical models and associated procedures used to determine the contributions of each parameter on the output characteristic (Technol, (2015)). In this Experimental study ANOVA is used to explicate the input parameters, i.e. welding current, arc voltage, and wire feed speed that mainly influence the hardness and tensile strength. This provides the information on weight age of each parameter on the hardness and tensile strength of the weld. Taguchi recommended a logarithmic transformation of mean square deviation (S/N ratio) for the analysis of results. ANOVA separates the overall variation from the average S/N ratio into contribution by each of the parameters and the errors.

If the p-value is less than the significance level, the factor is then regarded to be statistically significant. The relative significance of factors is often represented in terms of F-ratio or in percentage contribution. Greater the F-ratio indicates that the variation of the process parameter makes a big change on the performance. ANOVA for S/N ratio parametric optimization in GMAW process is 95% confidence level. Confidence level is how likely the value will fall within the experimental confidence interval and Confidence interval is a range of values that is expected to include an unknown experimental parameter based on the sample. Confidence intervals (or regions) are an important and often underused area of statistical inference, previously defined as the science of using a data sample to deduce various populations attributes (Madhusudhan, (2012)).

When the researcher wants to analyze the ANOVA; the following terms are calculated using MINITAB 18 software.

DF – Degree of Freedom

Seq. SS – Sum of Square of Variance

Adj. SS – Sum of Square of Variance,

Adj. MS –Mean of Square of Variance

F - Fisher value, it depends on the probability and obtained from bribability table at 95% confidence level.

F=Adj MS/Adj MS error

This value of F is to be compared to the F-limit for given degrees of freedom. If the F value we work out is equal or exceeds the F-limit value from F tables, we may say that there are significant differences between the sample means.

P - Probability of Variance

These can also calculated using mathematical expression

DF=Level-1

Total (Adj SS=Seq SS) = Seq $SS_{Current}$+Seq $SS_{Voltage}$+SeqSS_{WFS}+SeqSS_{Error}

For single parameter Seq SS_k is calculated using

$$\sum_{j=1}^{n}\left(\frac{S_{yj}}{n}\right)2\frac{G^2}{n} \quad (7)$$

Total Error=(Error/Total Seq SS)×100%

Adj MS=Adj SS/DF

Percentage contribution (%) = (Seq SS/Total) ×100%

Percentage Error (% Error) =

[(Experimental Value-Theoretical Value)/Theoretical value] ×100

Where G =the sum of resulting data of all trials

n= total number of trial runs

K =Represent one of the tested parameters

j=Level number of this parameter

Syj=Sum of all trials results involving this parameter at level j

Degrees of freedom

The total degrees of freedom (DF) are the amount of information in the research data. The analysis uses that information to estimate the values of unknown population parameters. The total DF is determined by the number of observations in the sample. The DF for a term show how much information that term uses. Increasing sample size provides more information about the population, which increases the total DF. Increasing the number of terms in the model uses more information, which decreases the DF available to estimate the variability of the parameter estimates.

If two conditions are met, then Minitab partitions the DF for error. The first condition is that there must be terms which can fit with the data that are not included in the current model. The second condition is that the data contain replicates. Replicates are observations where each predictor has the same value. If the two conditions are met, then the two parts of the DF for error are lack-of-fit and pure error. The DF for lack-of-fit allows a test of whether the model form is adequate. The lack-of-fit test uses the degrees of freedom for lack-of-fit (M., (2003)).

Adjusted sums of squares (Adj SS)

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

Sequential sums of squares (Seq SS)

Sequential sums of squares are measures of variation for different components of the model. Unlike the adjusted sums of squares, the sequential sums of squares depend on the order the terms are entered into the model. In the Analysis of Variance table, Minitab separates the sequential sums of squares into different components that describe the variation due to different sources. The only difference with Adj SS is Seq SS is order dependent.

Adjusted mean squares (Adj MS)

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

F-value

The F-value is the test statistic used to determine whether the model is missing higher order terms that include the predictors in the current model. With a higher fisher ‘f’ value; there will be higher performance change. A sufficiently large F-value indicates that the term or model is significant. Minitab uses the F-value to calculate the p-value, which is used to make a decision about the statistical significance of the terms and model. The p-value is a probability that measures the evidence against the null hypothesis. Lower probabilities provide stronger evidence against the null hypothesis.

P-value

The p-value is a probability that measures the evidence against the null hypothesis. Lower probabilities provide stronger evidence against the null hypothesis**.**

To determine whether the model explains variation in the response, compare the p-value for the model to your significance level to assess the null hypothesis. The null hypothesis for the overall regression is that the model does not explain any of the variation in the response. Usually, a significance level (denoted as α or alpha) of 0.05 works well. A significance level of 0.05 indicates a 5% risk of concluding that the model explains variation in the response when the model does not**.**

If the p-value is less than or equal to the significance level, it can be conclude that there is a statistically significant association between the response variable and the term. If the p-value is greater than the significance level, it cannot conclude that there is a statistically significant association between the response variable and the term. It may be necessary to refit the model without the term.

To determine whether the model correctly specifies the relationship between the response and the predictors, compare the p-value for the lack-of-fit test to your significance level to assess the null hypothesis. The null hypothesis for the lack-of-fit test is that the model correctly specifies the relationship between the response and the predictors. Usually, a significance level (denoted as alpha or α) of 0.05 works well. A significance level of 0.05 indicates a 5% risk of concluding that the model does not correctly specify the relationship between the response and the predictors when the model does specify the correct relationship.

If the p-value is less than or equal to the significance level, it can be conclude that the model does not correctly specify the relationship. To improve the model, you may need to add terms or transform your data and if the p-value is larger than the significance level, the test does not detect any lack-of-fit.

If ‘p‘ value is less than 0.05% it shows that; the parameter has greater change on the performance and 95% degree of confidence is allowable for the given parameter.

3.3. Experimental Test Works

3.3.1. Hardness Test

Weldability testing is widely used to assess the fabricability of materials by various welding processes and to determine the service performance of welded construction. Although there are hundreds of weldability tests that have been used to assess material performance, very few of these tests have been standardized. For mechanical testing of welded joints, there are a number of standardized tests that can be used. Some of these have been described as tensile, fatigue, and fracture toughness tests. The hardness test, while not actually a test that quantifies mechanical performance, can be a useful indicator of strength and ductility.

Testing is widely employed for process control and inspection, and the outcome is used in estimating mechanical properties like tensile strength. It is usually done using testing machines fitted with an indenter that is enforced into test matter over a period of time. The indenter’s shape varies by the hardness test type, and includes pyramid, ball and cone shapes. Each machine also makes use of different load or force application system, while recording a hardness value in kg-force as per the individual scales. Testing is performed to ASTM specifications, as well as other standards and customer requirements for the type of material and application.

Hardness Testing

Hardness is the ability of a material to resist permanent indentation. It is an empirical test, rather than material property. In order to define different hardness values for the same piece of material, there are several types of hardness tests. The outcome of each test should have a label identifying the method used, as it is dependent on it.

The three types of hardness are scratch, rebound, and indentation hardness. Measuring each type of hardness requires a different set of tools. Also, the same material will have different hardness values for each of the types.

Indentation Hardness:- This hardness type refers to the resistance to permanent deformation when subjecting a material to a continuous load.

Scratch Hardness:- This type of hardness refers to a material's ability to resist scratches on the surface. Scratches are narrow continuous indentations in the upper layer due to contact with a sharp, harder material. This type is also commonly used for brittle materials such as ceramics as they do not undergo significant plastic deformation.

Rebound or Dynamic Hardness: - Rebound hardness has more to do with elastic hardness than plastic hardness. The material absorbs the energy on impact and returns it to the indenter. An indenter is a reference material used for hardness testing. Dynamic hardness is usually measured by dropping a diamond-tipped hammer on the test piece and recording the hammer's bounce after it strikes the surface.

Types of Measuring Hardness

The various types of hardness are measured using different testing methods. A commonality among all methods is the use of an indenter to create the indentation on the test piece surface area. The indentation provides a tangible representation of the hardness of materials and it is easy to measure and replicate. Harder materials will have shallow indentations and softer materials will have deeper indentations.

Brinell hardness Test

The Brinell test was one of the first widely accepted hardness tests for indentation hardness measurement. In Brinell test, a steel ball of 10 mm diameter is used as an indenter to create an impression on the test piece to calculate its Brinell hardness number.

The ball is held in place for a predetermined time, usually 30 seconds, and a force is applied on the ball. This force will vary depending on the test metal being measured. The standard load is 3000 kg, but it may be reduced to 500 kg for softer metals. For harder metals, a tungsten carbide ball may be used to prevent distortion of the ball. The hardness unit HB (or HBN) will be changed to HBW in case of tungsten to notify its use. On removal of the indenter, the dent is observed with a low-power microscope and the size is calculated by taking the average of the measurements at right angles.

On completion of Brinell test, the hardness number is calculated as follows:

$$HB = \frac{2F}{\pi D\left(D - \sqrt{D^2} + d^2\right)} \tag{8}$$

Where , F – force, N,

D – Indenter diameter, mm and

d – Indentation diameter, mm

The Test Processes of Brinell Hardness and Knoop Hardness Test: During the Brinell Hardness Test, a carbide ball indenter is pressed into the sample with accurately controlled force for a specific amount of time. When removed, the material has a round indent that is measured to calculate material hardness according to a formula.

This Microhardness Test is used on very small parts and material features that are unable to be tested by the other methods and employs a test load of 1000 grams or less. The Knoop Test is performed like Brinell hardness by applying controlled force for a specific amount of time to an indenter in a rhombus-shape. The impression is measured microscopically and is used along with the test load to calculate the hardness value on the Knoop scale.

Rockwell Hardness Test

Rockwell hardness test is the most commonly used method for indentation hardness measurements. The value of Rockwell hardness is accompanied by the scale used. Depending on the material being tested, an appropriate scale must be selected. This hardness scale gives information on the type of indenter-load combination used.

In Rockwell hardness test, prior to applying the testing load, a small minor load is applied to seat the indenter into the test piece and remove the effect of any surface irregularities. This provides better accuracy. Then similar to the Brinell test, the indenter is used to create an impression on the material by applying the testing load also known as a major load. The impression is then measured for determining the hardness. A dial gauge is used to record the deformation. The net increase indent dimension (between the application of minor and major load) is considered for calculating the hardness value. Specifying the speed of loading is necessary. In soft metals, varying speeds of load application can produce an appreciable difference in the final value. It is important to carefully monitor that the rate of loading is according to the standard.

The formula for Rockwell hardness is:

$$HR = N - \frac{d}{s} \quad (9)$$

Where, N – scale factor depending on the scale used

s – Scale factor depending on the scale used

d – Depth of permanent indentation compared to minor load, mm

The Test Processes of Rockwell Hardness Test:- In addition to a Rockwell Hardness Test, there is a Superficial Rockwell. For each test, a minor load is applied to either a diamond cone or a steel ball indenter positioned on the test material's surface to establish a zero reference position. Next, a major load is applied for a specified amount of time, leaving the minor load applied upon release. The Rockwell hardness number will be the difference in depth between the zero reference position and the indent due to the major load.

The choice of indenter is dependent upon the characteristics of the test material. The Rockwell Hardness Test applies larger minor and major load values than the Superficial Rockwell, yet both tests offer three different major load options. More than thirty different scales are used between Rockwell and Superficial Rockwell hardness testing due to the various choices and combinations of tests, indenters and major loads.

Vickers Hardness Test

Vickers Hardness test is especially suitable for softer materials that do not need high loads. With soft materials, the Vickers method provides better accuracy. Also, calculating the hardness value is easier, as Vickers uses the same diamond indenter for all materials. Another important feature is the use of a magnifier, making it possible to test areas with a specific microstructure.

First, the tester has to place the part onto the machine and use the microscope to find the suitable height. Then, using the images, the correct place is determined.
The diamond indenter is in the shape of a four-sided pyramid. After touching the part, the machine soon reaches the pre-determined force value. It stays at the same load for a certain time. Then, the measuring of the indentation takes place. Calculating the Vickers hardness value uses the following formula:

$$HV = 0.1891\frac{F}{d^2} \tag{10}$$

Where, F – force, N

d – Indentation diagonal, mm

The Test Processes of Vickers Hardness Test: The Vickers Hardness Test can be performed on both the micro and macro hardness scales with a maximum test load of 50 kilograms. This type of hardness test is also performed by applying controlled force for a specific amount of time to an indenter, which in this case is a square-based diamond pyramid. The impression measurement and test load are used in the appropriate formula to calculate the Vickers hardness value. Like Brinell and Knoop, this method has one scale that covers its entire hardness range.

Scleroscope Test/ Rebound Hardness Test

A scleroscope is a device used to measure the rebound or dynamic hardness of materials. The setup consists of a hollow vertical glass tube connected to a stand. Through this tube, a diamond hammer is dropped onto the test piece and the bounce of the hammer is recorded.
The diamond hammer is dropped from a fixed height under its own weight. On coming in contact with the test piece, the hammer bounces back. This bounce will be higher for materials with higher hardness.

The bounce will be lower for a soft metal as a portion of the impact energy will be exhausted in creating a dent on the test surface. The glass tube has gradients to measure the height of the bounce. Rebound hardness is measured in shore units.

3.3.2. Tensile Properties and Test

Tensile properties: Tension tests are used to evaluate the breaking strength and ductility of a material and to determine that the material meets the specification requirements. Welding causes changes in the metallurgical structure and mechanical properties of a given material. Tension tests are made to assess the suitability of the welded joint for service and are also used to quality welding procedures for welder according to specific code requirements.

The Tension test for welds is not like that for the base metal because the weld test section is heterogeneous in nature containing base metal, heat affected zone and weld metal. To obtain correct assessment of the strength and ductility several different tests have to be carried out, using different specimens shown in fig 3.9. The following tests are commonly carried out. All weld-metal tension tests, specimen locations are shown in fig 3.10. (Khan, 2007)

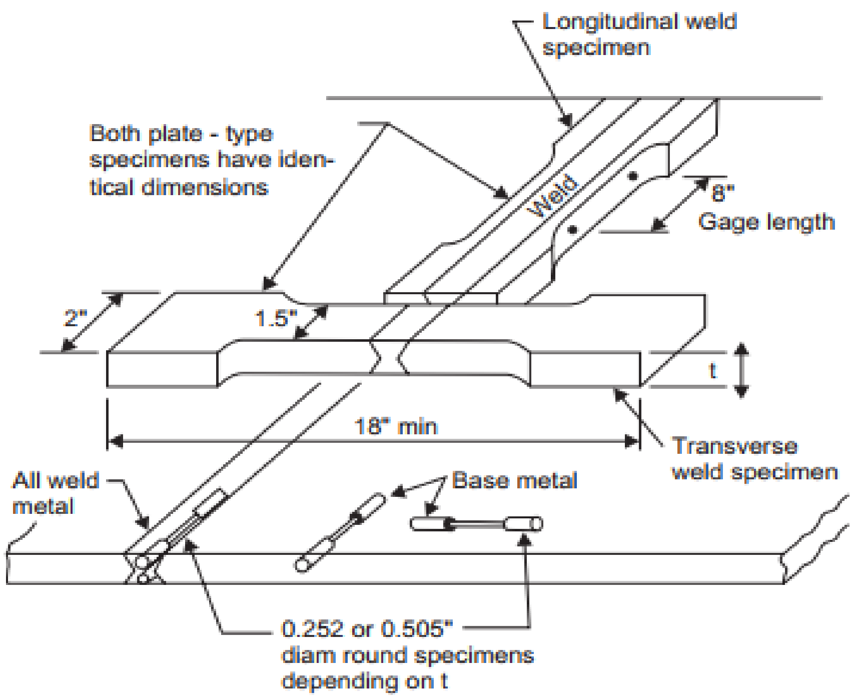


Figure 3.10.Typical test specimens for evaluation of welded joints (Khan, 2007)

the details of the specimen dimensions are shown in fig. 3.11.

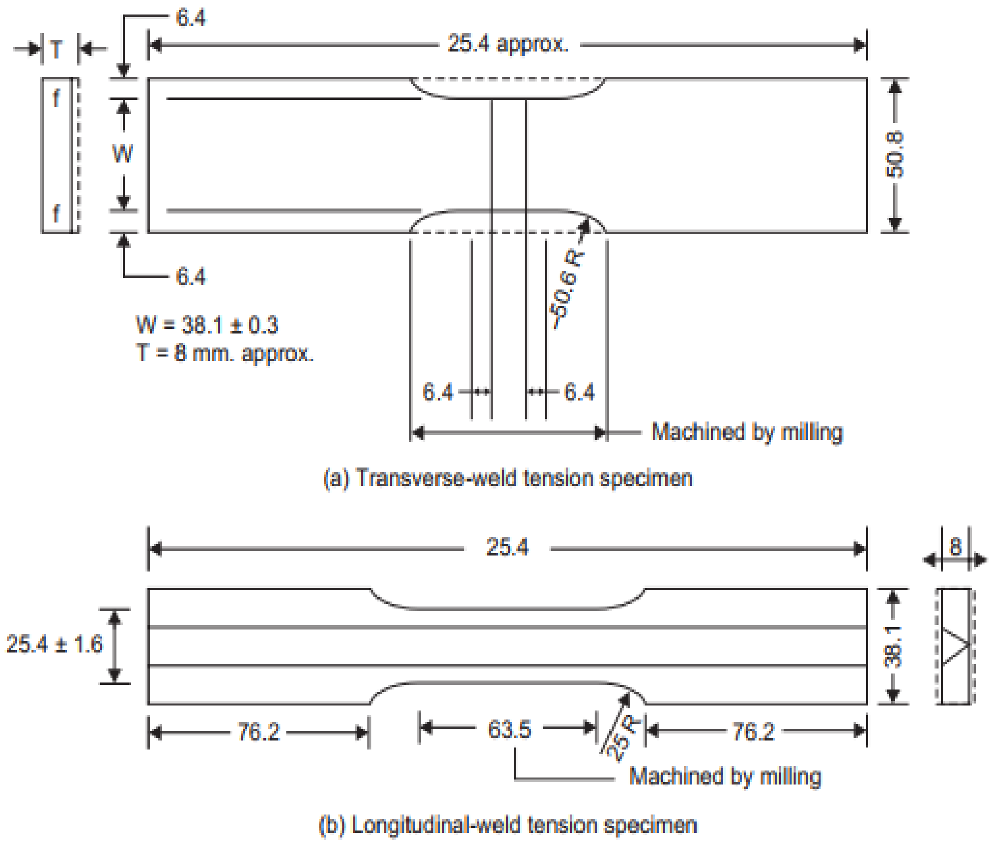


Figure 3.11. Tension test Specimen with dimension in mm. (Khan, 2007)

Transversal butt-weld test: the test shows that the weld metal is stronger than base metal if the failure occurs in the base metal. It fails to give comparative idea about different types of electrodes. When the weld strength is lower than the base metal, the plastic strain occurs in the weld joint. Ultimate strength is thus obtained but no uniform straining within the specified gauge length and therefore, it is not possible to obtain a reliable measure of yield strength across a welded joint.

Longitudinal butt-weld test: here the loading is parallel to the weld axis. It differs from all-weld-metal test in that it contains weld, HAZ and base metal along the gauge length. All these zones must strain equally and simultaneously. Weld metal elongates with the base metal until failure occurs. This test thus provides more information about the composite joint than the transverse test especially when base metal and weld- metal strengths differ significantly (Khan, 2007).

The Tensile Test Process

Tensile testing/tension testing is a destructive test process that measures and provides the strength, yield strength and ductility of a material when subjected to an applied force. The strength and ductility of a material under tension are essential characteristics required for design, quality control, and life prediction of metal parts and finished products. ASTM E8/E8M describes the methods of determination of mechanical properties that define the quality of a material: yield strength, yield point elongation, tensile strength, elongation, and reduction of area.

Material strength testing, using the tensile/tension test method, involves applying an ever-increasing load to a test sample up to the point of failure. The process creates a stress/strain curve showing how the material reacts throughout the tensile test. The data generated during tensile testing is used to determine mechanical properties of materials and provides the following quantitative measurements:

Tensile strength **(**Ultimate Tensile Strength (UTS), is the maximum tensile stress carried by the specimen, defined as the maximum load divided by the original cross-sectional area of the test sample.

Yield strength is the stress at which time permanent (plastic) deformation or yielding is observed to begin.

Ductility measurements are typically elongation, defined as the strain at, or after, the point of fracture, and reduction of area after the fracture of the test sample.

The test sample is securely held by top and bottom grips attached to the tensile or universal testing machine. During the tension test, the grips are moved apart at a constant rate to pull and stretch the specimen. The force on the specimen and its displacement is continuously monitored and plotted on a stress-strain curve until failure. The measurements, tensile strength, yield strength and ductility, are calculated by the technician after the tensile test specimen has broken. The test specimen is put back together to measure the final length, and then this measurement is compared to the pre-test or original length to obtain elongation. The original cross section measurement is also compared to the final cross section to obtain reduction in area.

Table 3.10.Tensile Test specimen preparation based on ASTM E8/E8M- 16a (ASTM Committee E28 and Subcommittee, 2016) (Appendices 7)

Dimensions (mm)	
	Standard Specimens
	Sheet-Type, 12.5 mm Wide
G—Gauge length	50.0 ± 0.1
W—Width	12.5 ± 0.2
T—Thickness	5.0
R—Radius of fillet, min	12.5
L—Overall length, min	200
A—Length of reduced parallel section, min	57
B—Length of grip section, min	50
C—Width of grip section, approximate	20

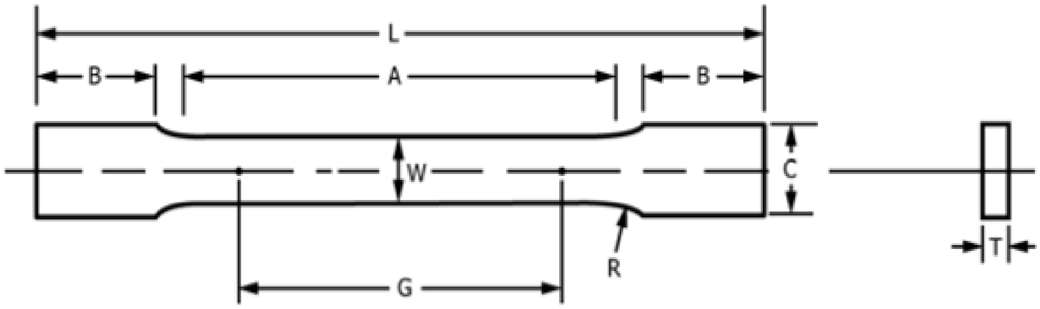
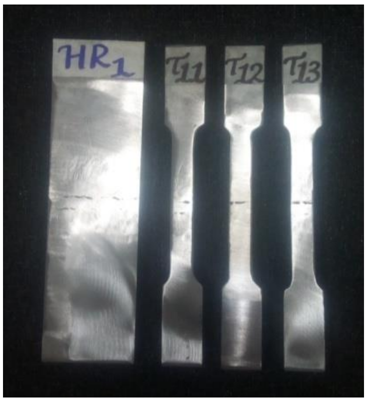
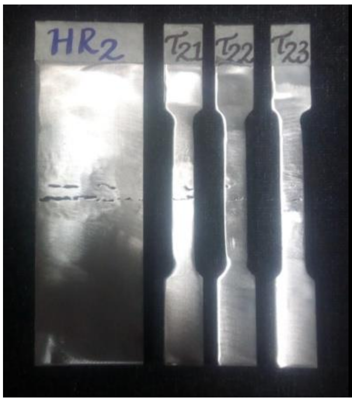


Figure 3.12. Diagram of a tensile test specimen prepared according to ASTM-E8 (ASTM Committee E28 and Subcommittee, 2016) (Appendices 9)



Experiment 1



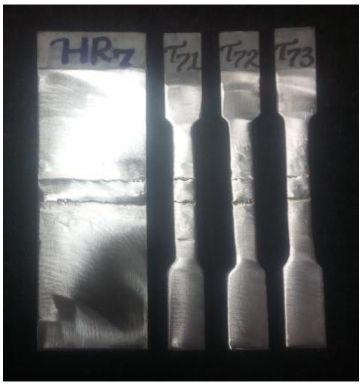
Experiment 2

Experiment 3

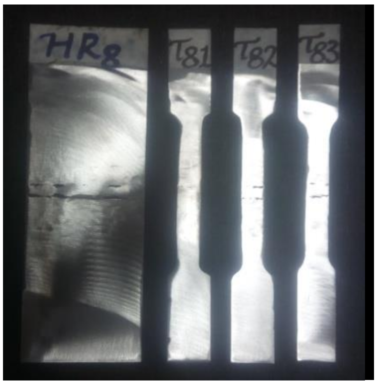
Experiment 4

Experiment 5

Experiment 6



Experiment 7



Experiment 8

Experiment 9

Figure 3.13 Photographic view of Hardness and Tensile Test specimen

As shown in fig 3.13, the test specimen for tensile strength of each experiment prepared based on ASTM E8/E8M- 16a Standard with a dimension in table 3.10 and **t**he test specimen for hardness of each experiment also provided by considering for 10 indentation trials

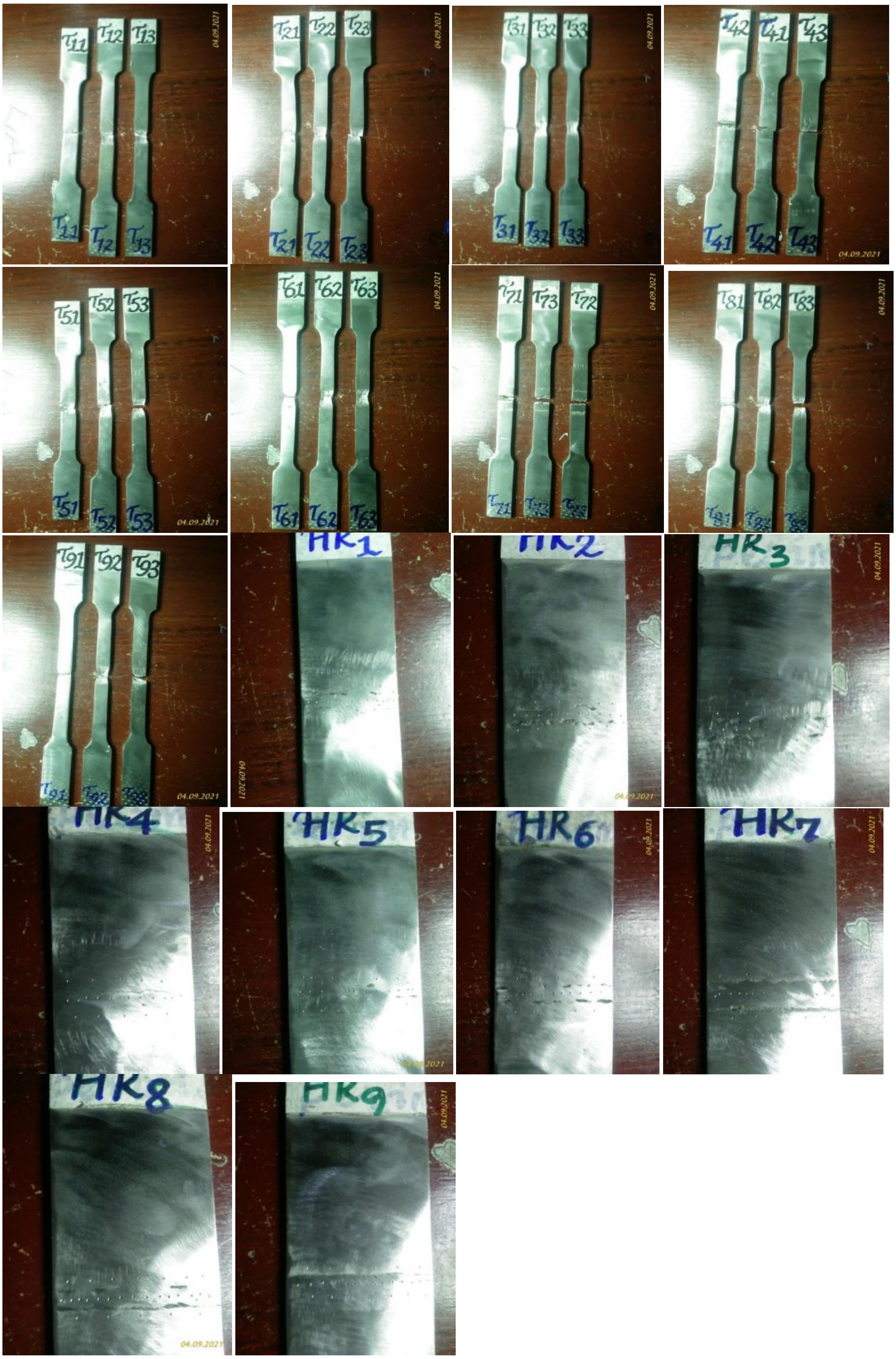


Figure.3.14. Experimental Result after Hardness and tensile testing

3.4. Tensile Testing Machine

A universal testing machine (UTM), also known as a universal tester materials testing machine or materials test frame, is used to test the tensile strength and compressive strength of materials. The “universal” part of the name reflects that it can perform many standard tensile and compression tests on materials, components, and structures.

UTM consists of

- Load frame - Usually consisting of two strong supports for the machine.
- Load cell - A force transducer or other means of measuring the load is required.
- Cross head - A movable cross head (crosshead) is controlled to move up or down.
- Means of measuring extension or deformation- Extensometers are sometimes used.
- Output device - A means of providing the test result is needed.
- Test fixtures, specimen holding jaws, and related sample making equipment are called for in many test methods.

The specimen is placed in the machine between the grips and the machine itself can record the displacement between its cross heads on which the specimen is held. However, this method not only records the change in length of the specimen but also all other extending / elastic components of the testing machine and its drive systems including any slipping of the specimen in the grips. The welded joints go through a destructive testing on Universal Testing Machine to determine tensile strength.

- The work piece with a total length of 200mm length stainless steels are fit into the jaws of Universal Tensile Machine.
- The load is slowly applied until the joint finally breaks.
- The value of tensile strength obtained is noted down. Also, graph is generated.

Figure 3.15. Testing machine for tensile strength

3.5. Rockwell Hardness Tester

The HRS-150 Rockwell hardness tester i.e. durometer, provides exceptional quality and flawless measurements of hardness in a wide gamut of materials. The high caliber machine is fully automated to facilitate outstanding, error-free performances and data-logging. The only manually accomplished task is the lowering and rising of the testing platform. The machine is outfitted with ultra-high technology in testing and a top-notch LCD display.

The digital machine conducts testing across a comprehensive range of Rockwell hardness scales such as HRA, HRB, HRC, HRD, HRE, HRF, HRG, HRH and HRK. It also provides various Rockwell hardness scales for hardness testing of plastic such as HRE, HRL, HRR and HRM. The measured values are interchangeable across diverse hardness scales like HV, HRT, HK and HBHRN.

The HRS-150 incorporates an integrated printer that produces printouts of test values on demand. It is also provided with an RS232 Hyper-port that facilitates expanding or adding to existing functions.

The machine is perfectly suitable to determine the Rockwell hardness of materials like iron/non-iron metals, cold/hard casting, hard alloy steel, copper/aluminum alloy, quenched/tempered/annealed/bearing steel, malleable cast iron, etc

Figure 3.16. Rockwell Hardness Tester / Bench top / Digital Display

Chapter Four

4. Result and Discussion

4.1. Introduction

The aim of the experimental plan is to find the optimize parameters those are influencing the Tensile Strength, Hardness of welded zone & heat affected zone of the weldment. The experiments were developed based on an orthogonal array, with the aim of relating the influence of welding current, welding arc voltage and wire feed speed. These design parameters are distinct and intrinsic feature of the process that influence and determine the composite performance.

4.2. Experimental Result

Experiments are conducted on the welded pieces by gas metal arc welding machine corresponding to L_9 Taguchi Orthogonal Array design of experiments shown in table 4.1and 4.2, to know the ultimate tensile strength (UTS) and hardness of fusion zone and heat affected zone.

Table 4.1. detail test data for Ultimate Tensile Strength (Appendices 10)

Exp. No	**Tensile Test specimen Trial (MPa)**			**Ultimate Tensile Strength (MPa)**
	T11	T12	T13	
1	865	1321	1271	**1152.33**
	T21	T22	T23	
2	1324	1456	1486	**1422.00**
	T31	T32	T33	
3	1350	1421	1414	**1395.00**
	T41	T42	T43	
4	1013	934	938	**961.67**
	T51	T52	T53	
5	1053	1623	1531	**1402.33**
	T61	T62	T63	
6	1422	1513	1485	**1473.33**
	T71	T72	T73	
7	1224	1012	1059	**1098.33**
	T81	T82	T83	
8	1476	1492	1432	**1466.67**
	T91	T92	T93	
9	1578	1522	1463	**1521.00**

Table 4.2. Detail test data for hardness on fusion zone and heat affected zone (Appendices 9)

Exp. No	Test Zone	Indentation Trial (HRC)										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
1	Fusion zone	26.1	17.3	24.0	35.7	25.1	18.6	16.1	21.7	18.2	15.9	**21.87**
	Heat Affected zone	17.8	19.9	20.6	17.6	19.0	17.1	18.7	21.1	17.5	20.8	**19.01**
2	Fusion zone	20.8	29.5	19.1	17.3	18.8	22.9	18.6	19.7	19.1	21.4	**20.72**
	Heat Affected zone	21.7	20.6	21.3	19.4	24.4	21.4	23.8	20.9	23.6	21.0	**21.81**
3	Fusion zone	21.1	27.7	24.6	20.1	20.1	19.7	21.0	26.7	19.9	24.6	**22.55**
	Heat Affected zone	15.8	21.2	26.0	13.6	20.1	11.4	17.0	12.9	20.9	24.5	**18.34**
4	Fusion zone	17.3	17.5	18.7	19.2	20.4	28.2	18.6	10.8	31.4	22.8	**20.49**
	Heat Affected zone	25.4	31.6	20.9	22.7	16.1	19.2	21.2	24.5	29.2	16.0	**22.68**
5	Fusion zone	22.6	17.6	16.0	18.5	26.4	30.0	13.5	20.8	14.6	12.2	**19.22**
	Heat Affected zone	19.5	22.8	18.5	11.1	19.5	16.8	21.8	23.0	33.6	15.5	**20.21**
6	Fusion zone	16.3	12.0	19.8	11.2	23.6	23.8	31.1	29.2	23.7	22.4	**21.31**
	Heat Affected zone	23.3	15.1	19.7	25.4	25.7	19.3	22.9	22.2	22.1	24.3	**22.00**
7	Fusion zone	22.3	31.8	34.1	29.4	15.6	15.3	38.4	14.1	23.8	15.0	**23.98**
	Heat Affected zone	22.0	24.9	19.8	20.0	25.6	27.3	24.7	15.6	19.4	18.4	**21.77**
8	Fusion zone	19.4	17.2	32.2	18.8	27.9	28.3	17.6	33.1	17.3	27.2	**23.90**
	Heat Affected zone	29.9	31.4	25.6	26.1	19.7	15.2	24.0	30.7	33.3	31.4	**26.77**
9	Fusion zone	38.2	25.4	38.0	20.5	22.7	27.2	30.1	23.2	16.4	14.4	**25.61**
	Heat Affected zone	22.6	19.4	15.8	23.2	27.2	20.6	17.3	33.3	15.4	27.2	**22.20**

As shown on the above table 4.2, the average HRC value on welded zone and Heat affected zone has been obtained by conducting ten time indentation trials of the Rockwell hardness testing for each experimental specimen.

The summary of experimental analysis is shown in Table 4.3. The experimental results after gas metal arc welding were estimated in terms of the following measured performance: (1) ultimate tensile strength of the welded specimen (UTS), (2) hardness on welded zone, and (3) hardness on heat affected zone. In order to attain supreme weldability, Taguchi experimental design was utilized for conducting experiments. For this, an L9 orthogonal array has been used for the experiment.

Table 4.3. Experimental tests result as per L9 Taguchi Orthogonal Array Design of experiment

Exp. No	**Current**	**Voltage**	**Wire Feed Speed**	**U.T.S (MPa)**	**HRC (FZ)**	**HRC (HAZ)**
1	160	22	8.5	1152.36	21.870	19.01
2	160	24	9.5	1422.00	20.720	21.81
3	160	26	10.5	1395.00	22.550	18.34
4	180	22	9.5	961.67	20.490	22.68
5	180	24	10.5	1402.33	19.220	20.21
6	180	26	8.5	1473.33	21.310	22.00
7	200	22	10.5	1098.33	22.980	21.77
8	200	24	8.5	1466.67	23.900	26.77
9	200	26	9.5	1521.00	25.610	22.20

Form the above table 4.3. The results indicate that for many of the welded samples test results are satisfactory.

- ❖ The best result in tensile testing has been obtained on the experiment no.9 (Corresponding to welding current 200A, Voltage 26V and Wire Feed Speed 9.5m/min) For this sample, ultimate tensile strength = 1521MPa.
- ❖ The top result in Hardness testing on welded zone and Heat affected zone has been obtained on exp. No 9 and exp. No 8, respectively (Corresponding to current 200A, voltage 26V and WFS 9.5 m/min for welded zone and current of 200A, voltage of 24V & WFS of 8.5 for heat affected zone). For this sample, HRC on FZ = 25.61 and HRC on HAZ = 26.77

- The reduced result in tensile testing has been obtained for the sample no. 4 (Corresponding to welding current 180A, Voltage 22V and Wire Feed Speed 9.5m/min). For this sample, ultimate tensile strength = 961.67MPa
- The least result in Hardness testing on welded and Heat affected zone has been obtained on exp. No 5 and exp. No 3, respectively (Corresponding to current 180A, voltage 24V and WFS 10.5 m/min for welded zone and to current of 160A, voltage of 22V & WFS of 8.5 for heat affected). For this sample, HRC on FZ = 19.22 and HRC on HAZ = 18.34.

4.3. Analyzing of Experimental Results

The results of tensile strength and hardness of welded and Heat Affected zone on different set of combination of parameters are shown in the table 4.4. On the basis of these results, the S/N ratio has been calculated separately for every single no. of experiments with the help of Minitab software 19.

Table 4.4. Experimental results for S/N ratio of UTS, HRC on FZ and HAZ

Exp. no.	Current (Amp)	Voltage (Volt)	Wire Feed Speed (m/min)	S/N Ratio UTS	S/N Ratio (HRC) on FZ	S/N Ratio (HRC) on HAZ
1	160	22	8.5	61.232	26.797	25.580
2	160	24	9.5	63.058	26.328	26.773
3	160	26	10.5	62.891	27.063	25.268
4	180	22	9.5	59.661	26.231	27.113
5	180	24	10.5	62.937	25.675	26.111
6	180	26	8.5	63.366	26.572	26.848
7	200	22	10.5	60.815	27.227	26.757
8	200	24	8.5	63.327	27.568	28.553
9	200	26	9.5	63.643	28.168	26.927

From table 4.4. The results show that experimental run nine (9) and run eight (8) gave the highest Signal-to-Noise values for UTS and HRC on welded & HAZ as 63.642584, 28.168192 and 28.5529674 respectively

4.4. Grey Relational Analysis

Grey relational analysis converts a multi objective problem into a single objective problem with the objective function of overall grey relational grade. The corresponding level of parametric combination with highest grey relational grade is considered as the optimum parametric combination (Lin and Lin, 2002).

4.4.1. Normalization of Resulted data

It is the first step in the grey relational analysis method and it is a process of conveying the original sequence to a comparable sequence. For which reason, the experimental results are normalized in the range between zero and one. The process is necessary when the sequence scatter range is too large, or when the directions of the target in the sequence are different (N. D. Ghetiya, 2015).

If the response is to be maximized, then larger is better characteristics are intended for normalization to scale it into an acceptable range by the following formula (Kasman, 2013).

In grey relational generation, the normalized data corresponding to Higher-the-Better (HB) criterion can be expressed as follows:

$$x_i\,(k) = \frac{yi(k) - minyi(k)}{max\;yi(k) - minyi(k)} \tag{11}$$

Where xi (k) is the value after the grey relational generation,

min yi(k) is the smallest value of yi(k) for the kth response, and

max yi(k) is the largest value of yi(k) for the kth response.

Normalizing of the experimental data according to Larger -the- Better (LB) by using the equation (5), Result of normalization of experimental data are shown in Table 4.5.

Table 4.5. Normalized data for ultimate Tensile Strength and hardness (HRC) on FZ and HAZ

Exp. No.	S/N ratio Output responses			Step 1: Normalized data		
	Ultimate. Tensile Strength	Hardness (HRC) on FZ	Hardness (HRC) on HAZ	Ultimate. Tensile Strength	Hardness (HRC) on FZ	Hardness (HRC) on HAZ
1	61.232	26.797	25.580	0.395	0.450	0.095
2	63.058	26.328	26.773	0.853	0.262	0.458
3	62.891	27.063	25.268	0.811	0.557	0.000
4	59.661	26.231	27.113	0.000	0.223	0.562
5	62.937	25.675	26.111	0.823	0.000	0.257
6	63.366	26.572	26.848	0.931	0.360	0.481
7	60.815	27.227	26.757	0.290	0.622	0.453
8	63.327	27.568	28.553	0.921	0.759	1.000
9	63.643	28.168	26.927	1.000	1.000	0.505

4.4.2. Calculation of deviation sequences and grey relational coefficients

The next step is to calculate the grey relational coefficient, ξi (k) from the normalized values by the following formula as follows. The GRC is used to explain the relationship between the reference sequence and the comparability sequence. The grey relational co-efficient GRC (ξ) is calculated to integrate the data achieved from equations (Sampath Kumar, 2016).

$$\xi i(k) = \frac{\Delta min + r\Delta max}{\Delta \theta i(k) + r\Delta max} \quad (12)$$

where Δθi = ||xθ(k) _ xi(k)|| = difference of the absolute value between xθ(k) and xi(k);

Δmin = smallest value of Δθi ;

Δmax = largest value of Δθi ; and here

'r' is distinguish co- efficient which is used to adjust the difference of the relational coefficient, usually r is within the set {0, 1}, generally 'r' value is taken as 0.5. ξi(k) is Grey relation co-efficient. The grey relational coefficient values are also given in Table 4.6.

Table 4.6 Grey relational coefficients

Exp. No.	Step 2: Deviation sequence Values of Δθi			Step 3: Grey relational coefficient		
	Ultimate. Tensile Strength	Hardness (HRC) on FZ	Hardness (HRC) on HAZ	Ultimate. Tensile Strength	Hardness (HRC) on FZ	Hardness (HRC) on HAZ
1	0.605	0.550	0.905	0.452	0.476	0.356
2	0.147	0.738	0.542	0.773	0.404	0.480
3	0.189	0.443	1.000	0.726	0.530	0.333
4	1.000	0.777	0.438	0.333	0.392	0.533
5	0.177	1.000	0.743	0.738	0.333	0.402
6	0.069	0.640	0.519	0.878	0.438	0.491
7	0.710	0.378	0.547	0.413	0.570	0.478
8	0.079	0.241	0.000	0.863	0.675	1.000
9	0.000	0.000	0.495	1.000	1.000	0.503

4.4.3. Calculation of Grey relational grades and ordering/rank

After obtaining the grey relational coefficient, grey relational grade is determined by taking the average of the grey relational coefficients. A Grey relational grade is a weighted sum of the Grey relational coefficients, and is defined as follows (Saadat A. Rizv, 2017):

$$\gamma_i(x_0^*, x_1^*) = \frac{1}{n}\sum_{i=1}^{n} wi\,\xi\left(x_0^*(k), x_i^*(k)\right) \tag{13}$$

Where $\gamma_i(x_0^*, x_1^*)$ is the GRG for i^{th} experiment *wi* is the weighting value of the i^{th} performance characteristics and *n* the number of performance characteristics or number of process responses.

Here, the Grey relational grade $\gamma_i(x_0^*, x_1^*)$ represents the level of correlation between the reference and comparability sequences. If the two sequences are identical, then the value of the Grey relational grade equals to one. The Grey relational grade also indicates the degree of influence exerted by the comparability sequence on the reference sequence.

Principal Component Analysis

The Principal Component Analysis (PCA) has been used to eliminate the response correlation. This matrix consists of Eigen values, Eigenvectors and quality characteristics contributions. The elements of the array for multiple performance characteristics listed in Table 4.6 represent the grey relational coefficient matrix and determine the corresponding Eigen value.

Table 4.7 Eigen values and explained variation (Appendices 15)

Principal component	Eigen values	Explained Variation (%)
UTS	1.7281	57.603
HRC on FZ	0.7642	25.473
HRC on HAZ	0.5077	16.923

The principal component with the highest Eigen values is chosen to replace the original responses for further analysis. In this case, the highest Eigen values were obtained in the UTS first principal component. Then, the contribution of each individual quality characteristic for the first principal components is shown in Table 4.9.

Table 4.8. The Eigen vectors for principal component (Appendices 15)

Quality characteristic (Variable)	Eigenvector		
	Principal Component 1	Principal Component 2	Principal Component 3
GRC UTS	0.608	-0.399	0.686
GRC HRC (FZ)	0.62	-0.301	-0.725
GRC HRC (HAZ)	0.496	0.866	0.064

Table 4.9. Quality characteristic contribution for principal component 1

Variable	Principal Component 1	% contribution
GRC UTS	0.36966	36.966
GRC HRC (FZ)	0.38440	38.440
GRC HRC (HAZ)	0.24602	24.602
Total	**1.00008**	**100.008**

Therefore, the grey relational coefficients values are taken $\xi = 1.00008$ is used.

The higher value of grey relational grade corresponds to intense relational degree between the reference sequence x0(k) and the given sequence xi(k). The reference sequence x0(k) represents the best process sequence. Therefore, higher grey relational grade means that the corresponding parametric combination is closer to the optimal.

The grey relational grade is obtained by averaging the grey relational coefficient values of ultimate tensile strength, Hardness on Fusion zone and Heat Affected Zone and its ordering shown in Table 4-10.

Table 4.10. Grey relational grade and ordering

Exp. No.	Grey relational grade [GRG]	Ordering
1	0.4378	8
2	0.5591	4
3	0.5542	5
4	0.4048	9
5	0.5000	6
6	0.6138	3
7	0.4893	7
8	0.8245	2
9	**0.8777**	**1**
Average GRG **= 0.5846**		

4.5. Evaluating Signal-to-Noise Ratios

In the present research work, tensile strength, Rockwell hardness (HRC) on FZ and Rockwell hardness (HRC) on HAZ of welded pieces were identified as the responses, therefore, “higher the better” consider response for Signal-to- Noise ratio of Tensile Strength and Rockwell hardness (HRC) on welded & Heat affected zone are chosen as characteristic for analysis purpose.

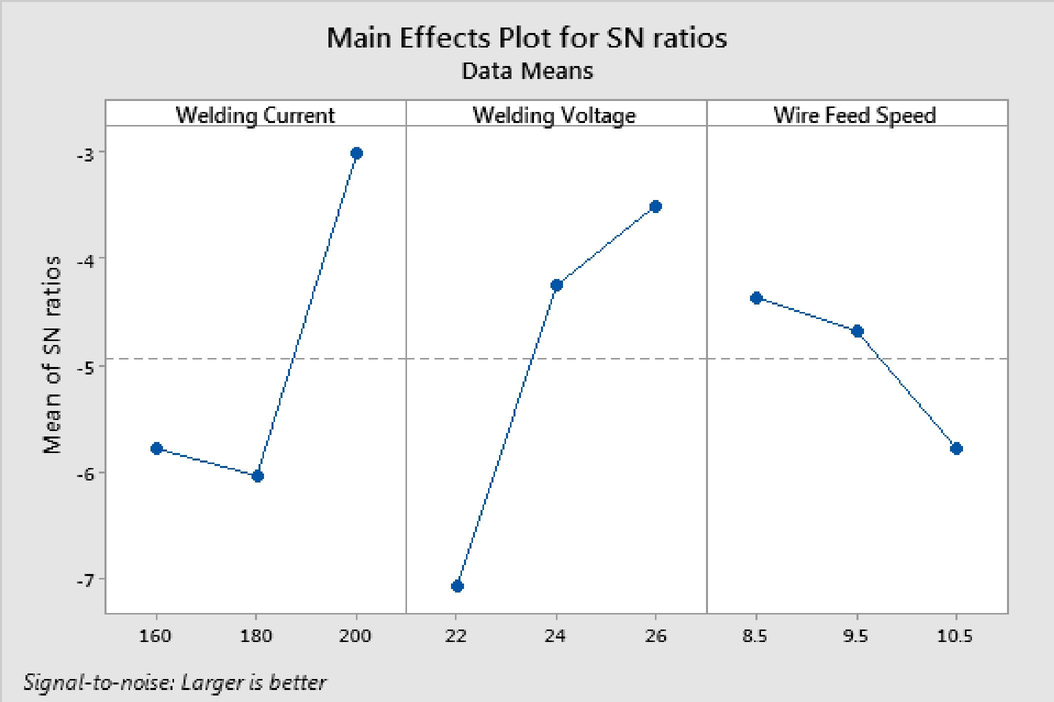


Figure 4.1. Main effects plot for S/N Ratios (Appendices 13)

As shown in Figure.4.1, the effect of the different levels of parameters for Signal –to Noise ratio on the ultimate tensile strength and hardness of welded and heat affected zone. The highest values are bold and underlined in Table 4-5.

- ❖ Level 3 for welding current (i.e. 200 A), indicated as the optimum condition in terms of S/N ratio (UTS, HRC on FZ and HAZ) while variation of current is only considered.
- ❖ Level 3 for welding voltage (i.e. 26 Volt), indicated as the optimum condition in terms of S/N ratio (UTS, HRC on FZ and HAZ) while varying voltage only.
- ❖ Level 1 for Wire Feed Speed (i.e. 8.5 m/min), is indicated as the optimum condition in terms of S/N ratio (UTS, HRC on FZ and HAZ)while varying wire Feed speed only

From Figure 4.1, Higher the S/N ratio, smaller is the variance of the UTS and hardness (HRC) towards the desired target (higher is the better). it is found that welding current at level 3, welding voltage at level 3 and wire Feed Speed at level 1 (i.e. current 200 Amp, voltage 26 volt and wire feed speed 8.5 m/min) is the parametric condition which will give maximum value of Ultimate Tensile Strength (UTS) and hardness of welded & heat affected zone.

4.6. Determination of the Optimal Level Setting of each Parameters

The main effect analysis of GRG is adopted to figure out the response table for grey relational analysis, as indicated in the response for mean Table 4.11 shows the average of each response characteristic for each level of each factor. The delta statistic is shown that the highest minus the lowest average of each factor. The table includes ranks based on delta statistics, which compare the relative magnitude of effects. Minitab 19 assigns the ranks of optimum parameters based on delta values, for instance, rank 1 is the highest delta value, and rank 2 is the second delta value and so on. These ranks indicate that the relative importance of each factor to the response and the mean response refers to the average value of the performance characteristic for each parameter at different levels.

Table 4.11. Main Effects for mean of GRG (Appendices 12)

Level	Welding Current [A]	Welding Voltage [B]	Wire Feed Speed [C]
1	0.5170	0.4440	**<u>0.6254</u>**
2	0.5062	0.6279	0.6139
3	**<u>0.7305</u>**	**<u>0.6819</u>**	0.5145
Delta	0.2243	0.2379	0.1109
Rank	2	1	3

As shown in table 4.11, considering the highest mean of GRG value for each parameter and the bolded and underlined values are indicated the optimal parameter setting of welding current at level 3, welding arc voltage at level 3 and wire feed speed at level 1 [A3B3C1] is an optimal parameter combination for the multiple performance characteristics. Based on the results presented in Table, welding arc voltage has the largest effect on the tensile strength of the welded joint and hardness of welded joint and HAZ.

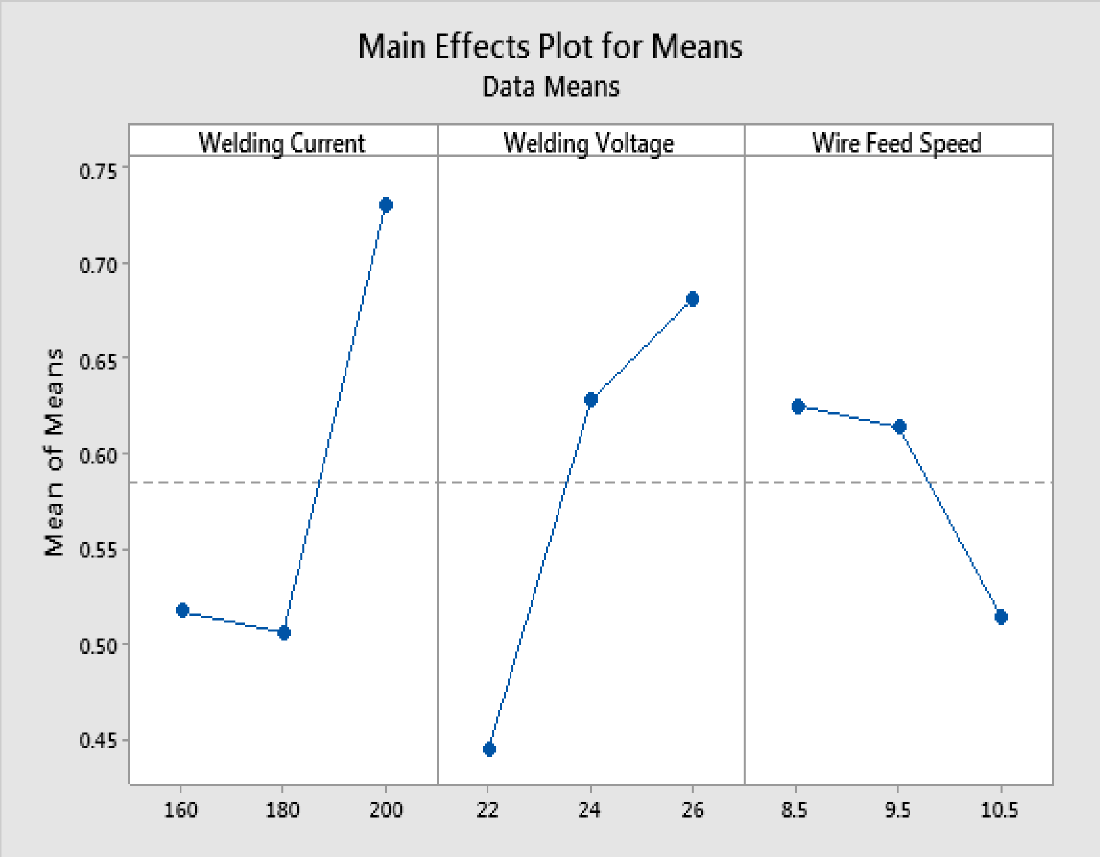


Figure 4.2. Main effects for means of gray relational grading (GRG) (Appendices 13)

As shown in the figure 4.2, in gray based-Taguchi's experiment, the mean of GRG value must be maximized. The level average in the mean response figure shows that the mean valves were maximized when the current was 200Amp, arc voltage was 26Volts and wire feed speed was 8.5 m/min. So these are the optimum welding parameters on which the highest tensile strength and hardness is obtained.

4.7. Perform Analysis of Variance (ANOVA)

The Analysis of variance (ANOVA) of the overall grey relation grade was made to investigate the influence of the design parameters on response by indicating that which parameter is significantly affected the quality characteristics. ANOVA results used to determine whether the factors are significantly related to the response data and each factor's relative importance on gray relational analysis.

If the P value for a factor becomes less than 0.05 then that factor is considered as significant factor at 95% confidence level. Statistical software with an analytical tool of ANOVA is used to determine which parameter significantly affects the performance characteristics. The results of ANOVA for the grey relational grades are listed in Table 5. It shows that the one parameters A is found to be the major factors with the selected multiple performance characteristics, because their corresponding P ratio is less than 0.05.

Table 4.12. Analysis of Variance for grey relational grade (GRG) (Appendices 14)

Source	DF	Adj SS	Adj MS	F-Value	Percentage contribution	Remark
A	2	0.095999	0.047999	7.20	38.27	Significant
B	2	0.093357	0.046678	7.00	37.04	Significant
C*	2	0.022305				
Error	2	0.004360	0.002180			
$Error_{pooled}$	4	0.026665	0.0066663		24.69	
Total	8	0.216021			100	
$F_{0.05}(2,4) = 6.94$						

S = 0.0466909, R-sq =97.98%, R-sq(adj) =91.93%, R-sq(pred) = 59.13%

* Indicates the parameter that was pooled.

A: Welding Current, B: Welding Voltage and C: Wire Feed Speed

From table 4.12, It is very clear from ANOVA that welding current (38.27%) and welding arc voltage (37.04%) has the most significant effect followed by wire feed speed. ANOVA table shows that the results are nearby related with Grey relation method.

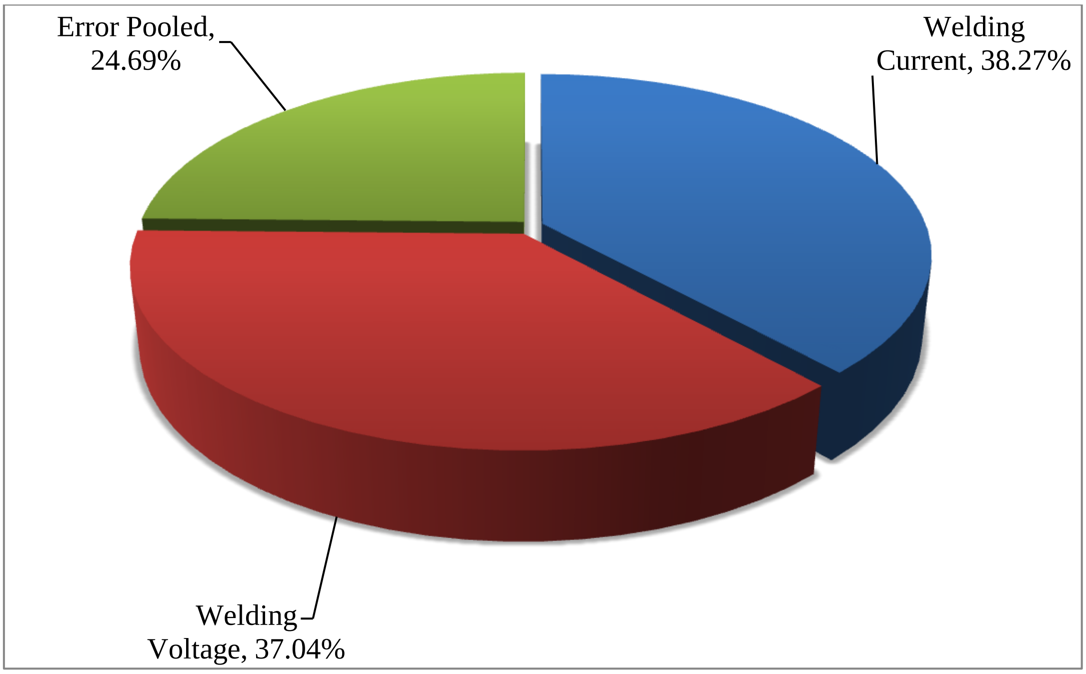


Figure 4.3. Pie chart for percentage contribution of different parameters for ANOVA

Based on to the ANOVA results, two parameter i.e. welding current and arc voltage are significant parameter because each parameter P-value is less than 0.05 and F-values are greater than the standard reading F-value (i.e $F_{0.05}$ (2,4) = 6.94). In addition, the parameter percentage of contributions is the welding currents of (38.27%) and welding voltage (37.04%) contributes. The total error pooled can be used to evaluate if an experiment possesses feasibility and sufficiency or not, since it is related to the uncertain or uncontrollable factors. The total error pooled for contribution is 24.69% as shown in figure 4.3 that indicates the proposed optimization method, as well as the outcome in this study, is proven highly acceptable.

4.8. Predicted mean value and confidence of interval

The optimal grey relational grade (μGRG) is predicted at the selected optimal setting of process parameters. The significant parameters with optimal levels are already selected as: A3 and B3. The estimated mean of the response characteristic is computed as (Ross, 1988).

$$\mu_{GRG} = \overline{T}_{GRG} + (\overline{A}_3 - \overline{T}_{GRG}) + (\overline{B}_3 + \overline{T}_{GRG})$$

Where $\overline{T}_{GRG}$ = overall mean of grey relational grade,

μ_{GRG} = predicted mean grey relational grade

A3 and B3 are the mean values of grey relational grade with parameters at optimum levels.

From table 4.10 $\overline{T}_{GRG}$= overall mean of grey relational grade **= 0.5846**. From table 4.11, A3 and B3 are the mean values of grey relational grade with parameters at optimum levels. i.e. A3 = **0.7305** and B3 = **0.6819**

$$\mu_{A3} = \overline{T}_{GRG} + (\overline{A}_3 - \overline{T}_{GRG}) + (\overline{B}_3 - \overline{T}_{GRG})$$

μ_{A3} = 0.5846 + (0.7305 – 0.5846) + (0.6819 – 0.5846)

= 0.5846 + 0.1459 + 0.0973

Hence, μGRG $_{(A3B3)}$ = **0.8278**

The predicted mean of the grey relational grade in the confirmation test is estimated by the following equation: confidence interval for the predicted mean on a confirmation run is calculated using the below equation (Kumar, 2013)

$$Cl = \sqrt{F_a\,(1, f_e)\; V_e\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]}$$

where $F\alpha; (1, f_e) = F_{0.05}; (1, 4) = 7.71$ (Appendices 11)

α = risk = 0.05,

f_e = error DOF = 4 (Table 4.13)

V_e = error variance = 0.0066663 (Table 4.13)

n_{eff} = effective number of replications

R = number of repetitions for confirmation experiment = 3

Also the effective number of replications (n_{eff}) is calculated by:

$$n_{eff} = \frac{T_n}{1 + T_s}$$

Where n_{eff} = is expressed in mathematical

T_n = Total number of experiments = 9

T_s = the sum of the total degree of freedom of significant factors/Total DOF associated with the mean (μGRG) = 4,

n_{eff} = 9/[1+4] = 9/5 = 1.8

Therefore, the calculated confident value CI is

$$\mathrm{Cl} = \sqrt{7.71 * 0.0066663 \left[\frac{1}{3} + \frac{1}{9/5}\right]} = \sqrt{7.71 * 0.0059256} = \sqrt{0.045686}$$

Cl = 0.2137

A confidence interval for the predicted mean on a confirmation run is ± 0.2137

The 95% confidence interval of the predicted optimal grey relational grade is:

[μGRG - CI] < μGRG < [μGRG + CI]

[0.8278 – 0.2137] < μGRG < [0.8278 + 0.2137]

[0.6141] < μGRG < [1.0415]

Therefore, the 95% confidence interval is 0.6141 < 0.8278 < 1.0415

At 95% of the confidence interval of the predicted GRG at optimum condition is between 0.6141 and 1.0415. Predicting value for multiple performance characteristics at optimal setting of process parameters are confirmed through experimental results as shown in Table 14.

Table 4.13 Predicted and Experimental Values at Optimal Setting

Performance Characteristics	Optimal Combination	Predicted Grey Relational Grade	Predicted Mean	Experimental Value
Tensile Strength	A3B3C1	0.8278	1521	
Hardness on FZ			25.61	
Hardness on HAZ			22.2	

4.9. Confirmation Experiment

Confirmatory test conducted at the optimal condition to verify improvement of output responses. Test result reveal that grey Taguchi method is effective to optimize Gas metal arc welding of austenitic stainless steel materials.

The confirmation test was conducted on three samples at optimal setting conditions of Gas Metal Arc Welding parameters: A3 (Welding Current of 200 Amperage) and B3 (Welding Arc Voltage of 26 Volts).

Table 4.14. Results of confirmation tests (Appendices 15 and 17)

Optimal combination	**The response of quality characteristics**					
A3B3	UTS	UTS $_{S/N}$	HRC_{FZ}	HRC $_{S/N}$	HRC $_{HAZ}$	HRC $_{S/N}$
Replication 1	1520.6	63.6403	25.00	27.9588	22.15	26.9075
Replication 2	1521	63.6426	25.60	28.1648	22.20	26.9271
Replication 3	1521	63.6426	25.61	28.1682	22.20	26.9271
Average	**1520.87**		**25.40**		**22.18**	
Mean of GRG for confirmation test = 0.7735						

Figure 4.4 Confirmation Experimental Result after Tensile and Hardness testing

If the predicted and observed GRG values of the multiple performance parameters are close to each other, the effectiveness of the optimal condition can be ensured. In order to the test, the predicted results confirmation experiments were conducted nine times at the optimum condition. The grey relational grade for the experiment is 0.7735, which is in the range of the 95% confidence interval between 0.6141 and 1.0415 and achieved hardness and tensile strength of 1520.87MPa, 25.40 HRC on FZ and 22.18 HRC on HAZ respectively. Hence, the results of the confirmatory experiment tests show that the experiment is safest.

Chapter Five

5. Conclusion and Recommendations

5.1. Conclusion

In this experimental study, grey relational analysis based on an Orthogonal array design Taguchi method was implemented to find the optimal conditions for Gas Metal Arc Welding parameters to analyze the effect of combined factors on the mechanical strength such as UTS and HR. Based on the mixed L9 orthogonal array, an experimental plan was conducted and the data taken from the experiments were analyzed using GRA. The analytical results are summarized as follows:

- The best result was obtained for the sample welded using the welding current of 200 Amp, welding Voltage of 26 Volt, and the wire feed speed of 8.5m/min. The worst result in tensile and Hardness testing was obtained for the sample welded using welding current of 180 Amp, welding Voltage of 22 Volt, and the wire feed speed of 9.5m/min.
- From the experiment and ANOVA, one can conclude that the welding current and welding voltage are significant influences the optimization of welding parameters on which the tensile strength of the weld and hardness of fusion and heat affected zone of 304L SS materials.
- Based on ANOVA results, the welding current and welding voltage have significant parameters at a 95% confidence interval. The contribution of welding current and arc voltage for tensile strength and hardness was 38.27 % and 37.04%, respectively.
- To summarize, different welding process parameters result different output response and a combination of controlled and uncontrolled process parameters provides significant results. Welding current and arc voltage parameters were observed to have a higher influence on the hardness and tensile strength of 304L SS material. Controllable factors/parameters provide a superlative result compared to uncontrolled/noise factors for welding of 304L Austenite stainless steel material using Gas Metal arc welding.

5.2. Recommendations

The use of Gas purge or back gas welding device on gas metal arc welding help to control the presence of oxidation and to have a proper penetration on weld. It is difficult to conduct a welding process on austenitic stainless steel material without gas purge. Therefore, there should be a mechanism to prepare such welding device in order to get supreme weldment result.

During base metal preparation, almost 90% of weld quality and strength is affected the proper selection of grinding disk and proper clean and position. So, special for austenitic stainless steel should be select a grinding disk that have a compatible chemical composition and properties with base material in order to sustain it characteristics up to pre-welding process.

5.3. Future Research Direction

Welding technology is undergoing rapid and continuous trial to develop more and more modified techniques that are aesthetic value, economic, and productive to enhance human day-to-day life activities. The following research gaps were identified for further investigation by interested authors may include:

- Utilization of tools like gas purge that have effects on the stainless steel base metal will improve strength of bead and control the impact of heat during the GMAW process.
- This research scenario can be extended to perform Microstructure analysis of welded authentic stainless steel by Scanning Electron Microscope and FEA.

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APPENDICES

Appendices 1: letter of professional support and cooperation for weld testing

	Institution Name የኢትዮጵያ ቴክኒካል ዩኒቨርሲቲ Ethiopian Technical University	ዶኩመንት ቁጥር/Document No. ETU/OF/GD/02	
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ጉዳዩ:- ትምህርታዊ የሙያ ድጋፍና ትብብርን ስለመጠየቅ

በባህር-ዳር ዩኒቨርሲቲ ቴክኖሎጂ ኢንስቲትዩት በኩል በቀረበው የሁለተኛ ዲግሪ ትምህርት መርሀ ግብር/ፕሮግራም በMechanical Engineering (Manufacturing Engineering) የምህንድስና ዘርፍ ትምህርታቸውን ሲከታተሉና የመመረቂያ ፁሁፍም እየሰሩ እንደሆኑ ይታወቃል፡፡

ስለሆነም አቶ አብርሃም መዘምር በOptimization of Gas Metal Arc Welding Parameters on Austenitic Stainless Steel SS304L Using Grey-Based Taguchi Method መመረቂያ ርዕስ ዙርያ ለሰሩት የብየዳ ተግባር ሙከራ የhardness and Tensile Testing አስፈላጊ በመሆኑ በእናንተ በኩል ተገቢውን ትምህርታዊና ሙያዊ ድጋፍ እንዲደረግላቸው በትህትና እንጠይቃለን፡፡

ከሠላምታ ጋር

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Welding Training Certification and Trainee Development Directorate Director

Ethiopian Technical University Welding Training & Technology centre

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0116 464309 Administrative Directorate
0118 548874 Distance and Continuing Education
0118 933128 General Director Office
0116 453334 HR
0118 548035 PR

Appendices 2: Recommended Shielding gas for different base material

Shielding Gas Recommendations

BASE MATERIAL	COMMON	SPECIALIZED	BEWARE
ALUMINUM	100% Ar	98/2 Ar/He (weld penetration > ¼" base material)	CO_2, O_2 (oxidation)
MILD STEEL	100% CO_2	75/25 to 90/10 CO_2/Ar (spray transfer)	—
CARBON STEEL	100% CO_2	75/25 to 90/10 CO_2/Ar (spray transfer)	—
LOW-ALLOY STEEL	98/2 Ar/O_2	—	—
STAINLESS STEEL	98/2 Ar/CO_2	98/2 Ar/O_2 (extra-low carbon con-tent)	—

Appendices 3: Nominal Compositions of Austenitic Stainless Steels

NOMINAL COMPOSITIONS

Type	UNS Number	Composition - Percent *							Other
		C	Mn	Si	Cr	Ni	P	S	
201	S20100	0.15	5.5-7.5	1.00	16.0-18.0	3.5-5.5	0.06	0.03	0.25 N
202	S20200	0.15	7.5-10.0	1.00	17.0-19.0	4.0-6.0	0.06	0.03	0.25 N
205	S20500	0.12-0.25	14.0-15.5	1.00	16.5-18.0	1.0-1.75	0.06	0.03	0.32-0.40 N
216	S21600	0.08	7.5-9.0	1.00	17.5-22.0	5.0-7.0	0.045	0.03	2.0-3.0 Mo; 0.25-0.5 N
301	S30100	0.15	2.00	1.00	16.0-18.0	6.0-8.0	0.045	0.03	
302	S30200	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.045	0.03	
302B	S30215	0.15	2.00	2.0-3.0	17.0-19.0	8.0-10.0	0.045	0.03	
303**	S30300	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.20	0.15 min.	0.6 Mo
303Se**	S30323	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.20	0.06	0.15 min. Se
304	S30400	0.08	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	
304H	S30409	0.04-0.10	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	
304L	S30403	0.03	2.00	1.00	18.0-20.0	8.0-12.0	0.045	0.03	
304LN	S30453	0.03	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.15 N
S30430	S30430	0.08	2.00	1.00	17.0-19.0	8.0-10.0	0.045	0.03	3.0-4.0 Cu
304N	S30451	0.08	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.16 N
304HN	S30452	0.04-0.10	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.16 N
305	S30500	0.12	2.00	1.00	17.0-19.0	10.5-13.0	0.045	0.03	
308	S30800	0.08	2.00	1.00	19.0-21.0	10.0-12.0	0.045	0.03	
308L		0.03	2.00	1.00	19.0-21.0	10.0-12.0	0.045	0.03	
309	S30900	0.20	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	
309S	S30908	0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	
309S Cb	S30940	0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	8 x %C - Nb(Cb)
309 Cb + Ta		0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	8 x %C (Nb(Cb) + Ta)
310	S31000	0.25	2.00	1.50	24.0-26.0	19.0-22.0	0.045	0.03	
310S	S31008	0.08	2.00	1.50	24.0-26.0	19.0-22.0	0.045	0.03	
312		0.15	2.00	1.00	30.0 nom.	9.0 nom.	0.045	0.03	
254SMo	S31254	0.020	1.00	0.80	19.5-20.5	17.50-18.5	0.03	0.010	6.00-6.50Mo; 0.18-0.22N; Cu=0.5-1.00
314	S31400	0.25	2.00	1.5-3.0	23.0-26.0	19.0-22.0	0.045	0.03	
316	S31600	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316F**	S31620	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.20	0.10 min.	1.75-2.5 Mo
316H	S31609	0.04-0.10	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316L	S31603	0.03	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316LN	S31653	0.03	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo; 0.10-0.30 N
316N	S31651	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo; 0.10-0.16 N
317	S31700	0.08	2.00	1.00	18.0-20.0	11.0-15.0	0.045	0.03	3.0-4.0 Mo
317L	S31703	0.03	2.00	1.00	18.0-20.0	11.0-15.0	0.045	0.03	3.0-4.0 Mo
317M	S31725	0.03	2.00	1.00	18.0-20.0	12.0-16.0	0.045	0.03	4.0-5.0 Mo
321	S32100	0.08	2.00	1.00	17.0-19.0	9.0-12.0	0.045	0.03	5 x %C min. Ti
321H	S32109	0.04-0.10	2.00	1.00	17.0-19.0	9.0-12.0	0.045	0.03	5 x %C min. Ti
329	S32900	0.10	2.00	1.00	25.0-30.0	3.0-6.0	0.045	0.03	1.0-2.0 Mo
330	N08330	0.08	2.00	0.75-1.5	17.0-20.0	34.0-37.0	0.04	0.03	
AL6-XN	N80367	0.030	2.00	1.00	20.0-22.0	23.5-25.5	0.04	0.03	6.00-7.00Mo; 0.18-0.25N; Cu=0.75
330HC		0.40	1.50	1.25	19.0 nom.	35.0 nom.			
332		0.04	1.00	0.50	21.5 nom.	32.0 nom.	0.045	0.03	
347	S34700	0.08	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	10 x %C min. Nb(Cb) +Ta
347H	S34709	0.04-0.10	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	10 x %C min. Nb(Cb) + Ta
348	S34800	0.08	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	0.2 Cu; 10 x %C min. Nb(Cb) + Ta(c)
348H	S34809	0.04-0.10	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	0.2 Cu; 10 x %C min. Nb(Cb) + Ta
384	S38400	0.08	2.00	1.00	15.0-17.0	17.0-19.0	0.045	0.03	
Nitronic 32	S24100	0.10	12.0	0.50	18.0	1.6			0.35 N
Nitronic 33	S24000	0.06	13.0	0.5	18.0	3.0			0.30 N
Nitronic 40	S21900	0.08	8.0-10.0	1.00	18.0-20.0	5.0-7.0	0.06	0.03	0.15-0.40 N
Nitronic 50	S20910	0.06	4.0-6.0	1.00	20.5-23.5	11.5-13.5	0.04	0.03	1.5-3.0 Mo; 0.2-0.4 N; 0.1-0.3 Cb; 0.1-0.3 V
Nitronic 60	S21800	0.10	7.0-9.0	3.5-4.5	16.0-18.0	8.0-9.0	0.04	0.03	1.5-3.0 Mo; 0.2-0.4 N;

* Single values are maximum. ** These values are general considered to be unweldable.

Appendices 4: Physical Properties of Groups of Stainless Steels

NOMINAL PHYSICAL PROPERTIES

Property	Austenitic Types	Ferritic Types	Martensitic Types	Precipitation Hardening Types
Elastic Modulus; 10^6 psi	28.3	29.0	29.0	29.0
GPa	195	200	200	200
Density; lb./in.^{3}	0.29	0.28	0.28	0.28
g/cm^3	8.0	7.8	7.8	7.8
Coefficiency of Thermal Expansion: µin./in. °F	9.2	5.8	5.7	6.0
µm/m °C	16.6	10.4	10.3	10.8
Thermal Conduct.; Btu/hrft. °F	9.1	14.5	14.0	12.9
w/mk	15.7	25.1	24.2	22.3
Specific Heat; Btu/lb. °F	0.12	0.11	0.11	0.11
J/k °K	500	460	460	460
Electrical Resistivity, µΩcm	74	61	61	80
Magnetic Permeability	1.02	600-1,100	700-1000	95
Melting Range °F	2,500-2,650	2,600-2,790	2,600-2,790	2,560-2,625
°C	1,375-1,450	1,425-1,530	1,425-1,530	1,400-1,440

Appendices 5: Mechanical Properties of Austenitic Stainless Steels

SS 304L

HPM HAMILTON PRECISION METALS

www.hpmetals.com

SS 304L (UNS S30403)

SS 304L is an austenitic Chromium-Nickel stainless steel offering the optimum combination of corrosion resistance, strength, and ductility. These attributes make it a favorite for many mechanical switch components. The low carbon content reduces susceptibility to carbide precipitation during welding.

GENERAL INFORMATION

The alloy is readily formed in the annealed temper. SS 304L may be joined by all commonly used brazing and welding methods including oxyacetylene. The corrosive resistance to acids is generally very good with the exception of halogen acids.

AVAILABILITY

SS 304L is available from Hamilton Precision Metals as strip product in thicknesses from 0.0005" to 0.050" (0.0127 mm to 1.27 mm) in widths up to 12.0" (304.8 mm). It is also available in foil as thin as 0.000200" (0.00508 mm) in widths of 4.0" (101.6 mm) maximum. The material conforms to ASTM A240, ASTM A666, FED QQ-S-766, MIL-S-4043, UNS S30403.

Technical Data

TYPICAL MECHANICAL PROPERTIES[1]

	ANNEALED	COLD ROLLED
Ultimate Tensile Strength	100,000 PSI	195,000 PSI
Yield Strength (0.2% Offset)	40,000 PSI	175,000 PSI
Elongation in 2" *	40%	2%
Modulus of Elasticity (Tension)	29×10^6 PSI	25×10^6 PSI
Poisson's Ratio	0.29	-

* The measured elongation will be less as thickness decreases to 0.002" and less.

[1] These values may be adjusted by control of process variables – consult HPM for desired values.

NOMINAL COMPOSITION

Chromium	18.2%
Nickel	8.5%
Manganese	1.6%
Silicon	0.5%
Carbon	0.015%
Iron	Balance

PHYSICAL PROPERTIES[2]

Density	0.284 lbs./cu.in.
Melting Point (Approx.)	1400°C
Electrical Resistivity @ R.T.	72 Microhm · cm
Thermal Expansion Coefficient (0° to 100°C)	17.3×10^{-6}/°C
Thermal Conductivity @ 100°C	16.3 W/m · K
Magnetic Attraction Annealed Cold Rolled	 None Slight
Magnetic Permeability (Annealed: H = 200 oersteds)	1.02 Max.

[2] Typical values to guide alloy selection but are not a guarantee of minimum or maximum.

Disclaimer: The information contained within this data sheet is for guidance only and is not intended for warranty of individual application - express or implied.

AMETEK® SPECIALTY METAL PRODUCTS

Appendices 6: Filler metal electrodes are classified based on variations in their chemical compositions

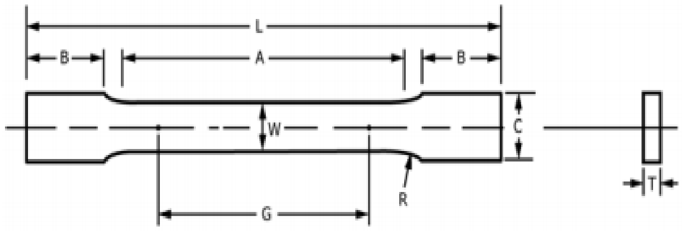
AWS Chemical Composition Requirements of Solid Stainless Steel Electrodes (%)

AWS Classification	Carbon	Chromium	Nickel	Molybdenum	Manganese	Silicon	Phosphorous	Copper
ER308	0.08 Max	19.5–22.0	9.0–11.0	0.75 Max	1.0–2.5	0.30–0.65	0.03 Max	0.75 Max
ER308H	0.04–0.08	19.5–22.0	9.0–11.0	0.50 Max	1.0–2.5	0.20–0.65	0.03 Max	0.75 Max
ER308L	0.03 Max	19.5–22.0	9.0–11.0	0.75 Max	1.0–2.5	0.30–0.65	0.03 Max	0.75 Max
ER308LSi	0.03 Max	19.5–22.0	9.0–11.0	0.75 Max	1.0–2.5	0.65–1.00	0.03 Max	0.75 Max
ER309	0.12 Max	23.0–25.0	12.0–14.0	0.75 Max	1.0–2.5	0.30–0.65	0.03 Max	0.75 Max
ER309L	0.03 Max	23.0–25.0	12.0–14.0	0.75 Max	1.0–2.5	0.20–0.65	0.03 Max	0.75 Max
ER309LSi	0.03 Max	23.0–25.0	12.0–14.0	0.75 Max	1.0–2.5	0.65–1.00	0.03 Max	0.75 Max
ER316	0.08 Max	18.0–20.0	11.0–14.0	2.00–3.00	1.0–2.5	0.30–0.65	0.03 Max	0.75 Max
ER316H	0.04–0.08	18.0–20.0	11.0–14.0	2.00–3.00	1.0–2.5	0.30–0.65	0.03 Max	0.75 Max
ER316L	0.03 Max	18.0–20.0	11.0–14.0	2.00–3.00	1.0–2.5	0.30–0.60	0.03 Max	0.75 Max
ER316LSi	0.08 Max	18.0–20.0	11.0–14.0	2.00–3.00	1.0–2.5	0.65–1.00	0.03 Max	0.75 Max
ER347	0.08 Max	19.0–21.5	9.0–11.0	0.75 Max	1.0–2.5	0.30–0.65	0.03 Max	0.75 Max
ER410	0.12 Max	11.5–13.5	0.60 Max	0.75 Max	0.60 Max	0.50 Max	0.03 Max	0.75 Max

TABLE 4-12

Note: Ni = Nickel added—high temperature strength, corrosion resistance, and added ductility

Appendices 7: Rectangular Tension Test Specimens



Dimensions			
	Standard Specimens		Subsize Specimen
	Plate-Type, 40 mm [1.500 in.] Wide	Sheet-Type, 12.5 mm [0.500 in.] Wide	6 mm [0.250 in.] Wide
	mm [in.]	mm [in.]	mm [in.]
G—Gauge length (Note 1 and Note 2)	200.0 ± 0.2 [8.00 ± 0.01]	50.0 ± 0.1 [2.000 ± 0.005]	25.0 ± 0.1 [1.000 ± 0.003]
W—Width (Note 3 and Note 4)	40.0 ± 2.0 [1.500 ± 0.125, -0.250]	12.5 ± 0.2 [0.500 ± 0.010]	6.0 ± 0.1 [0.250 ± 0.005]
T—Thickness (Note 5)		thickness of material	
R—Radius of fillet, min (Note 6)	25 [1]	12.5 [0.500]	6 [0.250]
L—Overall length, min (Note 2, Note 7, and Note 8)	450 [18]	200 [8]	100 [4]
A—Length of reduced parallel section, min	225 [9]	57 [2.25]	32 [1.25]
B—Length of grip section, min (Note 9)	75 [3]	50 [2]	30 [1.25]
C—Width of grip section, approximate (Note 4 and Note 9)	50 [2]	20 [0.750]	10 [0.375]

NOTE 1—For the 40 mm [1.500 in.] wide specimen, punch marks for measuring elongation after fracture shall be made on the flat or on the edge of the specimen and within the reduced parallel section. Either a set of nine or more punch marks 25 mm [1 in.] apart, or one or more pairs of punch marks 200 mm [8 in.] apart may be used.

NOTE 2—When elongation measurements of 40 mm [1.500 in.] wide specimens are not required, a minimum length of reduced parallel section (*A*) of 75 mm [2.25 in.] may be used with all other dimensions similar to those of the plate-type specimen.

NOTE 3—For the three sizes of specimens, the ends of the reduced parallel section shall not differ in width by more than 0.10, 0.05 or 0.02 mm [0.004, 0.002 or 0.001 in.], respectively. Also, there may be a gradual decrease in width from the ends to the center, but the width at each end shall not be more than 1 % larger than the width at the center.

NOTE 4—For each of the three sizes of specimens, narrower widths (*W* and *C*) may be used when necessary. In such cases the width of the reduced parallel section should be as large as the width of the material being tested permits; however, unless stated specifically, the requirements for elongation in a product specification shall not apply when these narrower specimens are used.

NOTE 5—The dimension *T* is the thickness of the test specimen as provided for in the applicable material specifications. Minimum thickness of 40 mm [1.500 in.] wide specimens shall be 5 mm [0.188 in.]. Maximum thickness of 12.5 and 6 mm [0.500 and 0.250 in.] wide specimens shall be 19 and 6 mm [0.750 and 0.250 in.], respectively.

NOTE 6—For the 40 mm [1.500 in.] wide specimen, a 13 mm [0.500 in.] minimum radius at the ends of the reduced parallel section is permitted for steel specimens under 690 MPa [100 000 psi] in tensile strength when a profile cutter is used to machine the reduced section.

NOTE 7—The dimension shown is suggested as a minimum. In determining the minimum length, the grips must not extend in to the transition section between Dimensions *A* and *B*, see Note 9.

NOTE 8—To aid in obtaining axial force application during testing of 6-mm [0.250-in.] wide specimens, the overall length should be as large as the material will permit, up to 200 mm [8.00 in.].

NOTE 9—It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips. If the thickness of 12.5 mm [0.500-in.] wide specimens is over 10 mm [0.375 in.], longer grips and correspondingly longer grip sections of the specimen may be necessary to prevent failure in the grip section.

NOTE 10—For the three sizes of specimens, the ends of the specimen shall be symmetrical in width with the center line of the reduced parallel section within 2.5, 1.25 and 0.13 mm [0.10, 0.05 and 0.005 in.], respectively. However, for referee testing and when required by product specifications, the ends of the 12.5 mm [0.500 in.] wide specimen shall be symmetrical within 0.2 mm [0.01 in.].

NOTE 11—For each specimen type, the radii of all fillets shall be equal to each other within a tolerance of 1.25 mm [0.05 in.], and the centers of curvature of the two fillets at a particular end shall be located across from each other (on a line perpendicular to the centerline) within a tolerance of 2.5 mm [0.10 in.].

NOTE 12—Specimens with sides parallel throughout their length are permitted, except for referee testing, provided: *(a)* the above tolerances are used; *(b)* an adequate number of marks are provided for determination of elongation; and *(c)* when yield strength is determined, a suitable extensometer is used. If the fracture occurs at a distance of less than 2 W from the edge of the gripping device, the tensile properties determined may not be representative of the material. In acceptance testing, if the properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the test and retest.

Appendices 8: Rockwell hardness scale of the machine

TABLE 1 Rockwell Hardness Scales

Scale Symbol	Indenter	Total Test Force, kgf	Dial Figures	Typical Applications of Scales
B	1⁄16-in. (1.588-mm) ball	100	red	Copper alloys, soft steels, aluminum alloys, malleable iron, etc.
C	diamond	150	black	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case hardened steel, and other materials harder than B100.
A	diamond	60	black	Cemented carbides, thin steel, and shallow case-hardened steel.
D	diamond	100	black	Thin steel and medium case hardened steel, and pearlitic malleable iron.
E	⅛-in. (3.175-mm) ball	100	red	Cast iron, aluminum and magnesium alloys, bearing metals.
F	1⁄16-in. (1.588-mm) ball	60	red	Annealed copper alloys, thin soft sheet metals.
G	1⁄16-in. (1.588-mm) ball	150	red	Malleable irons, copper-nickel-zinc and cupro-nickel alloys. Upper limit G92 to avoid possible flattening of ball.
H	⅛-in. (3.175-mm) ball	60	red	Aluminum, zinc, lead.
K	⅛-in. (3.175-mm) ball	150	red	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect.
L	¼-in. (6.350-mm) ball	60	red	
M	¼-in. (6.350-mm) ball	100	red	
P	¼-in. (6.350-mm) ball	150	red	
R	½-in. (12.70-mm) ball	60	red	
S	½-in. (12.70-mm) ball	100	red	
V	½-in. (12.70-mm) ball	150	red	

Appendices 9: Experimental HRC value on fusion zone and Heat affected zone

Ethiopian Technical University
Welding Training and Technology Center

Exp. No	Test Zone	Indentation Trial (HRC)											Remark
		1	2	3	4	5	6	7	8	9	10	Average	
Exp. 1	Fusion zone	26.1	17.3	24.0	35.7	25.1	18.6	16.1	21.7	18.2	15.9	**21.87**	
	Heat Affected zone	17.8	19.9	20.6	17.6	19.0	17.1	18.7	21.1	17.5	20.8	**19.01**	
Exp. 2	Fusion zone	20.8	29.5	19.1	17.3	18.8	22.9	18.6	19.7	19.1	21.4	**20.72**	
	Heat Affected zone	21.7	20.6	21.3	19.4	24.4	21.4	23.8	20.9	23.6	21.0	**21.81**	
Exp. 3	Fusion zone	21.1	27.7	24.6	20.1	20.1	19.7	21.0	26.7	19.9	24.6	**22.55**	
	Heat Affected zone	15.8	21.2	26.0	13.6	20.1	11.4	17.0	12.9	20.9	24.5	**18.34**	
Exp. 4	Fusion zone	17.3	17.5	18.7	19.2	20.4	28.2	18.6	10.8	31.4	22.8	**20.49**	
	Heat Affected zone	25.4	31.6	20.9	22.7	16.1	19.2	21.2	24.5	29.2	16.0	**22.68**	
Exp. 5	Fusion zone	22.6	17.6	16.0	18.5	26.4	30.0	13.5	20.8	14.6	12.2	**19.22**	
	Heat Affected zone	19.5	22.8	18.5	11.1	19.5	16.8	21.8	23.0	33.6	15.5	**20.21**	
Exp. 6	Fusion zone	16.3	12.0	19.8	11.2	23.6	23.8	31.1	29.2	23.7	22.4	**21.31**	
	Heat Affected zone	23.3	15.1	19.7	25.4	25.7	19.3	22.9	22.2	22.1	24.3	**22.00**	
Exp. 7	Fusion zone	22.3	31.8	34.1	29.4	15.6	15.3	38.4	14.1	23.8	15.0	**23.98**	
	Heat Affected zone	22.0	24.9	19.8	20.0	25.6	27.3	24.7	15.6	19.4	18.4	**21.77**	
Exp. 8	Fusion zone	19.4	17.2	32.2	18.8	27.9	28.3	17.6	33.1	17.3	27.2	**23.90**	
	Heat Affected zone	29.9	31.4	25.6	26.1	19.7	15.2	24.0	30.7	33.3	31.4	**26.77**	
Exp. 9	Fusion zone	38.2	25.4	38.0	20.5	22.7	27.2	30.1	23.2	16.4	14.4	**25.61**	
	Heat Affected zone	22.6	19.4	15.8	23.2	27.2	20.6	17.3	33.3	15.4	27.2	**22.20**	

Prepared by:- Abrham M

Approved By:-

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Appendices 10: Experimental Ultimate Tensile Strength (UTS)

Ethiopian Technical University
Welding Training and Technology Center

Exp. No	Tensile Test specimen Trial (MPa)			Ultimate Tensile Strength (MPa)
Exp. 1	T11	T12	T13	
	865	1321	1271	**1152.33**
Exp. 2	T21	T22	T23	
	1324	1456	1486	**1422.00**
Exp. 3	T31	T32	T33	
	1350	1421	1414	**1395.00**
Exp. 4	T41	T42	T43	
	1013	934	938	**961.67**
Exp. 5	T51	T52	T53	
	1053	1623	1531	**1402.33**
Exp. 6	T61	T62	T63	
	1422	1513	1485	**1473.33**
Exp. 7	T71	T72	T73	
	1224	1012	1059	**1098.33**
Exp. 8	T81	T82	T83	
	1476	1492	1432	**1466.67**
Exp. 9	T91	T92	T93	
	1578	1522	1463	**1521.00**

Prepared by:- Abrham M **Approved By:-**

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Appendices 11: Table of critical values for the F distribution

Table of critical values for the F distribution (for use with ANOVA):

How to use this table:

There are two tables here. The first one gives critical values of F at the p = 0.05 level of significance.
The second table gives critical values of F at the p = 0.01 level of significance.
1. Obtain your F-ratio. This has (x,y) degrees of freedom associated with it.
2. Go along x columns, and down y rows. The point of intersection is your critical F-ratio.
3. If your obtained value of F is equal to or larger than this critical F-value, then your result is significant at that level of probability.
An example: I obtain an F ratio of 3.96 with (2, 24) degrees of freedom.
I go along 2 columns and down 24 rows. The critical value of F is 3.40. My obtained F-ratio is larger than this, and so I conclude that my obtained F-ratio is likely to occur by chance with a p<.05.

Critical values of F for the 0.05 significance level:

	1	2	3	4	5	6	7	8	9	10
1	161.45	199.50	215.71	224.58	230.16	233.99	236.77	238.88	240.54	241.88
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.39	19.40
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14
10	4.97	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98
11	4.84	3.98	3.59	3.36	3.20	3.10	3.01	2.95	2.90	2.85
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49
17	4.45	3.59	3.20	2.97	2.81	2.70	2.61	2.55	2.49	2.45
18	4.41	3.56	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35
21	4.33	3.47	3.07	2.84	2.69	2.57	2.49	2.42	2.37	2.32
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.38	2.32	2.28
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.26
25	4.24	3.39	2.99	2.76	2.60	2.49	2.41	2.34	2.28	2.24
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.17
31	4.16	3.31	2.91	2.68	2.52	2.41	2.32	2.26	2.20	2.15
32	4.15	3.30	2.90	2.67	2.51	2.40	2.31	2.24	2.19	2.14
33	4.14	3.29	2.89	2.66	2.50	2.39	2.30	2.24	2.18	2.13
34	4.13	3.28	2.88	2.65	2.49	2.38	2.29	2.23	2.17	2.12
35	4.12	3.27	2.87	2.64	2.49	2.37	2.29	2.22	2.16	2.11

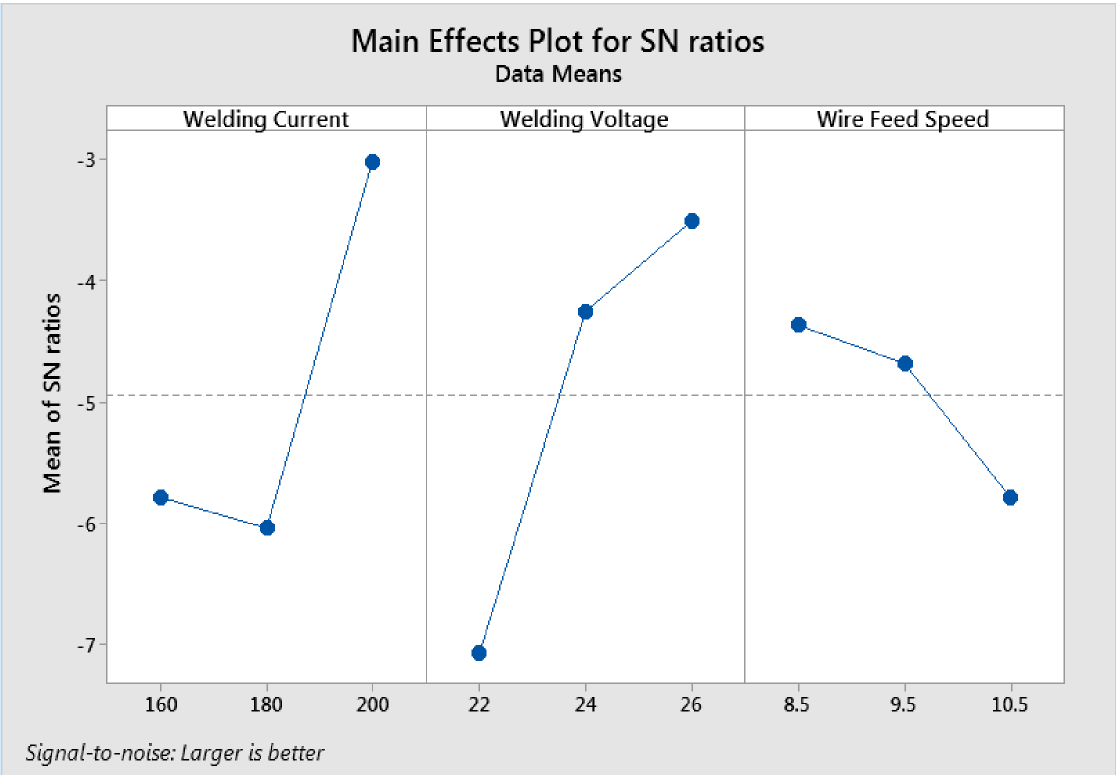
36	4.11	3.26	2.87	2.63	2.48	2.36	2.28	2.21	2.15	2.11
37	4.11	3.25	2.86	2.63	2.47	2.36	2.27	2.20	2.15	2.10
38	4.10	3.25	2.85	2.62	2.46	2.35	2.26	2.19	2.14	2.09
39	4.09	3.24	2.85	2.61	2.46	2.34	2.26	2.19	2.13	2.08
40	4.09	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08
41	4.08	3.23	2.83	2.60	2.44	2.33	2.24	2.17	2.12	2.07
42	4.07	3.22	2.83	2.59	2.44	2.32	2.24	2.17	2.11	2.07
43	4.07	3.21	2.82	2.59	2.43	2.32	2.23	2.16	2.11	2.06
44	4.06	3.21	2.82	2.58	2.43	2.31	2.23	2.16	2.10	2.05
45	4.06	3.20	2.81	2.58	2.42	2.31	2.22	2.15	2.10	2.05
46	4.05	3.20	2.81	2.57	2.42	2.30	2.22	2.15	2.09	2.04
47	4.05	3.20	2.80	2.57	2.41	2.30	2.21	2.14	2.09	2.04
48	4.04	3.19	2.80	2.57	2.41	2.30	2.21	2.14	2.08	2.04
49	4.04	3.19	2.79	2.56	2.40	2.29	2.20	2.13	2.08	2.03
50	4.03	3.18	2.79	2.56	2.40	2.29	2.20	2.13	2.07	2.03
51	4.03	3.18	2.79	2.55	2.40	2.28	2.20	2.13	2.07	2.02
52	4.03	3.18	2.78	2.55	2.39	2.28	2.19	2.12	2.07	2.02
53	4.02	3.17	2.78	2.55	2.39	2.28	2.19	2.12	2.06	2.02
54	4.02	3.17	2.78	2.54	2.39	2.27	2.19	2.12	2.06	2.01
55	4.02	3.17	2.77	2.54	2.38	2.27	2.18	2.11	2.06	2.01
56	4.01	3.16	2.77	2.54	2.38	2.27	2.18	2.11	2.05	2.01
57	4.01	3.16	2.77	2.53	2.38	2.26	2.18	2.11	2.05	2.00
58	4.01	3.16	2.76	2.53	2.37	2.26	2.17	2.10	2.05	2.00
59	4.00	3.15	2.76	2.53	2.37	2.26	2.17	2.10	2.04	2.00
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99
61	4.00	3.15	2.76	2.52	2.37	2.25	2.16	2.09	2.04	1.99
62	4.00	3.15	2.75	2.52	2.36	2.25	2.16	2.09	2.04	1.99
63	3.99	3.14	2.75	2.52	2.36	2.25	2.16	2.09	2.03	1.99
64	3.99	3.14	2.75	2.52	2.36	2.24	2.16	2.09	2.03	1.98
65	3.99	3.14	2.75	2.51	2.36	2.24	2.15	2.08	2.03	1.98
66	3.99	3.14	2.74	2.51	2.35	2.24	2.15	2.08	2.03	1.98
67	3.98	3.13	2.74	2.51	2.35	2.24	2.15	2.08	2.02	1.98
68	3.98	3.13	2.74	2.51	2.35	2.24	2.15	2.08	2.02	1.97
69	3.98	3.13	2.74	2.51	2.35	2.23	2.15	2.08	2.02	1.97
70	3.98	3.13	2.74	2.50	2.35	2.23	2.14	2.07	2.02	1.97
71	3.98	3.13	2.73	2.50	2.34	2.23	2.14	2.07	2.02	1.97
72	3.97	3.12	2.73	2.50	2.34	2.23	2.14	2.07	2.01	1.97
73	3.97	3.12	2.73	2.50	2.34	2.23	2.14	2.07	2.01	1.96
74	3.97	3.12	2.73	2.50	2.34	2.22	2.14	2.07	2.01	1.96
75	3.97	3.12	2.73	2.49	2.34	2.22	2.13	2.06	2.01	1.96
76	3.97	3.12	2.73	2.49	2.34	2.22	2.13	2.06	2.01	1.96
77	3.97	3.12	2.72	2.49	2.33	2.22	2.13	2.06	2.00	1.96
78	3.96	3.11	2.72	2.49	2.33	2.22	2.13	2.06	2.00	1.95
79	3.96	3.11	2.72	2.49	2.33	2.22	2.13	2.06	2.00	1.95
80	3.96	3.11	2.72	2.49	2.33	2.21	2.13	2.06	2.00	1.95
81	3.96	3.11	2.72	2.48	2.33	2.21	2.13	2.06	2.00	1.95
82	3.96	3.11	2.72	2.48	2.33	2.21	2.12	2.05	2.00	1.95
83	3.96	3.11	2.72	2.48	2.32	2.21	2.12	2.05	2.00	1.95
84	3.96	3.11	2.71	2.48	2.32	2.21	2.12	2.05	1.99	1.95
85	3.95	3.10	2.71	2.48	2.32	2.21	2.12	2.05	1.99	1.94

Appendices 12: Main Effects of GRG Table

Response Table for Means

Level	Welding Current	Welding Voltage	Wire Feed Speed
1	0.5170	0.4440	0.6254
2	0.5062	0.6279	0.6139
3	0.7305	0.6819	0.5145
Delta	0.2243	0.2379	0.1109
Rank	2	1	3

Appendices 13: Mean effect of GRG and S/N ratio plots



Appendices 14: ANOVA Table for GRG

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Welding Current	2	0.095999	0.047999	22.02	0.043
Welding Voltage	2	0.093357	0.046678	21.41	0.045
Wire Feed Speed	2	0.022305	0.011153	5.12	0.164
Error	2	0.004360	0.002180		
Total	8	0.216021			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0466909	97.98%	91.93%	59.13%

Appendices 15: Eigen analysis of the correlation matrix and vectors

Eigenanalysis of the Correlation Matrix

Eigenvalue	1.7281	0.7642	0.5077
Proportion	0.576	0.255	0.169
Cumulative	0.576	0.831	1.000

Eigenvectors

Variable	PC1	PC2	PC3
GRC UTS	0.608	-0.399	0.686
HRC (FZ)_1	0.620	-0.301	-0.725
HRC (HAZ)_1	0.496	0.866	0.064

Appendices 16: Confirmation test results of hardness test

Ethiopian Technical University

Welding Training and Technology Center

Confirmation test results of hardness test

Exp. No	Test Zone	Indentation Trial (HRC)											Remark
		1	2	3	4	5	6	7	8	9	10	Average	
Exp. 1	Fusion zone	21.81	22.01	23.21	23.71	24.91	32.71	23.11	15.31	35.91	27.31	**25.00**	
	Heat Affected zone	24.4	28.6	20.9	22.7	16.3	19.2	21.2	24.5	27.2	16.5	**22.15**	
Exp. 3	Fusion zone	20.3	20.2	23.6	22.2	27.6	27.8	31.1	29.2	27.7	26.4	**25.61**	
	Heat Affected zone	23.3	17.3	19.7	25.4	25.6	19.3	22.8	22.2	22.1	24.3	**22.20**	
Exp. 3	Fusion zone	38.2	25.4	38	20.5	22.7	27.2	30.1	23.2	16.4	14.4	**25.61**	
	Heat Affected zone	22.6	19.4	15.8	23.2	27.2	20.6	17.3	33.3	15.4	27.2	**22.2**	

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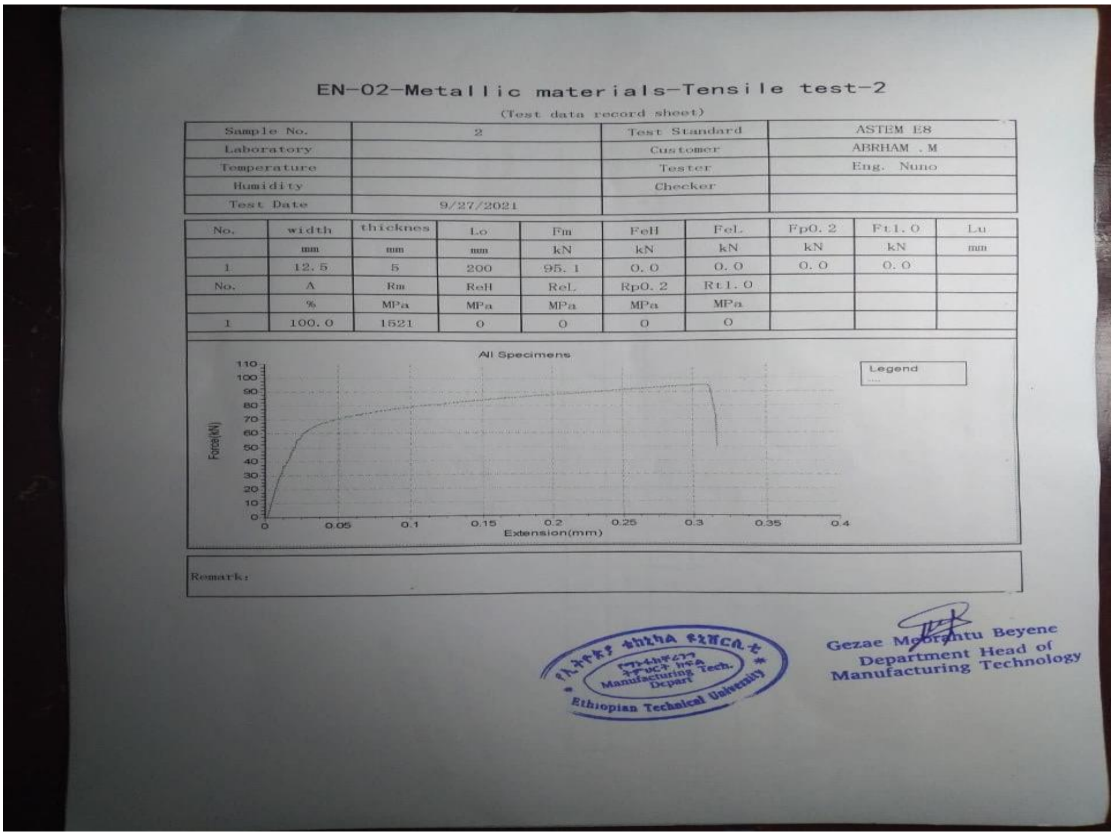
Appendices 17: Confirmation test results of tensile strength test

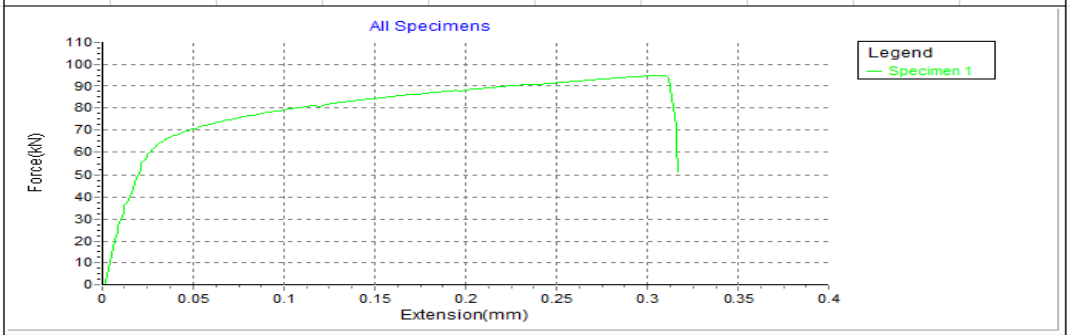


EN-02-Metallic materials-Tensile test-2

(Test data record sheet)

Sample No.	2	Test Standard	ASTEM E8
Laboratory		Customer	ABRHAM . M
Temperature		Tester	Eng. Nuno
Humidity		Checker	
Test Date	9/27/2021		

No.	width	thicknes	Lo	Fm	FeH	FeL	Fp0.2	Ft1.0	Lu
	mm	mm	mm	kN	kN	kN	kN	kN	mm
1	12.5	5	200	95.1	0.0	0.0	0.0	0.0	
No.	A	Rm	ReH	ReL	Rp0.2	Rt1.0			
	%	MPa	MPa	MPa	MPa	MPa			
1	100.0	1521	0	0	0	0			



Remark: