COMPARATIVE STUDY OF GAS METAL ARC WELDING (GMAW) AND GAS TUNGSTEN ARC WELDING (GTAW) FOR ALUMINIUM ALLOY 3003-H2 USING TAGUCHI METHOD

Thesis

Submitted to the

G. B. Pant University of Agriculture & Technology,
Pantnagar - 263145, (U. S. Nagar), Uttarakhand, INDIA

By

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M. Tech. (Mechanical Engineering)

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF

Doctor of Philosophy
(Production Engineering)

August, 2018

ACKNOWLEDGEMENT

I feel great pleasure to evince my profound sense of veneration and gratitude to my advisor Dr. R. S. Jadoun, Professor and Head, Department of Industrial and production Engineering for this relentless supervision, keen interest, ever encouraging inspiration, constructive criticism and valuable suggestion in every step of this research work, during the course of investigation to the final preparation of the manuscript. It was a great pleasure to study under the guidance of such a person with great zeal, enthusiasm and deviation to subject.

First to all, I express profound sense of obligation to almighty God for showing immense blessings upon me due to which I could accomplish this academic task words fail to express the noble sacrifice of my parents who brought me to this position.

Words in my lexicon fails to elucidate my profound sense of veneration and ineptness members of my advisory Committee Dr. Ajay, Associate Professor and Dr. Arun Kumar Chaudhary, Assistant Professor, Department of Industrial and Production Engineering and as well as for his meticulous guidance, scientific approach and indefatigable attitude during the course of my Ph.D. Research work which bore the fruit in the form of this dissertation.

I express my deepest gratitude and veneration to the esteemed member of my Advisory Committee, Dr. Anadi Misra, Professor Department of Mechanical Engineering, for their valuable suggestions and encouragement at various stages of the investigation and thesis writing.

I am unable to express my gratitude in words to Dr. Rajiv Suman, Assistant Professor, Department of Industrial and Production Engineering and Mr. Manish Tewari, Assistant Professor, IPED, who graciously provided me an opportunity to drive advantage of their meticulous guidance, prolific discussion, and outstanding cooperation during the entire course of investigation and construction of this manuscript.

I extended my gratefulness to the Dean, College of Technology, Dean, Post Graduate Studies for providing the necessary facilities during the period of investigation. With a sense of gratitude and great pleasure, I acknowledge the wholehearted cooperation extended by all teaching and non teaching members of the department of industrial and production engineering. My sincere regards goes to TEQIP-II cell, College of Technology for providing me financial aid during the course of my Ph.D. degree programme.

I wish to express my heartfelt thanks to my colleagues and batch mates. I wish to express my heartfelt thanks to my seniors also. Last but not the least; i would like to convey my thanks to all beloved juniors for their love and respect. Special thanks are due to my family members for his helping hand. Words would never be able to fathom the depth of feelings for my revered parents for their constant showering me with blessings.

This list is obviously incomplete, but let me submit that the omissions are inadvertent and once again I record my deep felt gratitude to all those who have cooperated, either directly or indirectly, with me in this endeavour.

Pantnagar
August, 2018

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CERTIFICATE

This is to certify that the thesis entitled **"Comparative Study of Gas Metal Arc Welding (GMAW) and Gas Tungsten Arc Welding (GTAW) For Aluminium Alloy 3003-H2 Using Taguchi Method"** submitted in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** with major in **Production Engineering** and with minor in **Mechanical Engineering** of the College of Post-Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of bonafide research carried out by **Mr. Ram Gopal, Id. No. 39340**, under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation and source of literature have been duly acknowledged.

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ABBREVIATIONS

Abbreviation	Descriptions
GMAW	Gas Metal Arc Welding
MIG	Metal Inert Gas
GTAW	Gas Tungsten Arc Welding
TIG	Tungsten Inert Gas
UTM	Universal Testing Machine
UTS	Ultimate Tensile Strength
ANOVA	Analysis Of Variance
S/N	Signal to Noise
Seq SS	Sequential sum of square
Adj SS	Adjusted sum of square
Adj MS	Adjusted mean sum of square
CF	Correction factor
CI_{CE}	Confidence interval for the confirmation experiments
CI_{POP}	Confidence interval for the population
HB	Higher-is-Better
LB	Lower-is-Better
NB	Nominal-is-Better
SS	Sum of square
MS	Mean of square (Variance)
MSD	Mean square deviation
V_e	Error of the variance
n	Number of units in a given sample
N	Total number of observations
OA	Orthogonal Array
mm	Millimetre
cm	Centimetre
m	Meter
kg	Kilogram
CO_2	Carbon dioxide
O_2	Oxygen
V	Volt
Amp	Ampere
RSM	Response Surface Methodology
DOE	Design of Experiment
AA	Aluminium Alloy
PM	Parent Material

Al	Aluminium
Mg	Magnesium
SiC	Silicon Carbide
Si	Silicon
MPa	Mega Pascal
WZ	Weld Zone
HAZ	Heat Affected Zone
Al4C3	Aluminium Carbide
AWS	American Welding Society
ASTM	American Society for Testing and Materials
ASME	American Society for Testing and Materials
H2	Heat Treatment Condition
I	Welding Current
V	Welding Voltage
GFR	Gas Flow Rate
S	Welding Speed
Lit	Litre
Fe	Iron
SEM	Scanning Electron Microscopy
EDS	Energy Dispersive Spectroscopy
FIB	Focused Ion Beam
F	Fisher ratio
TEM	Transmission Electron Microscopy
FSW	Friction Stir Welding
SAW	Submerged Arc Welding
WFR	Wire Feed Rate
ANN	Artificial Neural Network
GA	Genetic Algorithm
DOF	Degree of Freedom
CI	Confidence Interval
CE	Confirmation Experiment
ER	Electrode Rod
Fα (1, fe)	The F ratio at a confidence level of (1-α) against DOF, 1 and error degree of freedom fe
%	Percentage
$\overline{\mu_T}$	Overall mean value of tensile
$\overline{\mu_I}$	Overall mean value of Impact
$\overline{\mu_H}$	Overall mean value of Hardness
η_{opt}	Optimum Value
η_{eff}	Effective number of replication

Introduction

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

'Manufacturing' is a word derived from Latin, manus (hand) and factus (made), whose literal meaning is 'made by hand'. Manufacturing means making of goods and articles by hand and /or by machinery. Manufacturing processes are the steps through which raw materials are transformed into a product. There are many ways for categorizing manufacturing processes and one such is as follows (Sharma 2007).

I **Casting processes:** Product is made from pouring molten metal into a mould and allowed to solidify into a shape. The examples are sand casting, permanent mould casting and die casting etc.

II **Deformation processes:** Product is produced by plastically deforming the material under the action of external forces. In these processes no material is removed. It includes rolling, forging, extrusion, deep drawing and bending etc.

III **Machining processes:** Final shape of product is obtained by removing material from a workpiece. It includes turning, milling, grinding, ECM and EDM etc.

IV **Plastics materials/polymers processing methods:** It includes various methods for processing plastic materials/polymers, such as, shape casting, various moulding processes, thermoforming etc.

V **Powder metallurgy:** Product is directly produced by bringing a powder of the starting material into the desired final shape by compressing the powder in dies.

VI **Joining processes:** Product is produced by joining two or more components together. The examples are all welding processes, soldering, brazing, riveting and bolting etc.

VII **Heat treatment and surface treatment processes:** These are employed to improve the properties of a workpiece. They include annealing, quenching, tempering, electroplating and painting etc.

VIII **Assembly processes:** For machines and mechanism it is the part of the manufacturing process concerned with the consecutive joining of the finished parts into assembly units and complete machines of a quality that meets the manufacturing specifications.

Selection of a suitable manufacturing process is done on the basis of the following considerations:

I Type and nature of starting material

II Volume of production

III Expected quality and properties of the components

IV Technical viability of the process

V Economy

In this study a permanent joint is to be made from two materials in order to obtain maximum value of ultimate tensile strength and hardness and minimum value of impact strength. Welding is the best option for the purpose.

Welding is a process of joining two materials, which is extensively used in any manufacturing industry. It is more economical and is much faster process compared to both casting and riveting. Generally, all welding processes are used with the aim of obtaining a welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion (Hooda *et al.* 2012).

The demand for producing joints of dissimilar materials is continuously increasing due to their advantages, which can provide appropriate mechanical properties and good cost reduction. There are many issues / problems associated with the joining of dissimilar materials, depending on the materials being joined and process employed. In the welding of dissimilar materials following factors should be considered (Anawa *et al.* 2007):

(a) Carbon migration from the higher carbon containing alloy to the relatively lower carbon alloy steels, especially those which are highly alloyed

(b) The differences in thermal expansion coefficients, resulting in differences in thermal residual stresses across the different weldment regions

(c) Difficulty in executing the post weld heat treatment, especially in combinations wherein either of the materials being joined is susceptible to undesirable precipitation at elevated temperatures

(d) Electrochemical property variations in the weldment, resulting in environmentally assisted problems

Development of dissimilar weldments represents major challenge in modern manufacturing processes. One of the main reasons for the poor progress in this area is the relative lack of basic understanding of the process. In particular, very little is known about the weldments both in terms of heat transfer, fluid flow and the microstructure development. All these are crucial in developing sound dissimilar weldments in future. One of the major

problems in the dissimilar welding is the problem of mixing. The problem not only depends on the heat source and the melting point of the two constituent materials but also in the relative conductivity of heat. It is the latter which often determines the temperature profile and the mixing behaviour (Kumar *et al.* 2002).

All important metals used in different commercial applications such as aluminium, copper, stainless steel and carbon steel can be joined by Gas Metal Arc Welding and gas tungsten arc welding processes by choosing appropriate electrode, shielding gas and different welding conditions (Das *et al.* 2013).

Aluminium alloys have important advantages in relation with other structural alloys, because of their higher specific mechanical strengths and corrosion resistance. Aluminium alloys find wide applications in aerospace, automobile industries, railway vehicles, bridges, offshore structure topsides and high speed ships due to its light weight and higher strength to weight ratio. In all cases, welding is the primary joining method which has always represented a great challenge for designers and technologists. As a matter of fact, lots of difficulties are associated with this kind of joint process, mainly related to the presence of a tenacious oxide layer, high thermal conductivity, high coefficient of thermal expansion, solidification shrinkage and, above all, high solubility of hydrogen, and other gases, in the molten state (Lakshminarayanan *et al.* 2009).

For aluminium alloys, due to their elevated thermal conductivity, the weld penetration remains very shallow (less than 3mm in one pass). The elevated temperatures attained in fusion welding processes induce an important microstructural evolution especially concerning hardening precipitates (Jannet *et al.* 2013).

In today's manufacturing scenario, optimization of welding process is essential for a manufacturing unit to respond effectively to severely competitiveness and increasing demand of quality which has to be achieved at minimal cost.

1.2 WELDING

Welding is a process of joining of two materials (same or different) with the application of heat, with or without pressure, with or without filler rod. Welding may also be defined as a localized coalescence of metals wherein coalescence is obtained by heating to suitable temperature, with or without the application of pressure, with or without the use of filler metal (Sharma 2007).

1.2.1 Types of Welding

The broad classification of welding is depicted in Figure 1.1.

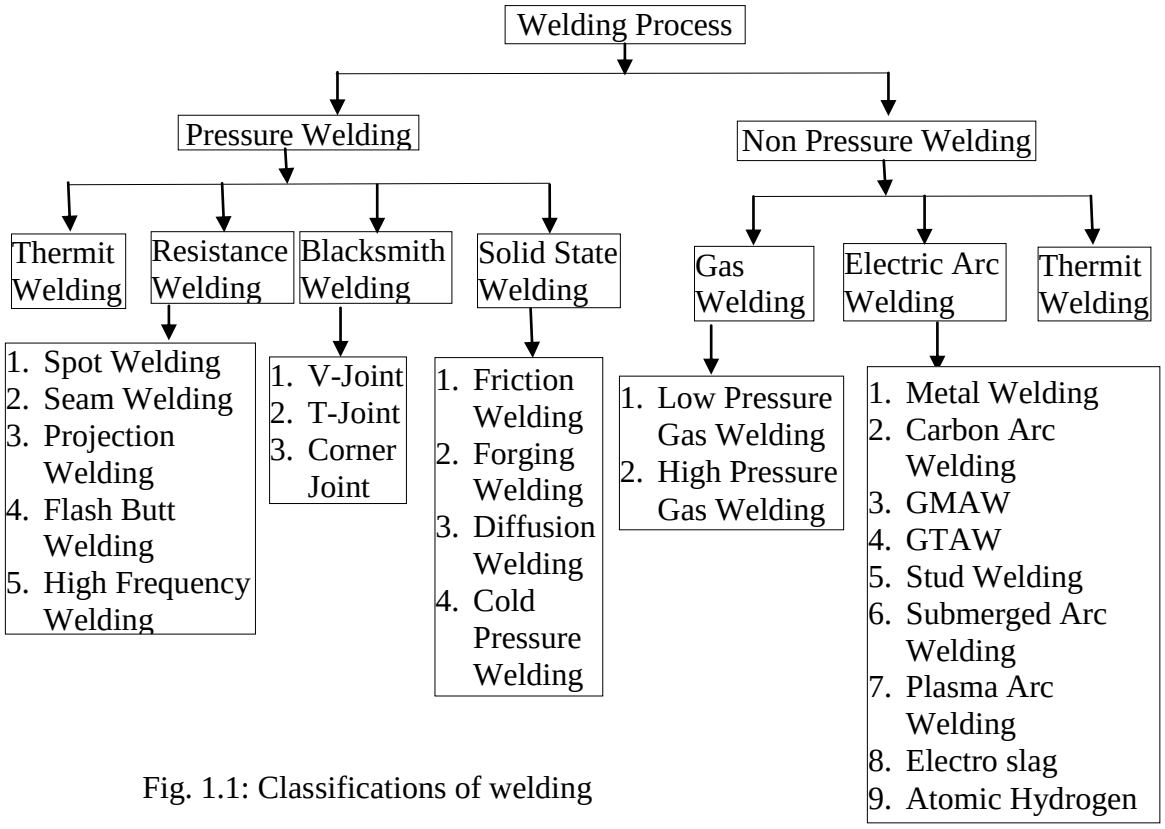


Fig. 1.1: Classifications of welding

Aluminium alloy 3003-H2 (IS 737) can be welded by the electron beam welding, oxyacetylene welding, the Gas Metal Arc Welding (GMAW), the gas tungsten arc welding (GTAW), spot and seam welding (aluminium.matter.org.uk). In the present study the GMAW and GTAW were used because of their many advantages like they being a simple techniques and very easy to learn and use, weld defects are minimized, produces no slag, machine is automatic or semi-automatic so less skilled worker can complete his tasks easily, metal deposition rates are high and a lot more efficient than most other forms of welding.

1.2.2 Conditions for Obtaining Satisfactory Welds (Houldcroft 1988)

To obtain the satisfactory welds, it is desirable to have:

- A source of energy to create union by fusion or pressure
- A method for removing surface contaminants
- A method for protecting metal from atmospheric contamination
- Control of weld metallurgy

1.3 GAS METAL ARC WELDING

The Gas Metal Arc Welding (GMAW) is an arc welding process which uses a consumable electrode to produce the weld. The weld area is protected from atmosphere with a shielding gas like argon or helium or sometimes mixture of argon and helium. In GMAW the filler metal may also be fed manually for proper welding in which the coalescence is produced by heating the workpiece with an electric arc which is established between a continuous fed of metal electrode and the workpiece. The arc is shielded from contaminants in the atmosphere by a shielding gas. The Gas Metal Arc Welding (GMAW) process consists of heating, melting and solidification of parent and a filler material, in localized fusion zone by a transient heat source to form a joint. The GMAW parameters are the most important factors affecting the quality, productivity and cost of welded joint. The metal transfer in GMAW refers to the process of transferring material of the welding wire in the form of molten liquid droplets to the workpiece (Abbasi *et al.* 2012).

The GMAW is one of the most widely used processes in the industry. The input parameters play a very significant role in determining the quality of a welded joint. In fact, weld geometry directly affects the complexity of weld schedules. Therefore, the parameters affecting the arc welding are required to be estimated. These are combined in two groups as first order adjustable and second order adjustable parameters defined before welding process. Former are welding current, arc voltage and welding speed. These parameters will affect the weld characteristics to a great extent, because these factors can be varied over a large range, they are considered the primary adjustments in any welding operation. Their values should be recorded for every different type of weld to permit reproducibility (Sapakal 2012). The Gas Metal Arc Welding is such a welding process which is extensively used in the industries for its high precision and accuracy capability. But performance of the welding depends largely upon the parameters like voltage, current and also on type of work-piece materials, electrode material combinations (Das *et al.* 2013).

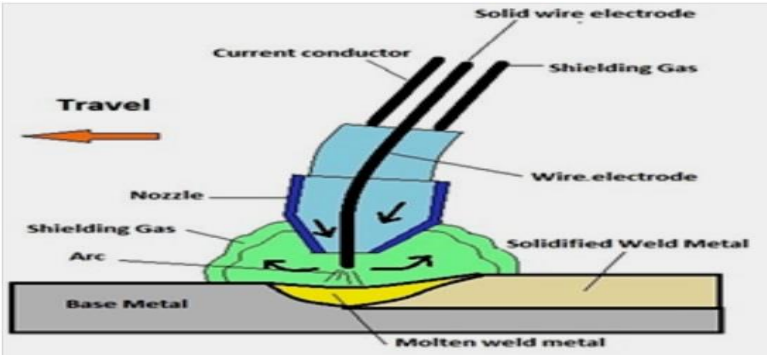


Fig. 1.2: The Gas Metal Arc Welding process (Das *et al.* 2013)

1.3.1 History of Gas Metal Arc Welding

The MIG was developed in the 1940's and 78 years later the general principle is still very much the same. The MIG uses an arc of electricity to create a short circuit between a continuously fed anode (Negative terminal, the metal being welded) and a cathode (Positive terminal, the wire-fed welding torch). The heat produced by the short circuit, along with a non-reactive (inert) gas locally melts the metal and allows them to mix together. Once the heat is removed, the metal begins to cool and solidify, and forms a new piece of fused metal.

A few years ago the full name metal inert gas (MIG) welding was changed to Gas Metal Arc Welding (GMAW). The GMAW is useful because it can be used to weld many different types of metal piece carbon steel, stainless steel, aluminium, magnesium, copper, nickel, silicon, bronze and other alloys (MIG-Welding.html).

1.3.2 Working Principle of Gas Metal Arc Welding

In the GMAW process, the wire is fed continuously from reel through a gun to constant surface which imparts a current upon the wire as shown in Figure 1.2. A fixed relationship exists between the rate of wire burn off and the welding current so that the welding machine at a given wire feed rate will produce necessary current to maintain the arc. The current ranges from 100 to 400A depending upon the diameter of the wire, and the speed of the wire may be up to 5m/min. The welding machine uses a DC constant voltage with both straight and reverse polarities. In GMAW, the welding area is flooded with a gas (inert gas) which will not combine with the metal. The rate of flow of this gas is sufficient to keep oxygen of the air away from the hot metal surface on which welding is being done. For welding aluminium or copper, the inert gases like argon or argon - helium mixture are used (Vineeta 2015). The experimental set up of GMAW welding is shown in Figure 1.3.

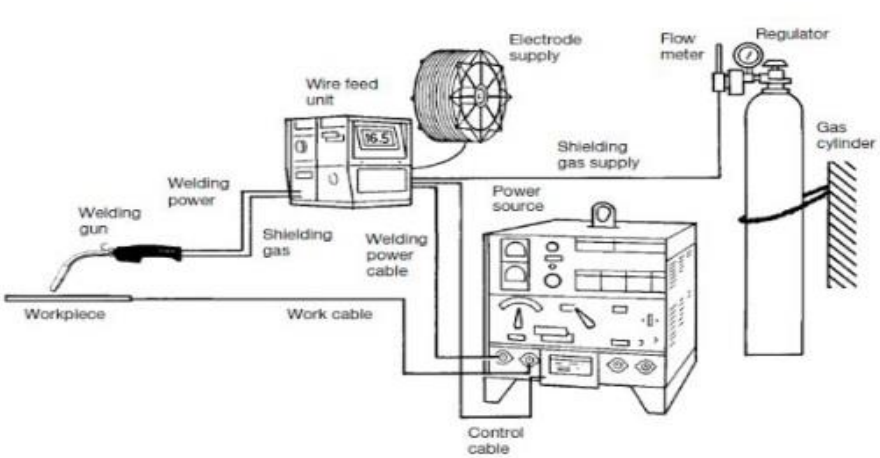


Fig. 1.3: The GMAW process and equipments (Vineeta 2015)

1.4 GAS TUNGSTEN ARC WELDING

The gas tungsten arc welding (GTAW) process is an arc welding process which uses a non consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere with a shielding gas generally argon or helium or sometimes mixture of argon and helium. In GTAW, the melting temperatures necessary to weld materials are obtained by maintaining an arc between tungsten electrode and a workpiece. An inert gas sustains the arc and protects the molten metal from atmospheric contamination. The GTAW produces the high quality low distortion weld, free of the spatter, and gives precise control of welding heat. The concentrated nature of a GTAW arc permits pin point control of heat input to the workpiece resulting in a narrow heat affected zone (HAZ). Narrow HAZ is an advantageous because the base metal undergoes the change due to superheating of arc and fast cooling rate (Chauhan 2013).

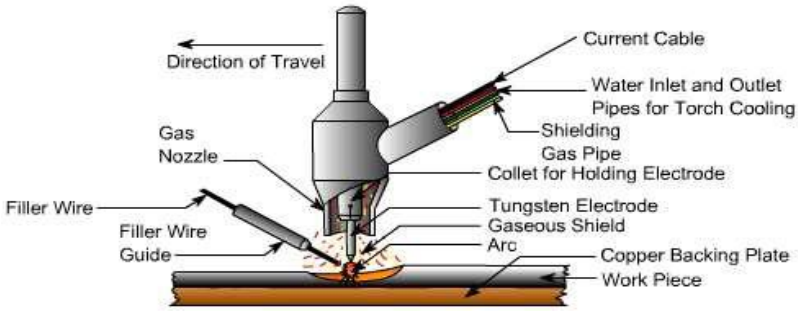


Fig. 1.4: The gas tungsten arc welding process (Pasupathy 2013)

1.4.1 History of Gas Tungsten Arc Welding

The gas tungsten arc welding (GTAW) is also known as tungsten inert gas (TIG) welding, which was developed in late 1930s, when a need to weld magnesium became apparent. The melting temperatures necessary to weld materials in GTAW process is obtained by maintaining an arc between tungsten electrode and a workpiece. An inert gas sustains the arc and protects the molten metal from atmospheric contamination. The inert gas may be argon, carbon dioxide, helium or the mixture of these gases (Thakur *et al*. 2016).

The American Welding Society (AWS) refers process as gas tungsten arc welding and has given it the letter designation GTAW. While a few countries such as the U.S.A. and Canada use helium and argon-helium mixture besides argon for arc shielding, most other countries including India use only argon, as helium is not available. In the latter countries the process is sometimes called argon arc process for the sake of simplicity. The concept of using gases in place of fluxes to shield the welding arc was first tried out by Roberts and van Nuys in 1919 and by other scientists in the following years. Besides inert gases, hydrogen and

hydrocarbons were also considered. A workable method of inert gas welding was first developed by the Northrop Aircraft Co. of the U.S.A. in 1940, using a simple tungsten electrode torch and a D.C. welding generator (Parthiv *et al*. 2012).

1.4.2 Working Principle of Gas Tungsten Arc Welding

In the gas tungsten arc welding (GTAW) process, the wire is fed continuously from reel through a tungsten electrode to constant surface which imparts a current upon the wire as shown in Figure 1.5. The GTAW process is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere by an inert shielding gas (argon or helium) and a filler metal is normally used. The power is supplied from the power source, through a hand piece or welding torch and is delivered to a tungsten electrode which is fitted into the hand piece. An electric arc is then created between the tungsten electrode and the work piece using a constant current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapors (praxairdirect.com).

The tungsten electrode and the welding zone are protected from the surrounding air by inert gas. The electric arc can produce temperatures of up to $20{,}000^0$ C and this heat can be focused to melt and join two the different part of the material. The weld pool can be used to join the base metal with or without filler material.

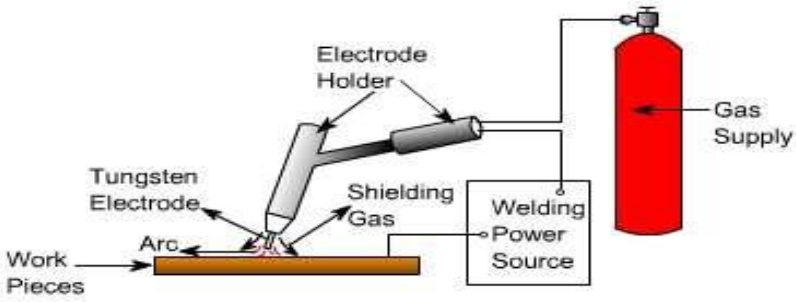


Fig. 1.5: The GTAW process and equipments (praxairdirect.com)

1.5 ALUMINIUM ALLOY

Aluminium is a light weight, soft, low strength metal, which can easily be cast, forged, machined, formed and welded. Aluminium is an abundant element of 8% on earth crust and normally found in oxide forms (Al_2O_3), i.e., bauxite, kaolinite, nepheline and alunite. (Hatch *et al.* 1998). The extraction of aluminium from its ore and challenges to weld dissimilar aluminium alloys are discussed below.

1.5.1 Extraction of Aluminium

Aluminium can be extracted from bauxite, Kaolinite or nepheline ores.

Bauxite →	30-50% Alumina (Al_2O_3) 3-13% Silica (SiO_2) 10-18% Titanium oxide (TiO_2) Balanced water (H_2O)
Kaolinite →	30-32% Alumina (Al_2O_3) Balanced Silica (SiO_2) and water (H_2O)
Nepheline →	30% Alumina (Al2O3) 40% Silica (SiO2) 20% Na2O + K2O

Aluminium alloys are alloys in which aluminium is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al–Si, where the high levels of silicon (4.0–13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required (Totten *et al*. 2003).

Alloys composed mostly of aluminium have been very important in aerospace manufacturing since the introduction of metal-skinned aircraft. Aluminium-magnesium alloys are both lighter than other aluminium alloys and much less flammable than alloys that contain a very high percentage of magnesium. Aluminium alloys surfaces will develop a white, protective layer of aluminium oxide if left unprotected by anodizing and/or correct painting procedures. In a wet environment, galvanic corrosion can occur when an aluminium alloy is placed in electrical contact with other metals with more positive corrosion potentials than aluminium, and an electrolyte is present that allows ion exchange. Referred to as dissimilar-metal corrosion, this process can occur as exfoliation or as intergranular corrosion. Aluminium alloys can be improperly heat treated.

1.5.2 Challenges to Weld Aluminium Alloys

Aluminium alloys can be joined by most fusion and solid-state welding processes as well as by brazing and soldering, gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW). The following problems associated with welding of high strength aluminium alloys are (John 2001):

(1) Porosity (2)Hot cracking (3)Stress corrosion cracking

(4)Due to great affinity for oxygen Al combines with oxygen in air to form a high melting point oxide on metal surface

The major difficulty in the welding of aluminium alloys is the formation of an oxide layer Al_2O_3 which is a very hard, adherent and durable material. Preventing the formation of this oxide is an important objective for welding of aluminium. The presence of this oxide layer will prevent a good weld and result in inclusions that weaken the weld.

The remedies which can be used for above challenge are:

(1)Oxide must be cleaned from metal surface before start of welding

(2)Use of large gas nozzles

(3)Use of trailing shields to shield face of weld pool

(4)When using, thoriated tungsten electrode to be used

(5)Welding must be done with DC electrode positive with matching filler wire

1.6 STATEMENT OF RESEARCH PROBLEM

From the available literature on the subject, it can be observed that much of the emphasis was laid only on optimization of parameters. Literature lacks in the systematic investigation of the effect of process parameters on the quality of the weld for aluminium alloys 3003 (parent material) and ER 4043 (filler wire). Thus there is a need to further investigate the comparative effect of process parameters on GMAW and GTAW processes of aluminium alloys 3003 (parent material) and ER 4043 (filler wire). There is further need to fully understand the mechanism of GMAW and GTAW process**es.**

1.7 OBJECTIVES OF PRESENT INVESTIGATION

The present work has been undertaken to carry out “Investigation and optimization of processes parameters affecting the quality of the weld for aluminium alloy 3003-H2 (AA3003) by GMAW and GTAW machining”. In order to accomplish this, following objectives have been identified.

(1) Investigation of the working ranges and levels of the GMAW and the GTAW processes parameters affecting the quality characteristics of the weld zone
(2) To obtain the quality of weld in AA 3003 using as parent material and 4043 as filler wire
(3) Study the effect of the following five parameters:
    (a) Welding current (b) Welding voltage (c) Welding speed
    (d) Gas flow rate (e) Root gap

On the quality of welding, which consists of following responses parameters (performance characteristics)

    (i) Ultimate tensile strength
    (ii) Impact strength
    (iii)Hardness

(4) To determine the optimum parameters using Taguchi method
(5) To compare the results of the GMAW and GTAW the processes with parent material

1.8 RESEARCH METHODOLOGY

The following methodology has been adopted:

(i) Preliminary experiments have been conducted to determine the working ranges of the GMAW and the GTAW processes parameters
(ii) Experiments have been conducted on the GMAW and the GTAW (GMAW PANA-AUTO KR II 400 and TECHNO WELD MDX-300) as per the Taguchi's design of experiment scheme
(iii) Results have been analyzed as per the procedures of the Taguchi's method to determine the optimum conditions
(iv) Confirmation experiments are to be conducted to verify the predicted results.

1.9 SCOPE OF PRESENT WORK

This research work may be used for selecting the optimum conditions and predicting the quality on the GMAW and the GTAW of aluminium alloy (AA3003). The data generated can be used for further study and investigations. Lastly, the science of manufacturing will be enriched by the knowledge contributed by these findings of the study, how so ever small it may be.

1.10 ORGANIZATION OF THESIS

This thesis has been organized as per the following plan of work:

Chapter 1 deals with the common introduction (Background), welding, types of welding processes, condition for obtaining satisfactory welds, history and basic mechanism of GMAW and GTAW, working principles, aluminium alloys, extraction of aluminium, challenges to weld aluminium alloys, statement of the research problem and research objectives of the present investigation, research methodology and scope of work.

Chapter 2 presents introduction, the review of the published literature on welding under different welding (condition), optimization of process parameters, comparative study of welding used in GMAW and GTAW processes and summary of review of literature. Also, the gaps in the literature have been identified and conclusions drawn are discussed.

Chapter 3 deals with introduction, experimental setup, testing and measuring equipments used for measurement of different output responses like SEM, EDS and mechanical properties (ultimate tensile strength, impact strength and hardness) and their evaluation criterion. An Ishikawa cause-effect diagram has been drawn for this research. Also, details about the use of Taguchi design of experiment technique have been discussed.

Chapter 4 presents the description of the process variables and their selection using Taguchi method for experimentation. The optimal levels of the process parameters for the selected output responses are identified and their respective confidence intervals are computed.

Chapter 5 contains the summary, conclusion and scope for future work of the investigation conducted in this thesis. Also, at the end of this chapter, expected contributions, some suggestions for future work on the related topic have been enumerated.

Literature cited, appendices and abstract are given in the end of the thesis.

Review of Literature

This chapter presents the review of literature of selected journals, articles, reference books and published materials from online sources.

2.1 INTRODUCTION

The review of literature is a very important milestone in the journey of research work. It reveals what has been done in the particular area and what further needs to be done in the chosen fields. It, was therefore, decided to review the existing available literature so as to avoid duplication and to carry forward the research in the right direction. Extensive review of literature has been done using different sources which include books, national & international journals, and internet. In order to investigate the effect of process parameters on the quality of butt welding in aluminium by gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW) machining processes, it is essential to fully understand all the facets of GMAW and GTAW processes and their analysis, which have already been attempted by different researchers in this field. The collected literature, on relevant aspects of the GMAW and GTAW process such as process capabilities, machining modes, process parameters, performance characteristics and effect of process parameters on performance characteristics and techniques used for analysis is presented here under following headings:

(1) Review of literature of GMAW process for aluminium alloys
(2) Review of literature of GTAW process for aluminium alloys
(3) Review of literature of GMAW, GTAW and other processes for aluminium alloys
(4) Review of literature of GMAW process for alloys other than aluminium alloy
(5) Review of literature of GTAW process for alloys other than aluminium alloy
(6) Review of literature of GMAW, GTAW and other process for alloys than aluminium alloy

2.1.1 Review of Literature of GMAW Process for Aluminium Alloys

James *et al.* (2008) carried out the investigation of the single line residual stress profiles for 8 mm aluminium alloy 5083-H321 plates joined by the gas metal arc welding (GMAW). The data have been obtained by synchrotron diffraction strain scanning.

The stresses of weld metal are quite scattered and unreliable because of the large epitaxial grain size in the fusion zone.

Lihui *et al*. (2012) discussed the double variable decoupling control scheme has been proposed for GMAW process of aluminum alloy 5081 the helping to efficiently develop the procedure of welding. The weld bead shape has been improved by changing the current waveforms to adjust the heat input while the arc length has been controlled to stabilize the welding process. The results show that good weld bead shape and stable the welding process can be obtained by the double variable decoupling control scheme without complex metal transfer control and considerable trial and error to identify the suitable combinations of the parameters of welding in GMAW.

Satyaduttsinh *et al*. (2014) discussed about the parameters for the GMAW are the most important factors affecting the quality, productivity and the cost of welding. The aim of the model is to predict the thermal analysis resulting from the welding of the AA6052 plates and experiments have been carried out in order to the compare to the FEM model result. For optimization of the welding parameters different combinations of the current, voltage, weld speed, GFR are used. If the values of the current, voltage, GFR are increase the temperature are increases.

Anas *et al*. (2015) carried out GMAW is among the most important processes in assembly operations for the aluminum alloys 6052. This work aims at identifying and the optimizing the main factors that have the significant effect on the weld joint and the strength through the design of experiments. The design of experiments and the analysis of variance (ANOVA) showed that the arc voltage and filler feed rate are the only significant factors of the five. The optimal settings of arc voltage and filler feed rate have been reached using the regression analysis at 24 V and 7 in/s, respectively, at which the mean weld strength is the maximum values.

Vineeta *et al*. (2015) carried out parametric optimization of the GMAW for hardness has been performed by using the taguchi technique. An orthogonal array, L9 has been used to conduct the experiments. In this research study the optimization of the process parameters for GMAW of aluminium alloys 5083 and 6061 with greater hardness has been reported. A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance (ANOVA) were used for the optimization of welding parameters. It was found that welding current has major influence on hardness of welded joints. The measurement tests have been conducted on the Rockwell hardness testing machine.

Vivek *et al*. (2015) discussed the aluminum alloy is widely used due to it’s the versatility especially in automotive industry on GMAW process. This work unveiled the influence of welding parameters on the tensile strength of AM-40 (EN AW 5083) aluminum

alloy the material during welding. The result obtained is in the form of the percentage contribution factor from individual parameter, by which the optimal parameters are identified for the maximum tensile strength. It is observed that the welding current and welding voltage is major parameters which influence on the tensile strength of butt welded joint.

2.1.2 Review of Literature of GTAW Process for Aluminium Alloys

Urena *et al*. (1999) discussed the influence of the interfacial reaction between the matrix and the reinforcement on the fracture behaviour of an aluminium alloy reinforced with SiC particles when it is arc welded. The gas tungsten arc welding GTAW) tests have been carried out on 4-mm thick sheets of AA2014/SiC/Xp (where X is 6, 13 and 20 vol%, respectively), which have been machined with the welding pool in the transverse position and tensile tested. The fractures of the tested welds have been studied and compared with those of the parent composites. Both surface studies of the fracture (SEM) and transverse preparations of these (LM and SEM) have been observed.

Wang *et al.* (2008) carried out the dynamic progress and the residual distortions of the out of plan of AA5A12 have been investigated under the different welding conditions of the GTAW. The dynamic out of plane the distortion has been measured by self developed distortion measuring system. The out of plane distortion mechanism and the effecting parameters on the distortion process have been analyzed, and the effect of plate thickness and the welding heat input on the distortion has been discussed.

Pasupathy *et al*. (2013) carried out the GTAW process is an important component in many industrial operations, material used AA1050. A plan of experiments based on the taguchi technique has been used to acquire the data. An orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the characteristics of welding for dissimilar joint and optimize the welding parameters. Taguchi orthogonal array, signal to noise (S/N) ratio and analysis of variance have been used for the optimization of welding parameters. A conformation experiment was also conducted and verified for the effectiveness of the Taguchi optimization method.

Lakshman *et al*. (2013) investigated the parameters of the GTAW and the influence on weld ability of AA5083 specimens are with dimension of 50 mm long x 50 mm wide x 5 mm thick is investigated. Investigate the effect of welding speed, gas flow rate and heat input on depth of weld penetration and found that the depth of penetration increases first by increasing the welding parameters till an optimum value and starts to decrease the depth of penetration by further increment of the welding parameters. Optimum weld ability can be

achieved at arc voltage of 22 volt, current of 215 ampere, welding speed of 146.48 mm/min., gas flow rate of 12.45 lit/min. and heat input of 1937.47 joule/mm.

Anoop *et al*. (2013) discussed the aluminium alloy 7039 is an Al-Mg-Zn alloy employed in aircraft, automobiles, infantry combat vehicles and high speed trains due to their low density, high specific strength and the excellent corrosion resistance. This study has discussed an application of the Taguchi method for investigating the effects of process parameters on the weld microhardness; grain size and HAZ width in the GTA welded aluminium alloy 7039. From the analysis of the results using the signal-to-noise (S/N) ratio approach, analysis of variance and Taguchi's optimization method, the following can be concluded. The peak current of 150A, base current of 75A and pulse frequency of 150 Hz are the optimized welding parameters for getting highest microhardness, smallest equiaxed weld grains and minimum HAZ width. The out of three selected parameters, the peak current finds out the highest contribution i.e. 61.58%.

Leo *et al*. (2015) discussed the analysis of the effect of arc and laser powers on the quality of the arc assisted fiber laser welding of an Al–Mg alloy in the butt configuration. The magnesium content of the fused zone the decreased as the laser power increased while the porosity increased with laser power. The micro hardness profiles and the tensile strengths have been explained on the basis of the joint microstructure and the defects and the related to the power distribution. The porosity level and Mg content in the fused zone affected both the tensile strength and the ductility. The power distribution that stabilized the GTAW process and minimizes the weld porosity was defined.

Sivasankaran *et al*. (2015) carried out the gas tungsten arc welding is one of the most widely used processes in the industry. The welding parameters are the most important factors affecting the cost and the quality of welding. Taguchi optimization method was successfully applied to find the optimal level of GTAW the parameters for maximizing weld strength of aluminium alloy 8011 weld specimen. The level of influence of the welding parameters on the weld strength is determined by using ANOVA. Confirmation experiment was also conducted and the effectiveness of Taguchi optimization method was verified. The experimental value of ultimate tensile strength that is observed from optimal level of welding parameters is 155.682 N/mm2. The improvement in S/N ratio is 0.894.

Chandrasheker *et al*. (2017) describe the experimental study and the presents an effective approach for the optimization of GTAW parameter using MINITAB 17 and the taguchi technique in varying condition. The response table and response graph for the each

level of the machining parameters are obtained from the taguchi approach and the optimum levels of the machining parameters are being selected on AA5072.

Sindiri Mahesh *et al*. (2017) in this investigation the problem that has faced the manufacturer is the control of the GTAW process input parameters to obtain a good welded joint with the required weld quality for AA5083-H18. An Orthogonal array, signal to noise (S/N) ratio and the analysis of variance (ANOVA) are employed to study the welding characteristics of material and optimize the welding parameters. The result calculated is in form of the contribution from each parameter, through which the optimal parameters are identified for maximum tensile strength. According to this study, it is observed that welding current and welding speed are major parameters which the influence on the tensile strength of the welded joint.

2.1.3 Review of Literature of GMAW, GTAW and other Processes for Aluminium Alloys

Moreira *et al.* (2007) discussed the increasing use of aluminium alloys 5082 in transportation, such as railways, shipbuilding and aeronautics, calls for more efficient and reliable welding processes that would require more in depth understanding of fatigue failure. The objective of this work focuses on the contrasting difference of the fatigue behaviour of joints made from the traditional process of the GMAW and the emerging process of friction stir welding (FSW). The effort is made to relate the macroscopic mechanical behaviour to the microstructural feature of the weldments.

Suresh et al. (2011) discussed the ultimate load of GTA welded AA6052 specimen is 57600 N where as for the GMA welded specimen is 56160N. Therefore we can say that GTA welded specimen can bear higher loads than GMA welded specimen. The ultimate tensile strength of GTA welded specimen is 675.22 MPa where as for the GMA welded specimen is 652.029 MPa. Therefore we can say that GTAW welded specimen has higher tensile strength.

Sushil *et al*. (2013) carried out the FSW is a new joining process of solid state that is the presently attracting the considerable interest. The mechanical properties of both the welding specimen has been compared and with the strength of the base metal. The microstructure has also been examined. Tensile strength of FSW is more than that of GTAW of AA 6101 T6. Friction stir welded and GTA welded joint both showing less values of % elongation. The welded specimens have lower mechanical properties compared to the base materials. In 6101-T6 alloy, the yield and ultimate tensile strengths decreased by

approximately 59% and 40%, respectively, from base material. The corresponding decrease for GTA welded specimen was found to be 70% and 60%. Also elongation was lower than the base material. The welded materials have lower yield stress, tensile strength and hardness compared to the base materials. Hardness of FSW is also more than that of GTAW of Al 6101 T6 aluminium alloy.

Borrego *et al*. (2014) discussed about the friction stir processing is an adaptation of the friction stir welding process. The friction stir processing technique presents several characteristics, between which can provide the localized modification and control of the microstructures in near-surface layers of processed metallic components in order to the modify the correspondent mechanical behaviour. In this research the GMAW welded butt joints the performed in AA5083-H111 the plates with 6 mm thickness, have been post-processed by the friction stir processing. The hardness and the mechanical strength of the welds have not significantly modified by the friction stir processing.

Jesus *et al*. (2014) studied of the several tool geometries has been developed and their effect on the weld morphology, material flow, microstructure and hardness of the processed regions has been analyzed. The feasibility of FSW and the GMA welds has been proved. The quality of processed regions is very influenced by tool geometry. The FSW removes defects in the GMA weld toe and increases its radius of curvature. Also promotes significant grain refinement in processed regions, reduces hardness in welds on AA 6082-T651 and hardens AA 5083-H111 welds.

Ashwani *et al*. (2014) discussed the friction stir welding (FSW) is a process in which the welds are prepared with the help of a tool and equipment having a profiled pin for AA6061. The comparison is made between the conventional welding processes of the GMAW and the GTAW to the FSW on the basis of heat input and joint efficiency. With the help of FSW as comparison to GTAW and GMAW, nice welds having higher joint efficiency with less heat input can be get.

Saurabh *et al*. (2014) investigated the GTAW and the GMAW is well known the welding methods that are using in the industries in current. The impact strength of GTAW joints is higher than that of the GMAW joints. It is found that hardness in weld metal region is less than that of the base material. The maximum hardness is found in GTA welded and the minimum hardness is found in GMA welded joint. The hardness pattern in the weld region in two welding processes is like, GMAW > GTAW. In case of GMAW the microstructure is very fine and equiaxed, having uniformly distributed grains with strengthening precipitates as compared to GTAW processes in which dendritic grain structures is found. Because of fine

grain structure the GMAW joint possesses good tensile and mechanical properties than that of the GTAW processes. On the basis of the above discussion it can be elaborate that the GMAW is the best suitable welding process to join AA6061 as compared to GTAW processes.

2.1.4 Review of Literature of GMAW Process for alloys other than Aluminium Alloy

Manoj *et al.* (2010) discussed the gas metal arc welding (GMAW) is a process in which the source of heat is an arc format between consumable metal electrode and the work piece with an externally supplied gaseous shield of gas either inert such as argon, helium. This experimental study aims at the optimizing various gas metal arc welding parameters including welding voltage, welding current, welding speed and nozzle to the plate distance (NPD) by the developing a mathematical model for sound weld deposit area of a mild steel specimen.

Aghakhani *et al*. (2011) discussed for this work the proper selection of input welding parameters is the necessary in order to obtain a good quality weld and the subsequently increase the productivity of the process. It is found that the parameter design of Taguchi method provides a simple, systematic and efficient methodology for the optimization of the GMAW parameters. For main effects wire feed rate, welding voltage, welding speed, nozzle-to-plate distance; have significant effect on the weld dilution. This is consistent with the conclusions from the study of other investigators. The wire feed rate has the most significant effect on the weld dilution. The gas flow rate did not have any significant effect as such as far as the dilution is concerned.

Abbasi *et al*. (2012) carried out the effect of the GMAW parameters on the weld bead and shape factor characteristic of bright drawn mild steel specimen of the dimensions 144 x 31 x 10 mm has been the investigated. The depth of weld penetration and weld width have been measured for every specimen after the welding operation and the effect of heat input and welding speed rate parameters on depth of weld penetration and weld width have been investigated. It can, therefore, be concluded that at a given current of 165 amp and arc voltage of 16 V as the welding speed increases the penetration depth increases until optimum value is reached, at which penetration depth and shape factor are optimum. Beyond that speed penetration depth and shape factor start decreasing.

Pawan *et al.* (2013) investigated about the welding is widely used by the manufacturing engineers and the effectively set up the manufacturing processes for new products. In this study the discussed an investigation into the use of Taguchi's parameter

design approach for the parametric study of the gas metal arc welding (GMAW) of low carbon steel and stainless steel. In this research work, the bead on the plate welds have been carried out on low carbon steel plates and AISI 304 using the gas metal arc welding (GMAW) process. Taguchi method is used to design the experimental formulate. In this study the optimization of the process parameters for GMA welding of stainless steel and low carbon steel with greater weld strength has been reported. The Nominal-the-better quality characteristic is considered in the hardness prediction. The Taguchi method is adopted to solve this problem. The experimental result shows that the hardness is greatly improved by using this approach.

Patil *et al*. (2013) discussed the influence of GMAW parameters like welding current, welding voltage, welding speed on ultimate tensile strength (UTS) of AISI 1030 mild steel material during welding. A plan of an experiments based on the taguchi technique has been used. The compute of result is in form of the contribution from each welding parameter, through which the optimal parameters are identified for the maximum tensile strength. In this study, the mild steel failure problems encountered by loads have been successfully addressed by applying the Taguchi Method. A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance (AVOVA) have been used for the optimization of welding parameters. The optimum levels obtained are A3B3C3. It is found that welding speed has major influence on tensile strength of welded joints.

Mohan *et al*. (2014) carried out the case study to find out the design optimization for special operation for the purpose of GMAW process, it was used to weld ferrite and austenitic steel, and mild steel. The GMAW process parameters are the most important factors affecting the quality, productivity and cost of welding. Taguchi optimization method was applied to find the optimal process parameters for penetration. A conformation experiment was also conducted and verified the effectiveness of the Taguchi optimization method. The improvement of S/N ratio is 2.13. The experiment value that is observed from optimal welding parameters, the penetration is 5.25mm. & S/N ratio is 14.40.

Deepak *et al*. (2014) discussed gas metal arc welding (GMAW) is a fusion welding process having wide applications in the industry. Experimental design method provides a simple, systematic and efficient methodology for the optimization of the GMAW parameters. Tensile strength increases with increase in voltage. But in case of current and gas flow rate, it increases up to the optimum level and decreases on further increasing these values. Voltage has the greatest percentage contribution followed by current and gas flow rate. Voltage is the

significant factor for tensile strength but current and gas flow rate are the non-significant parameters in 1018 mild steel material on GMAW.

Priti *et al*. (2014) carried out the GMAW process finds the wide application because all commercially important applicable metals. In this work, an attempt has been made to determine the important welding process parameters for the three performance characteristics bead width, dilution and depth of HAZ in the GMAW process for mild steel plates of thickness. Factors such as weld feed rate, arc voltage, welding speed and their interactions play a significant role in the GMAW process in hard facing. Taguchi's experimental design strategy was applied to obtain optimum welding-process-parameter combinations for each of the performance criteria maximization of bead width, minimization of dilution and depth of HAZ cause significant contribution to dilution. Interestingly, the optimal levels of the factors for all the three objectives happened to be different. The analysis was further supplemented by a more rigorous statistical analysis known as ANOVA.

Gagandeep *et al*. (2015) investigated GMAW process is an important welding operation for the joining ferrous and non-ferrous metals. After the collecting data signal-to-noise (S/N) ratios have been conducted and used in order to obtain optimum levels for every input parameter. The subsequently, using the analysis of variance (ANOVA) the significant coefficients of each input parameter on the tensile strength and hardness have been determined and validated.

Vikas *et al*. (2015) studied the scope of the arc welding have increased in the various engineering field. As a result, the process parameters are needed to improve the existing process of welding. The GMAW process has successfully used for the joining similar and dissimilar metals. In this investigation the dissimilar metals, low carbon steel plates and stainless steel (SS-304) are joined by the GMAW successfully. A plan of experiments based on the taguchi technique has been used to acquire the data. The analysis for signal-to-noise ratio has been done using MINITAB-13 for the higher-to-better quality characteristics. The significance of the each parameter has been studied by using the ANOVA.

Rahul *et al*. (2015) the investigated of an experimental design proposed by the taguchi technique to involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. This study presented an efficient method for the determining the optimal the gas metal arc (GMAW) welding parameters for increasing the weld ability of low carbon steel and high speed steel of grade M2 under the varying conditions through the use of the taguchi parameter design process." The Taguchi methods offers a strategy for finding optimal , stable results based on a predefined set of

analyzed parameter combinations Robust Design takes up the concepts of the Taguchi method and offers a standard, homogenous procedure based on actual and scientific knowledge. Design of experiment is expected to gain more accurate answers on system behaviour and interaction effects, especially when created on basis of fractional factorial design

Prasenjit *et al*. (2015) discussed the dissimilar metal welded joints are integral parts of the modern day power and process plant equipment. The joining of mild steel and the stainless steel is very critical because of the carbon precipitation and the loss of chromium leads to increase in the porosity which affects the quality of joint leads the deteriorates strength. Analysis of variance (ANOVA) helps to find out the significance level of the each parameter. The optimum value was predicted using MINITAB-16 software. The effect of parameters on the MRPI can be ranked in decreasing order as follows: voltage > current >speed. The experimental results confirmed the validity of the used Taguchi method for enhancing the welding performance and optimizing the welding parameters in GMAW.

Mohit *et al*. (2015) discussed the objective of this research has been to study the influence parameters affecting to the mechanical property of austenitic stainless steel grade 304 (AISI 304) with the gas metal arc welding (GMAW). The present work aims at the study of factors affecting to the mechanical property of the austenitic stainless steel with GMAW at the different welding parameters. Arc Current has the highest influence on the Tensile strength with contribution of 41% followed by Arc voltage with contribution of 20% and Gas flow rate with contribution of 16%. Thus design of experiments by Taguchi method has been successfully used to find the optimum welding parameters for Tensile strength.

Diganta *et al*. (2015) discussed the objective of this research work is to investigate the effect of the three process parameters of the GMAW**,** welding current, welding voltage and shielding gas flow rate on the tensile strength of welded joints having grade C20 carbon steel as parent metal and ER70S-4 electrode as filler wire. In this study 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). Shielding gas flow rate has insignificant effect on the tensile strength of the weld. The effect of shielding gas flow rate being found the insignificant, kept at the most economic level (8 lit/min).

Rakesh Kumar *et al*. (2017) manufacturer often face the problem to achieve a good welded joint with the required quality due to control of the input process variables. The main objective of this investigation is to find best process parameters for good quality weld in

GMAW. The present research work describes the use of Taguchi method and statistical techniques for analyzing and optimizing the minimum residual stresses and maximum hardness in GMAW of low carbon steel. The main effect plots reveal that voltage and travel speed has significant influence on hardness whereas welding voltage and welding current has considerable effect on residual stresses.

2.1.5 Review of Literature of GTAW Process for alloys other than Aluminium Alloy

Choi *et al*. (2008) investigated the effect of welding condition according to the mechanical properties of the pure titanium and presents the optimum GTAW the condition through the evaluation about the weld ability of the pure titanium by the welding conditions. According to research study to find out the optimum welding condition by the mechanical properties of pure titanium, the annealed pure titanium of the ASTM B265 grade 2 is selected as a specimen and is classified by several welding conditions. The hardness value at the HAZ (heated affected zone) is higher than that for the WMZ and reveals almost the constant value more and more distance at the HAZ. In this work current and voltage are high significant and welding speed insignificant.

Jun *et al*. (2009) investigated the microstructure and the mechanical properties of SS304 joints by the GTAW, the laser welding and the laser GTAW welding. The X-ray diffraction has been used to analyze the phase composition, while the microscopy has been conducted to study the microstructure characters of joints. The tensile tests have been performed and analyzed. The results showed that the joint by the laser welding had the highest tensile strength and the smallest dendrite size in all the joints, while the joint by the GTAW had the lowest tensile strength, the biggest dendrite size .

Wang *et al*. (2011) investigated the influences of parameters of the GTAW on the morphology; microstructure, the mechanical property and the fracture of the welded joints of Ni base super alloy has been studied. The results show that the increase of welding current and the decrease of welding speed bring about the large amount of the heat input in the welding pool and the enlargement of width and deepness of the welding pool. The effect of the welding parameters on the tensile strength has been analyzed.

Parthiv *et al*. (2012) investigated the gas tungsten arc welding (GTAW) is one of the widely used method for the joining for ferrous and non-ferrous metals. Experiments have been carried out as per the regression analysis and the central composite design has been conducted to determine the relationships between input and output of the process of welding. To consider the mechanical characteristics for a constrained problem for optimization has

been design. Effect of welding speed: Bead height decreases with the increase in welding speed. Effect of current: Bead height increases with the increase in current. Effect of gas flow rate: There is a slight decrease in bead height with the increase in gas flow rate.

Sathish *et al*. (2012) discussed about the research work is welding of dissimilar metals, such as stainless steel pipes and carbon steel which find out the wide application in the field of oil, chemical and the petroleum industries. The specimen of carbon steel pipe (A106 Grade B) and the specimen of stainless steel pipe (A312 TP 316L) each have been selected. The taguchi approach is used to design the formula for an experimental layout to rank on the GTAW input parameters which affects the weld quality is influenced by the parameters like gas flow rate followed by current and bevel angle. The variation in heat input resulted in significant changes in the mechanical properties of the weld. Gas flow rate is the factor that significantly contributed to a higher percentage and has greater influence on the tensile strength followed by contributions from current and bevel angle

He *et al*. (2014) studied the hot rolled plates of high alloys have been butt welded by the GTAW using the base metal as the filler. The results indicate that the welding quality of the high boron Fe-Ti-B alloys is very good, there are no obvious defects such as cracks, lack of fusion, the incomplete penetration and strip defects in the butt weld joints. The tensile tests have been carried out on the GTA welded joints after the post weld heat treatment. The result shows that the welds have slightly higher yield strength (YS), and lower the ultimate tensile strength compared to those of the base metal.

Karthik *et al*. (2014) studied the properties of weld ability, namely tensile strength of the shielded gas metal arc welded and gas tungsten welded austenitic 304 stainless steel have been studied. And it shows the yield strength and ultimate strength of GTAW properties has been better than the GMAW properties.

Simhachalam *et al*. (2015) studied the effect of welding process parameters on the mechanical properties of the stainless steel 304(18Cr-8 Ni) welded joint obtained by the GTAW. In this work, it is observed that by keeping constant gas flow rate and welding current and by varying the filler rod diameter in increasing order the depth of penetration and impact strength decreases From the experimental values, it is observed that by keeping constant gas flow rate and filler rod diameter and by varying the current in increasing order the depth of penetration decreases , impact strength decreases, and hardness increases at weld zone using Minitab-13 software response surface optimization has done for minimizing hardness and maximizing the impact strength and depth of penetration. The filler rod

diameter also has the similar effect on the welding current but the welding current has a higher effect compared to the filler rod diameter.

Ahir *et al*. (2015) discussed about the GTAW is a widely applied the manufacturing process. In this investigation carried on the optimization of weld process parameters with the taguchi approach for the distortion control applied to the austenitic stainless steel 316 structures of 8.5 mm thickness with two pass GTA weld process. The L9 orthogonal array has been selected for the design of an experiment towards the distortion optimization caused by the butt welding. The ANOVA was perfumed to obtain the significant parameter which gives the percentage contribution of each process parameter under operating condition. Weld distortion analysis for optimum GTAW process parameters control with lowest number of experiments.

Jeyaprakash *et al*. (2015) in this case study, we discuss the influence of the power source, type of current, gas flow rate, electrodes, filer wire, GTAW machines settings, and shielding gases which are most important in determine arc stability, arc penetration and defect free welds. To do this a thorough literature survey is carried out on various aspects of the proposed topic, in various peer-reviewed journals, patents, books and other research resources. We have identified the suitable range of current, the thickness of the base metal, the diameter of electrode, the composition of electrode and filler wire, the gas flow rate required for high quality GTAW process for stainless mild and high tensile steels.

Junhao *et al*. (2015) investigated the comparison of dissimilar metals of AA6013 and Q 235 low-carbon steel of 2.5 mm thickness have been used to butt joined for 10 kW fiber laser welding system with ER4043 as filler metal on GTAW. The joints had dual characteristics of a welding joint on the aluminum side and a brazing joint on the steel side. The smooth Fe_2Al_5 layer adjacent to the steel matrix and the serrated-shape $FeAl_3$ layer close to the weld metal have been formed at the brazing interface.

Shekhar *et al.* (2015) discussed welding is the manufacturing process, which is carried out for joining of metals by the GTAW. This investigation the influence of welding parameters like welding current, welding voltage and gas flow rate on hardness of 304 grade materials and austenitic stainless steel during welding. Taguchi optimization method has been applied to find the optimal process parameters for hardness. A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance have been used for optimization of welding parameters. A conformation experiment was also conducted and verified the effectiveness of the Taguchi optimization method. The improvement of S/N ratio is 0.04. The

experiment value that is observed from optimal welding parameters, the Hardness is 188.70 BHN & S/N ratio is 45.51.

Balaram *et al*. (2016) carried out the investigated to the welding process has been conducted using the GTAW technique. The GTAW is used very commonly in regions, such as rail car manufacturing, automotive and chemical industries. The present work is aimed at experimental analysis of GTAW by considering the effect of various input parameters on certain performance measures using Taguchi's orthogonal array experimental design on Duplex Stainless Steel (2205).The comparison of Activated GTAW with GTAW has been investigated. The activated GTAW can increase the joint penetration.

Sanap *et al*. (2016) studied of the welding speed and geometry to find out the tensile strength and impact strength in case of structural steel (A633 Grade E) for the butt weld joint will be done on GTAW process. In this work the experimentation will be done on the different welding speed to prepare a V-groove butt weld joint. After the studying the Indian welding journal published by Indian welding society (AWS) it is observed that the strength of the joint is depends upon the depth of penetration of the filler material and the heat affected zone.

2.1.6 Review of Literature of GMAW, GTAW and Other Processes for alloys other than Aluminium Alloy

Ahmed *et al.* (2010) discussed the GTAW is one of the widely used techniques for the joining ferrous and non ferrous metals. The GTAW process offers several advantages like joining of the unlike metals, the low heat effected zone, absence of slag etc the compared to the GMAW. The accuracy and the quality of the welded joints largely depends upon the type of power supply (DCSP or DCRP or ACHF), welding speed, type of inert gas used for shielding. This paper deals with the investigation of the effect of welding speed on the tensile strength of the welded joint.

Liang *et al.* (2011) welding experiment is performed to verify the accuracy of the FE model developed. It is found that the angular distortion first increases to its maximum value at the threshold of heat input, then decreases with the further increasing of heat input, while the transverse shrinkage increases with the increasing of heat input continuously.

Akellaa *et al.* (2013) the design of experiments (DOE) towards the distortion optimization caused by butt joint on GMAW and GTAW. It has been found from these experiments that root gap has a major contribution of 43% and weld current of 36% influence on distortion.

Urso *et al*. (20014) discussed about this research work for friction stir welded (FSW) butt joints have been performed on 8 mm thick sheets made of AA6060 T6 by means of a CNC machine tool, at feed rates between 117 and 683 mm/min and tool rotational speed between 838 and 1262 rpm. The tensile tests, metallographic analyses and micro-vickers tests have been carried out to evaluate the mechanical properties of the joints as a function of the welding parameters. The results show the influence of welding parameters on the mechanical properties.

2.2 SUMMARY OF LITERATURE REVIEW

The literature review has been summarized in following Table 2.1:

Table 2.1: Summary of review of literature

Research work of aluminium alloy for GMAW process				
Author (Year)	Workpiece	Parameters	Responses	Methods
James *et al.* (2008)	AA5083-H321	I, V & GFR	Residual stress	Taguchi
Lihui *et al*. (2012)	AA6052	I & Arc length	UTS	Taguchi
Satyaduttsinh *et al*. (2014)	AA6052	I, V, WS and GFR	Temperature distribution	FEM
Anas *et al*. (2015)	AA 6058	V & filler feed rate	UTS	Regressio n analysis
Vineeta *et al*. (2015)	AA5083 and 6061	I, V, WS	UTS and Hardness	Taguchi
Vivek *et al*. (2015)	AA5083	I, V, GFR	UTS, Impact strength	SR method
Research work of aluminium alloy for GTAW process				
Urena *et al*. (1999)	AA2014/SiC/Xp			
Wang *et al.* (2008)	AA5A12	I, V & Angle B/W workpiece	Residual distortion	-
Pasupathy *et al*. (2013)	AA1050	I, S and distance W/B E and W	UTS	Taguchi method
Lakshman *et al*. (2013)	AA5083	I and welding speed	UTS	Taguchi
Anoop *et al*. (2013)	AA 7039	Pulse, base current and frequency	Hardness	Taguchi
Leo *et al*. (2015)	Al–Mg alloy	I, V & GFR	Hardness & Tensile	Taguchi
Sivasankaran *et al*. (2015)	aluminium alloy 8011	Pulse and base, freq. and duty cycle	Tensile strength	Taguchi
Chandrashek er *et al*. (2017)	AA6058	Cutting speed, feed, depth of cut	Surface roughness	Taguchi
Sindiri *et al*. (2017)	AA5083-H18	I, S and V	UTS	Taguchi

Research work for aluminium alloy on GMAW, GTAW and other processes				
Moreira et al. (2007)	AA5082	GFR, I & root gap	Hardness	Taguchi
Sushil *et al*. (2013)	Al 6101 T6	Welding speed & feed rate	UTS & Poisson's ratio	-
Borrego et al. (2014)	AA5083-H111	V & Welding speed	Hardness	Taguchi
Jesus et al. (2014)	AA 6082-T651	I, V & GFR	Hardness	Taguchi
Ashwani *et al*. (2014)	AA6061	I, V, GFR & Welding speed	Efficiency & heat input	-
Saurabh *et al*. (2014)	AA6061	I, V, S	Tensile and Hardness	Taguchi
Arun *et al*. 2015	AA6061 and ER4043	I, V and Welding speed	Tensile, hardness, microstructure	-
Research work of other alloys than aluminium alloy for GMAW, GTAW and other processes				
Manoj *et al*. (2010)	mild steel specimen	I, V, welding speed & nozzle to plate distance	weld deposit area	Factorial Design
Aghakhani *et al*. (2011)	ST-37 steel plates	Wire feed, V, nozzle to plate dist. Gas flow rate	Fluid dilution	Taguchi
Suresh et al. (2011)	AISI 304 & 316	I, S, Root gap, angle	Hardness, Tensile	Taguchi
Abbasi *et al*. (2012)	mild steel	Arc time, welding speed, heat input, & shape factor	penetration depth & weld width	-
Pawan *et al*. (2013)	low carbon steel SS & AISI 304	I, V & GFR	Hardness	Taguchi
Patil *et al*. (2013)	AISI 1030 mild steel	I, V & welding speed	UTS	Taguchi
Mohan *et al*. (2014)	austenitic steel, and mild steel	I, V & welding speed	Penetration	Taguchi
Deepak *et al*. (2014)	1018 Mild Steel	I, V & GFR	Tensile strength	Taguchi
Priti *et al*. (2014)	mild steel plates	Wire feed rate, V, GFR, welding speed & NPD	bead width, dilution and depth of HAZ	Taguchi
Gagandeep *et al*. (2015)	ferrous and non-ferrous metals	GFR, V & Root gap	Tensile strength & hardness	Taguchi
Jadoun *et al*. (2015)	SS-304	I, V and speed	Tensile, hardness, shear and elongation	Taguchi
Rahul *et al*. (2015)	HSS & Mild steel of grade M2	I, V, GFR	Tensile strength	Taguchi
Prasenjit *et al*. (2015)	stainless steel	I, V & welding speed	Tensile, hardness	Taguchi
Mohit *et al*. (2015)	AISI 304	I, V & GFR	UTS	Taguchi
Diganta *et al*. (2015)	grade C20 carbon steel and ER70S-4	I, V & GRF	Tensile	Taguchi
Rakesh Kumar *et al*. (2017)	low carbon steel	I, V, Travel speed & welding passes	Hardness & Residual stress	Taguchi

Research work of other alloys than aluminium alloy for GTAW process				
Choi *et al*. (2008)	ASTM B265	I, v & welding speed	Hardness	Taguchi
Jun *et al*. (2009)	SS304	I, V & GFR	Tensile	-
Wang *et al*. (2011)	Ni base super alloy	I & welding speed	UTS	Taguchi
Parthiv *et al*. (2012)	ferrous and non-ferrous	I, welding speed & GFR	Weld bead height & width	Genetic Algorithm
Sathish *et al*. (2012)	A106 Grade B and A312 TP 316L	I, Bevel angle & GFR	UTS, YS & elongation	Taguchi
He *et al*. (2014)	boron alloys	I, V & wire speed	Yield & UTS	Taguchi
Karthik *et al*. (2014)	austenitic 304 SS	Shielding gas	Tensile	taguchi
Simhachalam *et al*. (2015)	stainless steel 304(18Cr-8 Ni)	I, GFR and voltage	Tensile and impact	Taguchi
Ahir *et al*. (2015)	austenitic stainless steel 316	I, S and groove angle	Angular Distortion	Taguchi
Jeyaprakash *et al*. (2015)	stainless mild and high tensile steels	Power source, I, GFR and filer wire	Arc stability	Taguchi
Junhao et al. (2015)	AA6013 and Q 235 low-carbon steel	I, V, GFR	Tensile strength	Taguchi
Shekhar *et al*. (2015)	304 grade and austenitic SS	I, V and GFR	Hardness	Taguchi
Balaram *et al*. (2016)	Duplex Stainless Steel (2205)	Electrode dia, Time, I and GFR	Tensile strength	Taguchi
Sanap *et al*. (2016)	structural steel (A633 Grade E)	Groove angle, bevel height, root opening and welding speed	Tensile and elongation	Taguchi
Research work of other alloys than aluminium alloy for GMAW, GTAW and other processes				
Ahmed *et al*. (2010)	AA6351	S, bevel angle & bevel height	Tensile strength	Taguchi
Liang *et al*. (2011)	AA5082	Heat input	distortion	FEM
Jay Joshi	AA3100	I, Feed rate and GFR	Tensile	Grey relational
Akellaa *et al*. (2013)	AA6060 T6	I, Root gap	distortion	Taguchi
Urso *et al*. (2014)	AA6060	I, V and speed	Tensile, hardness	-

2.3 CONCLUSIONS

The review of literature in the preceding section establishes the fact that efforts are still continuing for improving the tensile strength, impact strength and hardness of materials. In this chapter, summary of research papers and journals, related to the optimization of process parameters is presented using various methods. These papers show the effect of various input parameters on the output characteristics and variation in result due to the method used, material used or the levels of parameters being used. In the present study, the effect of input parameters such as welding Current, welding voltage, welding speed, gas flow rate and root gap has been investigated in detail for optimizing the performance characteristics such as ultimate tensile strength, impact strength and hardness from the literature reviewed it has been found that less work has been done in welding of dissimilar aluminium alloys. Hence the present research work focuses on optimization of parameters for aluminium alloys 3003-H2 (parent material) and ER4043 (filler wire).

Materials and Methods

3.1 INTRODUCTION

This chapter describes about the materials and methods used for the welding of the aluminium alloys under this investigation. In order to study the effect of process parameters on the gas metal arc welding (GMAW) and the gas tungsten arc welding (GTAW), experiments were conducted. Measurements related to the above mechanical characteristics were made. The details of experimental setup, the measuring tools and equipment used for the present investigation have been detailed in this chapter.

The experimental setup consists of the following:

- Gas Metal Arc Welding (GMAW) set up
- Gas tungsten arc welding (GTAW) set up

3.2 GAS METAL ARC WELDING SETUP

The experiments were conducted on the semiautomatic 'Pana-auto KR (Panasonic) II 400' Machine. The schematic diagram of the gas metal arc welding (GMAW) setup is shown in Figure 3.1.

Fig. 3.1: The setup of GMAW

3.2.1 Specifications of GMAW

Various constant parameters which are used on the gas metal arc welding (GMAW) machine for joining operation:

Type of machine	:Semiautomatic Pana-auto KR (Panasonic) II 400
Electrode material	:2% thoriated tungsten electrode
Electrode size	:3.5 mm diameter
Shielding gas	:A mixture of 75 % helium and 25 % argon

Arc length	:2.5 mm		
Duty cycle at	:20^0C,	80 % DC: 300A	and 100 % DC: 270A
Duty cycle at	:40^0C,	60 % DC:300A	and 100 % DC: 250
Open circuit voltage	:92V		
Ambient temperature	:-10C to +40C		
Wire feed drive unit	:4-roller (37 mm)		

Table 3.1: The main technical variable parameters range for the GMAW machine

Si No.	Welding parameters	Parameters range
1.	Welding current (Amps)	0-600
2.	Welding voltage (Volts)	0-80
3.	Welding speed (cm/min)	0-100
4.	Gas flow rate (Lit/min)	0-250
5.	Root gap (mm)	0-50

3.2.2 Equipment and Resources of Gas Metal Arc Welding Process

The complete GMAW setup is divided into the following sub systems:

1. Power source
2. Shielding gas
3. Welding torch
4. Wire feeder
5. Electrode wire
6. Earth clamp
7. GMAW Gun
8. Fume extractor

3.2.2.1 Power source

It is the important resource and provides the power for some kinds of welding. The solid – state power supply converts conventional single – phase 50 Hz line current to 20 kHz electrical energy. It contains all the electronic controls and can be located up to 30 feet from the converter assembly. The automatic frequency control eliminates the need for adjusted of the power supply after initial setup. The power supply is operated by various voltage stepped switches, wind handles and indicators located on the front. The alternating current is rarely used in the GMAW process as shown below in Figure 3.2 (minaprem.com).

1. Power on /off switch (1/0)
2. Wide range wire feed speed (WFS) control (up to 700 rpm). The dial is calibrated in true inches per minute for easy, accurate procedural change.
3. Seven voltage tapes
4. Brass to brass gun connection bushing and work clamp access
5. Gun trigger lead connection

Fig. 3.2: Power control system

Electrical specifications of power supply unit

Line voltage	: 230 V;	Output power	:500W
Phase	: Single;	Output frequency	:20 kHz
Line current	:5.5 Amp		

Physical specifications of power supply unit

Length	: 559 mm;	Width	: 317 mm
Height	: 168 mm;	Weight	25 kg

3.2.2.2 Shielding gases

The primary roll of shielding gas in the gas metal arc welding (GMAW) process is to protect the molten metal for the weld zone from oxidation and other contamination by the atmosphere. If the weld pool is contaminated fusion defects can be caused, also porosity and the embrittlement of the weld metal. It ranges from the inert gases to reactive ones. The commonly used gases are argon, helium, carbon dioxide and oxygen. In the present investigation argon and helium was used as a shielding gas because it has the lower ionization potential than helium, it shield the welding bead pool more effectively (MIG-welding.html).

3.2.2.3 Welding torch

This provides the method of delivery from the wire feed unit to the point at which the welding is required. The GMAW torch has a handle with a trigger that is attached to the wire feed through a cable. It feeds the shielding gas, the filler wire and electricity to the joint.
The GMAW torch can be air cooled or water cooled and the most modern air cooled torches have a single cable, in which the welding wire slides through a liner (Vineeta 2015).

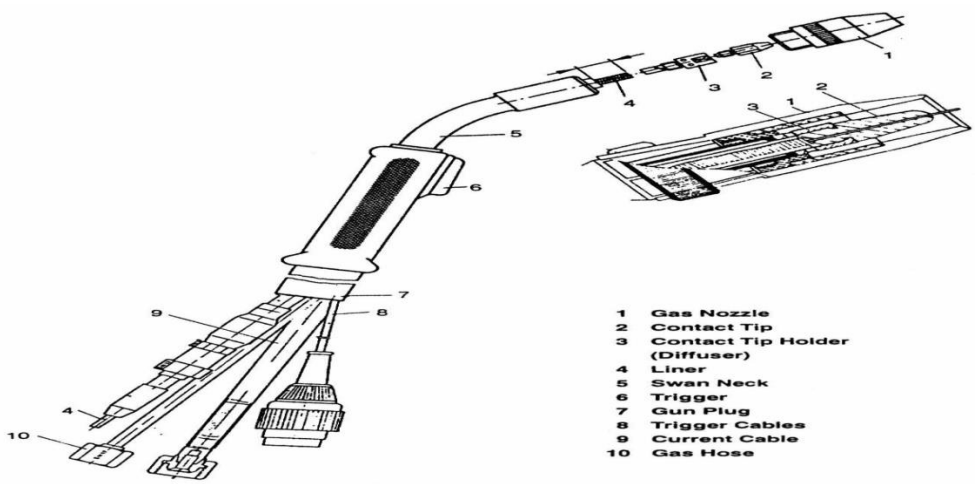


Fig. 3.3: Gas metal arc welding torch

3.2.2.4 Wire feeder system

The wire feeder continually draws a small diameter electrode wire from the spool and drives it through the cable assembly and gun at a constant rate of speed. The constant rate of wire feed is necessary to assure a smooth even arc. This must be adjustable to provide for the different welding current settings that may not be undesired. These drive wheels the depending upon their location in the wire feed unit are either the push type or the pull type as shown in Figure 3.4 (Satyaduttsinh *et al*. 2014).

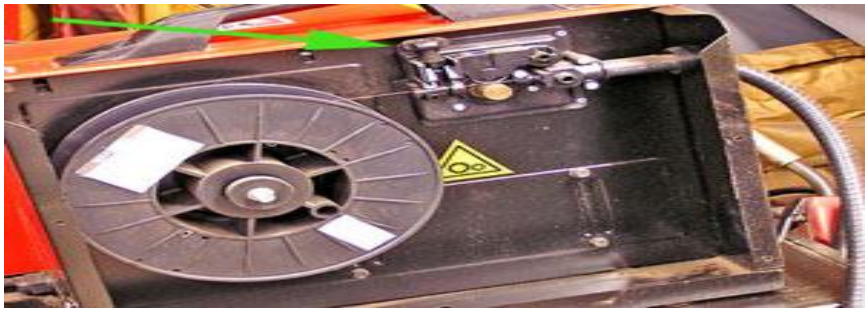


Fig. 3.4: Gas metal arc welding wire feeder system

3.2.2.5 Electrode wire

The selection of the correct electrode wire is an important decision and the success of the welding operation depends on the correct selection as shown in Figure 3.5.

There are some factors to consider when selecting the correct electrode (Lihui *et al*. 2012):

a) Consider the type of metal to be welded and choose a filler wire ER 4043 to match the base metal AA 3003 in analysis and mechanical properties
b) Examine the surface condition of the metal to be welded. If it is rusty or scaly, it will have an effect on the type of the wire selected
c) The GMAW process the welding is not effective on rusty or the painted surfaces as the lower voltage is not the effective a scouring the surface in the same manner as a stick electrode

Fig. 3.5: Wire used for gas metal arc welding

3.2.2.6 Earth clamp

It is the cathode in the circuit and completes the circuit between the welder, the project and the welding torch. It should either be clipped directly to the piece of metal being welding

or onto a metal welding table. The earth clamp must be making good contact with the piece being welded for it to work so be sure to grind off any rust or paint that may be preventing it from the making a connection with work as shown in Figure 3.6 (Mamatha *et al*. 2014).

Fig. 3.6: Earth clamp

3.2.2.7 GMAW gun

This equipment used for the direct shielding gas over the puddle during the GMAW. A nozzle that is too the large or too the small may result in air from the atmosphere reaching the puddle and contaminating the weld. The nozzle is made of the copper alloy to the help remove the heat from the welding zone as shown in Figure 3.7 (Anas *et al*. 2015).

Fig. 3.7: Gas metal arc welding gun

3.2.2.8 Fume extractor

The fumes that are generated in the welding are injurious to health. The smoke and fumes are removed by its help; it is shown as below in Figure 3.8.

Fig. 3.8: Fume extractor

3.2.3 Selection of Various Parameters Affecting GMAW

To the determination of contributing which needs to be the investigated depends on the responses of interest. Theoretical studies and review of literature suggested that when doing welding with the GMAW on aluminium alloys (AA3003) plate of 5 mm thickness the values of different parameters range should be:

Welding current:	170-200 Amps,	Gas flow rate:	15-23 Lit/min
Welding voltage:	20-28 Volts,	Root gap:	1.5-2.5 mm
Welding speed:	50-80 cm/min,		

3.3 GAS TUNGSTEN ARC WELDING SETUP

The experiments were conducted on the semiautomatic 'Techno weld MDX-300' machine. The schematic diagram of the gas tungsten arc welding (GTAW) setup is shown in Figure 3.9. The GTAW is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. It is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminium, and copper alloys.

The complete setup is divided into the following sub system.

Fig. 3.9: The setup of GTAW

3.3.1 Specifications of GTAW

The various constant parameters which are used on the gas tungsten arc welding (GTAW) machine for joining operation:

Type of machine: Techno weld MDX-300

Electrode material: 2% thoriated tungsten electrode

Electrode size: 3.5 mm diameter

Shielding gas: A mixture of 25% helium and 75 % argon

Arc length: 2.5 mm.

Table 3.2: Main technical variable parameters range for GTAW machine

Si. No.	Welding parameters	Parameters range
1.	Welding current (Amps)	0-600
2.	Welding voltage (Volts)	0-80
3.	Welding speed (cm/min)	0-150
4.	Gas flow rate (Lit/min)	0-200
5.	Root gap (mm)	0-50

3.3.2 Equipment and Resources of Gas Metal Arc Welding Process

The following equipments and resources used for gas tungsten arc welding process are given below (TIG-welding.html):

1. Power source
2. Shielding gas
3. Welding torch
4. Filler wire
5. Electrode wire

3.3.2.1 Power source

A constant current power source is used in the gas tungsten arc welding uses the meaning that the current and obviously heat remains relatively constant even if the electrode to the work piece gap and voltage change. This is important because the operator holds the torch in manual or the semiautomatic applications of the GTAW process. The maintaining a suitably steady the electrode to the work piece gap is difficult in a constant voltage power source since it can cause the dramatic heat variations and the make welding more difficult. The type of metal being welded effect the preferred polarity of the GTAW in Figure 3.9.

3.3.2.2 Shielding gases

In other welding processes like as the gas metal arc welding (GMAW) process and the shielding gases are necessary in the GTAW to protect the welding area from the atmospheric gases like as the oxygen which can cause the fusion defects and the porosity, the weld metal embrittlement, if they come in the contact with the electrode the arc or the welding metal. The gas also transfers heat from the tungsten electrode to the metal and it helps in the starting and the maintaining a stable arc. The selection of a shielding gas depends on the several elements or factors including the type of the material being welded the joint design and the desired final weld. The argon is the most commonly used shielding gas for the GTAW since it helps in the preventing defects due to a varying arc length. The argon helium mixtures are frequently used in the GTAW process since they can increase the control of the heat input while maintaining the benefits of using argon as shown in Figure 3.9.

3.3.2.3 Welding torch

The GTAW torches are designed for the both automatic and the manual operation and are equipped with the cooling systems using water or air. The automatic and manual torches are similar in the construction. The angle between the centerline of the handle and the centerline of the tungsten electrode can be varied on some manual torches according to the

preference of the operator The hand switches (if possible or not) to control the welding current can be added to the manual GTAW torches as shown in the Figure 3.10.

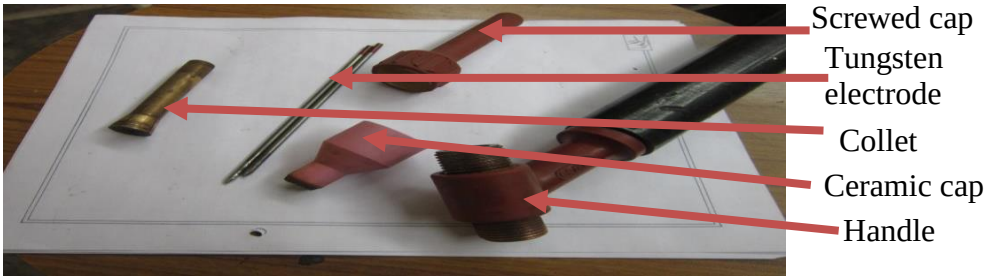


Fig. 3.10: GTAW torch parts

3.3.2.4 Filler wire

The selection of the gas tungsten arc welding the wire as shown in Figure 3.5 to be used in the both process (GMAW and GTAW) is a decision that will depend on the following aspects:

- The element composition of the material being welded
- Mechanical properties of the weld material and those that are a match for the PM
- The corrosion resistance should match
- Design of the joint
- Thickness of the parent material
- Cost of the material

3.3.2.5 Electrode

The electrode used in the GTAW is made of tungsten or tungsten alloy because the tungsten has the highest melting temperature among the pure metals at 3300^0 C. The electrodes can have either a ground finish or a clean finish. The clean finish electrodes have been the chemically cleaned while ground finish electrodes have been ground to a uniform size and have a polished surface making them the effective for the heat conduction. The diameter of the electrode can vary between 0.5 and 6.4 mm and their length can vary from 75 to 610 mm. A number of the tungsten alloys have been standardized by the international organization for standardization (ISO 6848) and the AWS A5.12 for use in the GTAW electrode is shown in Figure 3.10.

3.3.3 Selection of Various Parameters Affecting GTAW

The determination of contributing which needs to be investigated depends on the responses of interest. Theoretical studies and review of literature suggested that when doing

welding with the GTAW machine on aluminium alloys (AA3003) plate of 5 mm thickness the values of different parameters range should be:

Input parameters:	Range,	Input parameters	Range
Welding current:	210-240 Amps,	Gas flow rate:	12-20 Lit/min
Welding voltage:	22-30 Volts,	Root gap:	1.0-2.0 mm
Welding speed:	60-90 cm/min,		

3.4 Materials

The material is an important element of the experimental setup. The type of material along with their relevant properties and geometry of the material used in the present investigation are being discussed here.

3.4.1 Parent Material

It is one of the most extensively used alloys in the 3xxx series. The manganese is the major alloying element of alloys in this group which are generally non heat treatable. Because only a limited percentage of the manganese between 1.0-1.5 percent can be the effectively added to the aluminium it is used as a major element in only a few instances. One of these however is the popular AA3003 which is the widely used as a general purpose alloy for the moderate strength applications requiring good workability.

The extraction of aluminium is the complex and the expensive nevertheless aluminium is used due to it’s the favourable properties in many applications such as beverage cans, thin foils and vessels or aircraft components. The aluminium welding becomes more and more important also since welding is a very efficient and comparably cheap joining technology. The properties of the aluminium can be improved significantly with alloying elements where the most important ones are manganese, copper, magnesium, silicon and zinc.

One generally distinguishes between the aluminium cast alloys and the wrought alloys. The most cast alloys are Al-Si alloys with Si contents between 5 and more than 20 percent weight providing a good castability (lincolnelectric.com).

The American aluminum association (AAA) divides the wrought aluminium alloys into the nine different series according to their main alloying element as shown in Table 3.3 and Aluminum Association. Dependent upon the alloy content the degree of cold work and the heat treatment the aluminium provides the several important characteristics compared to the steel (McGraw Hill):

- Low density/specific gravity (2.70 $g.cm^{-3}$ compared to 7.80 $g.cm^{-3}$ for the steel at 20^0c) [6]
- Melting point is 660^0c
- Favourable strength weight ratio
- High corrosion resistance
- High ductility and toughness
- High thermal conductivity (230 $cal.sec^{-1}.m^{-1}\cdot K^{-1}$ for the commercial aluminium compared to 50 $cal.sec^{-1}.m^{-1}\cdot K^{-1}$ for the low alloy steel)
- High electrical conductivity (38.106 s/m for the commercial aluminium compared to 10.106 s/m for the low alloy steel)
- Reflectivity for light the tungsten filament (90 %)

All these properties made aluminium over the years the most important non-ferrous metal and light weight construction material in industrial applications (Davis *et al*. 1998).

Table 3.3: Wrought aluminium alloys series

No. of series	Main alloying element(s)	Main strengthening mechanism	One important property	One typical application
1xxx	Al	Solid solution Hardening	High formability	Packaging foils
2xxx	Cu	Precipitation Hardening	High strength	Aircraft components
3xxx	**Mn**	**Strain hardened/ Cold work**	**High corrosion resistance**	**Cans**
4xxx	**Si**	**Cold work**	**High formability**	**Pistons**
5xxx	Mg	Solid solution Hardening	High corrosion resistance	Ship bodies
6xxx	Mg + Si	Precipitation Hardening	High formability	Car frames
7xxx	Zn	Precipitation Hardening	High strength	Bicycle frames
8xxx	Misc.	Precipitation Hardening	High strength	Aircraft components
9xxx	-	Reserved for future use	-	-

The material chosen for all tests was aluminium alloy with IS designation AA3003-H2 (IS 737). The material was borrowed from the BHEL, Rudrapur as a hot rolled plate with a thickness of 5 mm. AA3003 is stronger and harder than 19000 but has a good weldability and workability the corrosion resistance. The aluminium of a grade 19000 is commercially pure the very ductile and the excellent in the corrosion resistant (Davis *et al*. 1998).

Table 3.4: Chemical composition of the element for the parent material AA3003 in % age (South Eastern Railway. 2001)

Mat. Grade	Size (mm)	Element	Cu	Mg	Si	Fe	Mn	Zn	Ti	Cr	Al	Condition
AA3003 (IS-737)	Thickness 5	Wt %	0.05-0.20	-	0.6	0.70	1.0-1.5	0.1	-	-	Balance	H2
H2 = Strain hardened and partially annealed												

Table 3.5: Physical properties of aluminium alloy 3003 (IS - 737)

Property	Thermal expansion (K^{-1})	Melting point (^oC)	Density ($g.cm^{-3}$)	Thermal conductivity ($W.m^{-1}K^{-1}$)	Electrical resistivity (Ω m)	Modulus of elasticity (GPa)
Value	21.6×10^{-6}	579-641	2.69	163	0.031×10^{-6}	69

Table 3.6: Mechanical properties of aluminium alloy 3003 (IS - 737)

Alloy	Density (kg/m^3)	Tensile strength (MPa)	Proof stress (MPa)	Shear strength (MPa)
AA3003	2730	140-280	269	170

The widely applications for the aluminium alloy 3003 used as a general purpose alloy for the moderate strength and the excellent workability. These samples that have used in the present investigation are shown in the Figure 3.11.

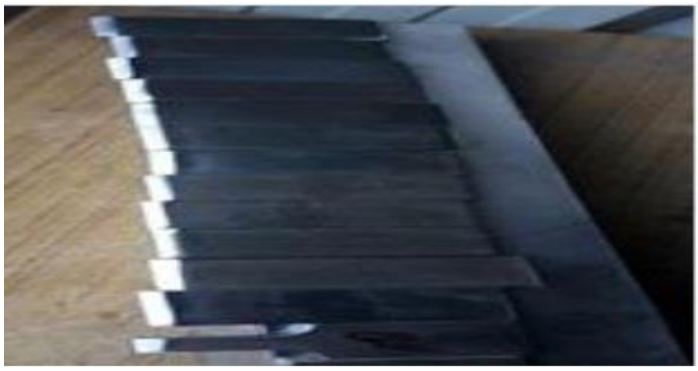


Fig. 3.11: Parent material AA3003 samples (IS - 737)

The work-pieces were cut into the standard sizes (American Welding Society Standard) of 100 mm × 40 mm × 5 mm by EDM wire cut machine. Figure 3.11 shows the photograph of the all samples used in the present investigation.

3.4.2 Filler Material

In the present research work AA4043 has been used as filler material (wire). It is one of the oldest and most widely used welding and the brazing alloy. The chemical composition, the physical properties and the mechanical properties are shown in Table 3.7, Table 3.8 and Table 3.9 respectively, the extracted from Hindalco extrusions (Davis *et al*. 1998).

Table 3.7: The element composition of aluminium alloy ER4043 (filler wire)

Element	Size(mm)	Cu	Si	Fe	Mn	Mg	Cr	Zn	Ti	Al
% age	Φ 1.6	0.30	4.5-6.0	0.8	0.05	0.0	0.0	0.10	0.20	Balance

Table 3.8: The physical properties of aluminium alloy ER4043 (filler wire)

Property	Density ($g.cm^{-3}$)	Melting point (^oC)	Electrical resistivity (Ω m)	Thermal conductivity ($W.m^{-1}K^{-1}$)	Thermal expansion (K^{-1})	Modulus of elasticity (GPa)
Value	2.69	570	4.16×10^{-8}	163	22.1×10^{-6}	72

Table 3.9: The mechanical properties of aluminium alloy ER4043 (filler wire)

Alloy	Temper	Proof stress (MPa)	Tensile strength (MPa)	Shear strength (MPa)
AA4043	O (annealed)	145	145	90

3.5 METHODS OF WELDING

The preliminary setup was done in accordance with the instructions provided in the instruction manual for AWS. The experiment were performed on a semiautomatic the gas metal arc welding (GMAW Pana-auto KR II 400) and the gas tungsten arc welding (Techno weld MDX-300, AC/DC) welding machine.

The aluminium alloy as parent material selected for experimentations were AA3003 in H2 condition and the filler rod as ER4043 for better penetration and good bead. All the samples and the filler rod surface were cleaned by the stainless steel wire brush with the acetone for removing the dust, oil grease and the thin oxide coating before the welding. A consumable electrode (for GMAW) was used with 75 % helium and 25 % argon (mixture used when deeper root penetration and reduced porosity are desired) as a shielded gas and a non-consumable tungsten electrode (GTAW) of 3.5 mm diameter was used with 25 % helium and 75 % argon (mixture used when deeper root penetration and reduced porosity are desired) as a shielded gas simple butt the weld joints were prepared with AC sinusoidal wave at various currents and frequencies. These welded samples were used to measure the ASTM grain size of scanning electron microscope (SEM) and Electron dispersion spectroscopy (EDS) and the mechanical properties like as ultimate tensile strength, impact strength and hardness at weld zone.

3.5.1 Procedure for Experimentation

The parent material used for the present research work is an aluminium alloy 3003-H2 (IS - 737) with the dimensions of the work piece as 100 mm x 40 mm x 5 mm. The filler wire of 1.6 mm diameter and the consumable electrode with the helium and the argon as inert gas

was used for the gas metal arc welding (GMAW) and the non-consumable electrode with the helium and argon as inert gas was used for the gas tungsten arc welding (GTAW).

The welding of specimens has been carried out by the GMAW and the GTAW setup and samples preparation with the used EDM wire cut for UTS, impact test and hardness. All the machining process like as GMAW, GTAW and EDM are available at Durga dhalai udhyog, B-20, industrial area, Rudrapur (U.S Nagar), India. The element composition of parent material and the filler wire is given in Table 3.4 and Table 3.7 respectively.

The input welding process parameters selected for this research work were welding current, welding voltage, welding speed, gas flow rate and root gap. The ultimate tensile strength, impact strength, hardness, the scanning electron microscope (SEM) and the electron dispersion spectroscopy or the energy dispersive X – ray spectroscopy (EDS) test was taken as the output quality characteristic.

The each of these response parameters was varied at 3 levels. The range and levels of these response parameters were decided on the basis of preliminary experiments conducted by using one variable at a time approach. The feasible range for two processes of the GMAW and the GTAW machining parameters was defined for the first process by varying welding current (170–200 Amps), welding voltage (20–28 Volts), welding speed (50-80 cm/min), gas flow rate (15–23 Lit/min), root gap (1.5-2.5 mm). The second process by varying welding current (210-240 Amps), welding voltage (22-30 Volts), welding speed (60-90 cm/min), gas flow rate (12-20 Lit/min), root gap (1.0-2.0 mm) for the welding of selected parent material and the filler wire. According to the number of input factors and their levels L_{27} orthogonal array is selected from the Taguchi's special set of standard arrays used MINITAB-18.

3.5.2 Preliminary Setup

The steps are used for all experimental procedure in all setup as under (Jadoun 2005):

(1) Initial starts the setup one by one used Connecting the power line from power supply and pumping system to the appropriate stand outlets
(2) Setting power switches on stand to 'OFF' position
(3) Setting switches on front of power supply to 'ON' position
(4) Setting power supply power control to minimum condition
(5) Connecting power line from stand to electrical outlet
(6) Turning on the pump switch
(7) Turning all the machine power supply
(8) Turning the machine off

3.5.3 Power Supply Tuning for GMAW and GTAW

The tuning control is located on the front panel of the power supply. The tuning optimizes the solid state circuitry for the best possible operation. The tuning procedure is performed every time a new coupler is used. The following steps must be taken care of while tuning the arc power supply (Jadoun 2005).

(i) Setting the power control to minimum before beginning

(ii) Depressing and holding the 'ON/OFF/TEST' switch in the 'TEST' position

(iii) Rotating the tuning control in a clockwise or counter- clockwise direction to find the lowest meter reading

(iv) Checking for overloading. If the overloading light comes on during the tuning procedure, release the switch and rotate the tuning control to a new position before trying to tune again

(v) The process is repeated until the machine shows overloading. Once tuned and the machine is running, the power control is set at desired position

(vi) Lifting the switch and setting it to the 'ON' position for normal operation

3.6 TAGUCHI EXPERIMENTAL STRATEGY FOR DESIGN AND ANALYSIS

Taguchi recommends orthogonal arrays (OA's) for laying out of experiments. These OA's are generalized Graeco-Latin squares. To design an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns. Thus use of linear graphs and triangular tables suggested by Taguchi makes the assignment of parameters simple. The array forces all experiments to design almost identical experiments (Roy 1990). In the Taguchi method the result of the experiments are analyzed to achieve one or more of the following objectives (Roy 1990).

(1)To establish the best or the optimum condition for a product or process

(2)To estimate the contribution of individual parameters and interactions

(3)To estimate the response under the optimum condition

The optimum condition is identified by studying the main effects of each of the parameters. The main effects indicate the general trend of influence of each parameter. The knowledge of contribution of individual parameters is a key in deciding the nature of control to be established on a production process. The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments in determining the percent contribution of each parameter against a stated level of confidence. Study of

ANOVA table for a given analysis helps to determine which of the parameters need control and which do not (Ross 1988).

Taguchi suggests two different routes to carry out the complete analysis. First, the standard approach; where the results of a single run or the average of repetitive runs are processed through main effect and ANOVA analysis (Raw data and analysis). The second approach, which Taguchi strongly recommends for multiple runs, is to use signal-to-noise (S/N) ratio for the same steps in the analysis. The S/N ratio is a concurrent quality metric linked to the loss function (Barker 1990). By maximizing the S/N ratio, the loss associated can be minimized. The S/N ratio determines the most robust set of operating conditions from variation within the results. The S/N ratio is treated as a response (transform of raw data) of the experiment. Taguchi recommends (Ross 1988) the use of outer OA to force the noise variation into the experiment i.e. the noise is intentionally introduce into the experiment. However, processes are often subject to many noise factors that in combination strongly influence the variation of the response. For extremely 'noisy' systems, it is not generally necessary to identify specific noise factors and to deliberately control them during experimentation. It is sufficient to generate repetitions at each experimental condition of the controllable parameters and analyze them using an appropriate S/N ratio (Byrne and Taguchi 1987).

In the present investigation, both the analysis: the raw data analysis and S/N data analysis have been performed. The effects of the selected GMAW and GTAW process parameters on the selected performance characteristics have been investigated through the plots of the main effects based on raw data. The optimum condition for each of the performance characteristics have been established through S/N data analysis aided by the raw data analysis. No outer array has been used and instead, experiments have been repeated three times at each experimental condition.

3.6.1 Loss function, S/N Ratio and their Inter-Relationship

The heart of Taguchi method is his definition of the nebulous and elusive term 'quality' as the characteristic that a voids loss to the society from the time the product is shipped. Loss is measured in terms of monetary units and is related to quantifiable product characteristics (Jadoun 2005). Taguchi define quality loss via his 'loss-function'. He unites the financial loss with the functional specification through a quadratic relationship that comes from a Taylor series expansion. The quadratic takes the form of a parabola. Taguchi define the loss-function as a quantity proportional to the deviation from the nominal quality

characteristic (Roy 1990). He has found the following quadratic form to be practical workable function (Roy 1990).

$L(y) = k\,(y-m)^2$ 3.1

Where, L = Loss in monetary unit

M=value at which the characteristic should be set

y=actual value of the characteristic

k= constant depending on the magnitude of the characteristic and the monetary unit involved

The loss function represented in equation 3.1 is graphically shown in Figure 3.12 (a) the characteristics of the function are (Roy 1990)

(i) The further the product's characteristic varies from the target value, the greater is the loss. The loss must be zero when the quality characteristic of a product meets its target value.

(ii) The loss is a continuous function and not a sudden step as in the case of traditional approach (Figure 3.12 (b)). This consequence of the continuous loss function illustrates the point that merely making a product within the specification limits does not necessarily mean that product is of good quality as shown in Figure 3.12 (a).

The difference between Taguchi loss – function and the traditional quality control approach is graphically shown in Figure 3.12 (a, b) (Ross 1988)

3.6.2 Average Loss-Function for Product Population

In a mass production process, the average loss per unit is expressed as (Roy 1990):

$L(y) = [k(y_1-m)^2 + k\,(y_2-m)^2 + \ldots + k\,(y_n-m)^2]$ ….....3.2

Where, $y_1, y_2 \ldots y_n$ = actual value of the characteristic for unit 1, 2,…....n respectively

n = number of units in a given sample

k = constant depending on the magnitude of the characteristic and the monetary unit involved

m = target value at which the characteristic should be set

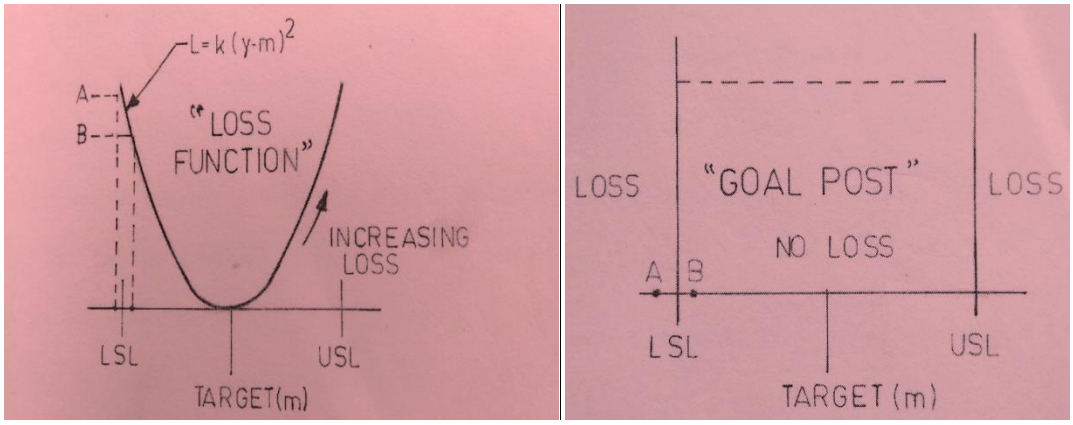
The equation 3.2 can be simplified as:

$L(y) = [k(y_1-m)^2 + k\,(y_2-m)^2 + \ldots + k\,(y_n-m)^2]$.....3.3

$= k\,(MSD_{NB})$

Where, MSD_{NB} = Mean squared deviation or the average of squares of all deviations from the target or nominal value

NB = 'Nominal-is-best'



(a)Taguchi loss function (b) Traditional

Fig. 3.12: (a, b) Taguchi's Loss Function & Traditional Approach (Rajurkar *et al*. 1999)

3.6.3 Other Loss Function

The loss function can also be applied to product characteristics other than the situation where the nominal value is the best value (m).

The loss –function for a lower-is-better type of product characteristic (LB) is shown in Figure 3.13 (a). The loss function is identical to the nominal-is-best type of situation when m=0, which is the best value for lower is better characteristic (no negative value).

The loss function for a higher-is-better type of product characteristic (HB) is shown in Figure 3.13 (b), where also m=0 (Jadoun 2005).

3.6.4 Signal-to-Noise (S/N) Ratio

The loss function discussed above is an effective Figure of merit for making engineering design decision. However, to establish an appropriate loss-function with its k value to use as a figure of merit is not always cost effective and easy. Recognizing the dilemma, Taguchi create a transform for the loss-function which is named as the signal-to-noise (S/N) ratio (Barker 1990).

The S/N ratio, as stated earlier, is a concurrent statistic. A concurrent statistic is able to look at two characteristics of a distribution and roll these characteristics into a single number or figure of merit. The S/N ratio combines both the parameters (the mean of level of the quality characteristic and variance around this mean) into single metric (Barker 1990).

A high value of S/N implies that the signal is much higher than the random effect of noise factors. Process operation consistent with highest S/N, always yields optimum quality with minimum variance (Baker 1990).

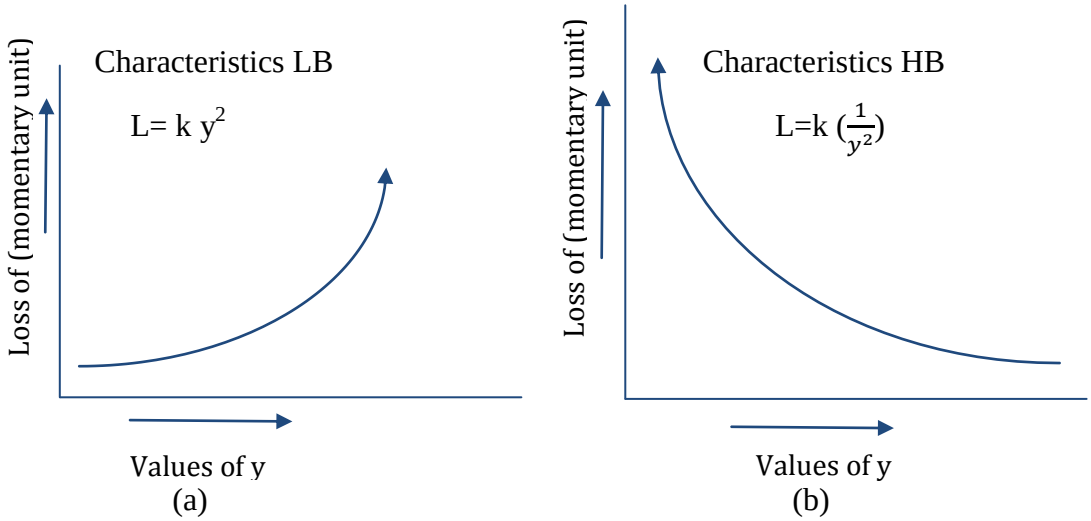


Fig. 3.13: Loss functions for LB and HB Characteristics (Barker 1990)

The S/N ratio consolidates several repetition (at least two data points are required) into one value. The equations for calculating S/N ratios for Lower-is-better (LB), Higher-is-better (HB) and Nominal-is-best (NB) type of characteristics are (Roy 1988):

(i) Lower is better (LB)

$$(S/N)_{LB} = -10 \log \left[\frac{1}{R}\sum_{j=1}^{R} y_j^2\right] \quad \text{.....3.4}$$

Where y_j = value of the Characteristics in an observation j

R = number of observation or number of repetitions in a trial

Alternatively equation 3.4 may be written as (Roy 1990),

$$(S/N)_{LB} = -10 \log (MSD_{LB}) \quad \text{.....3.5}$$

Where $MSD_{LB} = [y_1^2 + y_2^2 + \dots\dots\dots\dots y_R^2]/R$

Here target value m=0

(iii)Higher is better (HB)

$$(S/N)_{LB} = -10 \log \left[\frac{1}{R}\sum_{j=1}^{R} \frac{1}{y_j^2}\right] \quad \text{.....3.6}$$

Where y_j = value of the Characteristics in an observation j

R = number of observation or number of repetitions in a trial

Alternatively equation 3.6 may be written as (Roy 1990),

$$(S/N)_{HB} = -10 \log (MSD_{HB}) \quad \text{.....3.7}$$

Where $MSD_{HB} = \left[\frac{1}{y_1^2} + \frac{1}{y_2^2} + \dots\dots\dots \frac{1}{y_R^2}\right]/R$

Here target value m=0

(iii) Nominal is better (NB)

$$(S/N)_{NB} = -10 \log \left[\frac{1}{R}\sum_{j=1}^{R}\left(y_j - y_0\right)^2\right] \quad \text{.....3.8}$$

Where y_j = value of the characteristics in an observation j

R = number of observation or number of repetitions in a trial

Y_0 = nominal value of the

Alternatively equation 3.8 may be written as (Roy 1990),

$$(S/N)_{NB} = -10 \log (MSD_{NB}) \quad \text{.....3.9}$$

Where $MSD_{NB} = [(y_1 - y_0)^2 + (y_2 - y_0)^2 + \cdots \ldots \ldots + (y_R - y_0)^2]/R$

The Mean Squared Deviation (MSD) is a statistical quantity that reflects the deviation from the target value. The expressions for MSD are different for different quality Characteristics. For the Nominal-is-best characteristics, the standard definition of MSD is used. For the other two characteristics the definition is slightly modified. For Lower-is-better, the unstated target value is zero. For Higher-is-better, the inverse of each large value becomes a small value and again, the unstated target value is zero. Thus for all three expression, the smaller magnitude of MSD is being sought (Jadoun 2005).

3.6.5 Relationship between S/N Ratio and Loss-Function

Figure 3.13 (a) shows a signal sided quadratic loss-function with minimum loss at the zero value of the desired characteristic. As the value of y increases, the loss grows. Since, loss is to be minimized the target in this situation for y_i is zero.

$L(y) = k(y-m)^2$

If m=0,

$L(y)\ k(y)^2$

The loss may be generalized by used by using k=1 and the expected value of loss may be found by summing all the losses for a population and dividing by the number of samples (R) taken from this population. This in turn gives the following expression (Barker 1990).

$$EL = \text{Expected Loss} = \left[\frac{\sum y^2}{R}\right] \quad \text{.....3.10}$$

The above expression is a figure of demerit. The negative of this demerit expression produces a positive quality function. This is a thought process that goes into the creation of

S/N ration from the basic quadratic loss-function. Taguchi adds the final tough to his transformed loss-function by taking the log (base 10) of the negative expected loss and then he multiplies by 10 to put the metric into the 'decibel' terminology (Barker 1990). The final expression for Lower-is-better S/N ratio takes the form of the equation 3.4. The same thought pattern follows in creation of other S/N ratios.

3.7 STEPS IN EXPERIMENTAL STRATEGY FOR DESIGN AND ANALYSIS

The Taguchi experimental design and analysis flow is shown in Figure 3.14. The important steps are discussed in the subsequent articles (Jadoun 2005).

3.7.1 Selection of Orthogonal Array

To select an appropriate orthogonal array for the experiments, the total degrees of freedom need to be computed. In this research work for the each three level parameter has 2 degree of freedom (DOF = Number of level–1) the total DOF required for the five parameters each at the three levels is 10. Once the degrees of freedom required are known the next step is to select an appropriate orthogonal array to fit the specific task. Basically, the degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. In this investigation the L_{27} (L_3^5) orthogonal array (3-level OA) having 10 degree of freedom was selected from the Taguchi's special set of standard arrays used Minitab-18 software tool. In selecting an appropriate OA, the pre-requisite are (Ross 1988, Roy 1990):

(1) Selection of process parameters and/ or interaction to be evaluated

(2) Selection of number of levels for the selected parameters

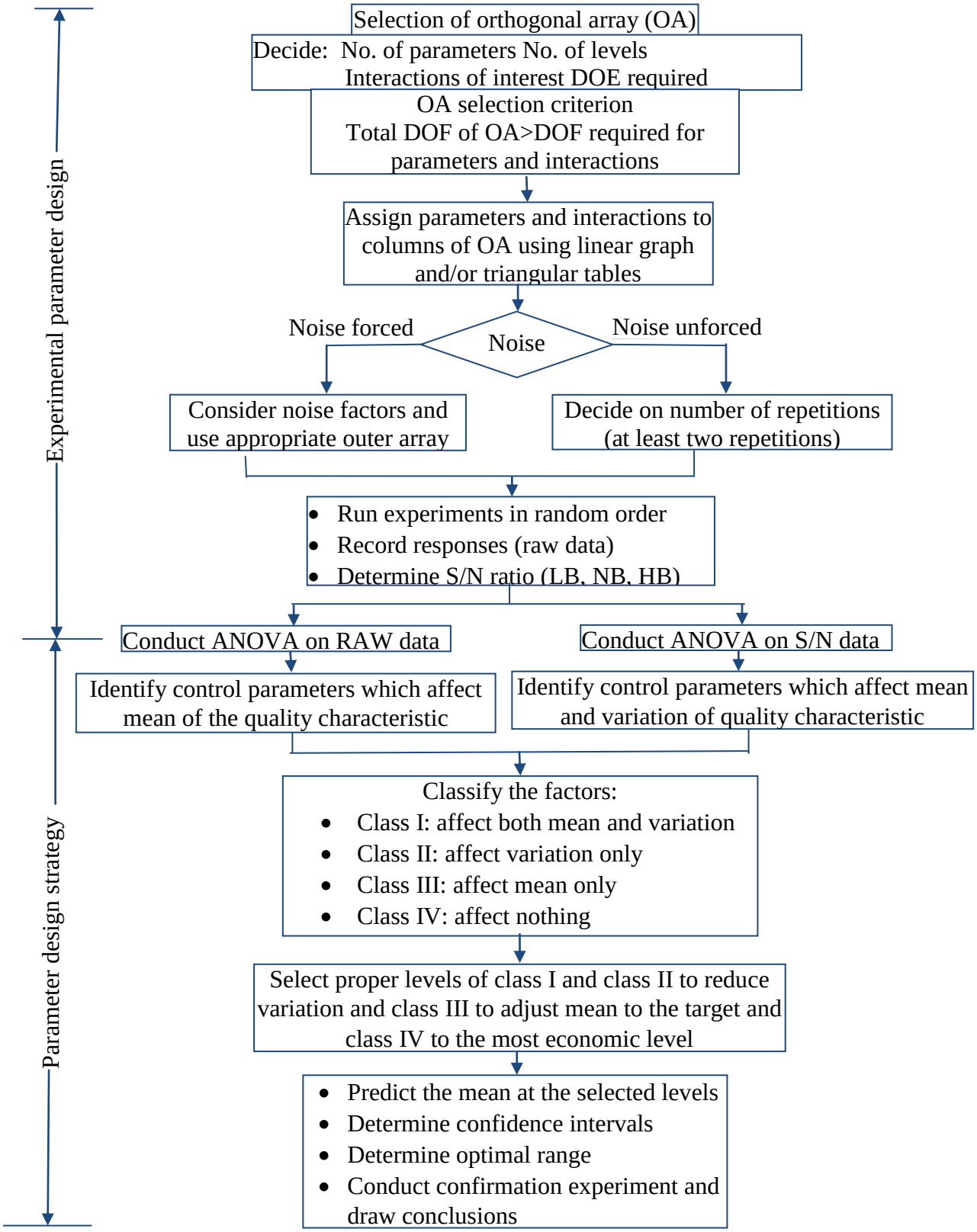


Fig. 3.14: Taguchi experimental strategy for design and analysis flow diagram (Jadoun 2005)

The determination of parameters to investigate, hinges upon the product or process performance characteristic (s) or response (s) of interest (Ross 1988). Taguchi suggests several methods for determining which parameters to include in an experiment. These are (Ross 1988):

(i) Brainstorming

(ii) Flow charting

(iii) Cause-Effect diagram

The total degrees of freedom (DOF) of an experiment are a direct function of total number of trials. If the number of levels of a parameter increases, the DOF of the parameter also increases because the DOF of a parameter is the number of levels minus one. Thus, increasing the number of levels for a parameter increases the total degree of freedom in the experiment and in turn, increases the total number of trials. Thus, two levels for each parameter are recommended to minimize the size of the experiment (Ross 1988). If curved or higher order polynomial relationship between the parameters under study and the response is expected, as least three levels for each parameter should the considered (Barker 1990).

The basic kinds of OA's developed by Taguchi are either two-level arrays or three-level arrays. The standard two-level and three-level arrays (Taguchi and Wu 1979, page 103-110) are:

(i) Two-level arrays: $L_4L_8L_{12}L_{16}L_{32}$

(ii) Three-level arrays: $L_9L_{18}L_{27}$

The number in the array designation indicates the number of trials in that array. The total degrees of freedom available in an OA are equal to the number of trials minus one (Ross 1988).

$f_{LN} = N-1$……..3.11

where,

f_{LN} = total degrees of freedom of an (OA)

L_N = OA designation

N = number of trials

When a particular OA is selected for an experiment, the following inequality must be satisfied (Ross 1988):

$f_{LN} \geq$ Total DOF required for parameters and interactions…….3.12

Depending on the number of levels in the parameters and total DOF required for the experiment, a suitable OA is selected.

3.7.2 Assignment of Parameters and Interaction to OA

The OA's have selected several columns available for assignment of parameters and some columns subsequently can estimate the effect of interactions of these parameters. Taguchi has provided two tools to aid in the assignment of parameters and interactions to arrays (Ross 1988, Roy 1990):

(a) Linear graphs

(b) Triangular tables

Each OA has a particular set of linear graphs and triangular table associated with it. The linear graphs indicate various columns to which parameters may be assigned and the columns subsequently evaluate the interaction of these parameters. The triangular tables contain all the possible interaction between parameters (columns). Using the linear graphs and/ or the triangular table of the selected OA, the parameters and interactions are assigned to the columns of the OA. The linear graphs of L_{27} OA are given in Appendix E (Figure E.1).

3.7.3 Selection of Outer Array

Taguchi separates factors (parameters) into two main groups: controllable factors and uncontrollable factors (noise factors). Controllable factors are factors that can easily be controlled. Noise factors, on the other hand, are nuisance variables that are difficult, impossible, or expensive to control (Byrne and Taguchi 1987). The noise factors are responsible for the performance variation of a process. Taguchi recommends the use of outer array for the noise factors and inner arrays for controllable factors. If an outer array is used, the noise variation is forced into the experiment. However, experiments against the trial conditions of the inner-array (the OA used for the controllable factors) may be repeated and in this case the noise variation is unforced into the experiment (Byrne and Taguchi 1987).

The outer array, if used will have the same assignment considerations. However, the outer array should not be as complex as the inner array because the outer array is noise only which is controlled only in the experiment (Ross 1988, page 204). An example of inner and outer array combination is shown in Appendix E (Table E.1).

3.7.4 Experimentation and Data Collection

The experiment is conducted against each of the trial conditions of the inner array. Each experiment at a trial condition is repeated simply (without using any outer array) or according to the outer array used. Randomization strategies should be considered during the

experiment. The data (raw data) are recorded against each trial condition and S/N ratios of the repeated data points are calculated and recorded against each trial condition (Ross 1988).

3.8 SPECIFIC TERMS USED IN THE TAGUCHI METHOD

In Taguchi method the world "optimization" implies that "the determination of BEST levels of the control factors. The BEST levels of the control factors are those that maximize the signal – to - noise ratio. The signal - to - noise ratios are log functions of the desired output characteristics. The experiments that are conducted to determine the BEST levels are based on "orthogonal arrays" are balanced with the respect to all the control factors are the minimum in number. This in the term implies that the resources (materials and time) required for the experiments are also minimum. In other think the optimization technique the engineer is interested in determining optimal settings of the process factors that is to determine for the each factor the level of the factor that optimizes the process response. For example, you may want to maximize process yield or reduce product variability (Vineeta 2015).

3.8.1 Quality Characteristics

The quality characteristics (QC) generally refer to the measured results of the experiment. The QC can be single criterion such as pressure, temperature, hardness, surface finish and efficiency etc. or a combination of the several criteria together into a single index. The QC also refers to the nature of the performance objectives such as "bigger is better", "smaller" or "nominal is the best" for results.

3.8.2 Scope and Size of Experiment

The scope of the investigation the cost and the time availability is the factors that help determine the size of the experiment. The number of experiments that can be accomplished in a given period of time and the associated costs are strictly dependent on the type of research under the study. The total number of samples available divided by the number of repetitions yields the size of the array for design. The array size dictates the number of factors and their appropriate levels included in the study.

3.8.3 Order of Running Experiments

There are two common ways of the running experiments:

Suppose an experiment uses an L_{27} array and each trial is repeated 3 times. How is the $3\times 27 = 81$ experiments carried out.

(1)REPLICATION: The most desirable way is to run these 81 in random order

(2)REPETITION: The most practical way is to select the trial condition in the random order then complete all the repetitions in that trial

In the developing conclusions from the results of the designed experiments and the assigning statistical significance it is assumed that the experiments were unbiased in any way thus the randomness is desired and should be maintained when possible.

Minimum requirement: A number (minimum) of one experiment per trial condition is required. The avoid experiment in an upward or downward sequence of the trial numbers.

3.9 DESIGN OF EXPERIMENT

The design of experiment (DOE) is a systematic method to determine the relationship between the factors affecting a process and the output of that process (responses). The experiments are performed by the investigators in all field of inquiry usually to discover something about a particular process or the system, literally an experiment is a test.

The more formally we can define an experiment as a test or series of test in which the purposeful changes are made to the input variables of the processor system so that we may observe and identify the reasons for changes that may be observed in the output response characteristics. When a large number of an experimental works have to be the carried out when the number of the process parameters increases. Therefore to reduce the number of experiments and to obtain the good quality of the investigation term named the design of experiments (DOE) is getting familiar in all over the world.

3.9.1 Steps Involved in DOE Application

According to Dr. Genechi Taguchi has standardization the technique for each of these DOE application steps the described below. Thus the design of experiment using the Taguchi approach has become a much more attractive tool to the practicing engineers and the scientists.

(1)Experiment planning and the problem formulation: The experiment planning guidelines are consistent with the modern work disciplines of the working as teams. The consensus decisions about the experimental objectives and the factors make the projects more successful.

(2)Experiment layout: The high emphasis is put on the cost and size of the experiments. Size of the experiment for a given number of the factors and levels is standardized. Approach and priority for the column assignments are established.

The clear guidelines are available to deal with the factors and the interactions. The uncontrollable factors are formally treated to the reduce variation. The discrete prescriptions for the setting up test conditions under the uncontrollable factors are described. The guidelines for carrying out the experiments and the number of samples to be tested are defined.

(3)The data analysis: The steps for the analysis are standardized (the main effect of ANOVA and optimum value). The standard practice for the determination of the optimum is recommended. The guidelines for test of the significance and the pooling are defined.

(4)The interpretation of the results: The clear guidelines about the meaning of the error term. The discrete indicator about confirmation of the results (confidence interval). The ability to quantify improvements in terms of dollars (loss function).

(5)The overall advantage: The design of experiment using the Taguchi approach attempts to improve the quality which is the defined as the consistency of the performance. The consistency is achieved when variation is reduced. This can be done by moving the mean performance to the target as well as by the reducing variations around the target. The prime motivation behind the Taguchi experiment design approach is to achieve the reduced variation (also known as ROBUST DESIGN). According to The Taguchi approach is focused to attain the desired quality objectives in the all steps. The classical DOE does not specifically address the quality.

3.10 PARAMETERS CLASSIFICATION AND SELECTION FOR OPTIMAL LEVELS (PARAMETER DESIGN STRATEGY)

When the ANOVA on the raw data (identifies control parameters which affect average) and S/N data (identifies control parameters which affect variation) are completed the control parameters may be put into main four classes (Ross 1988):

Class I	:	Parameters which affect both average and variation
Class II	:	Parameters which affect variation only
Class III	:	Parameters which affect average only
Class IV	:	Parameters which affect nothing

The parameter design strategy is to select the proper levels of class I and class II parameters to reduce variation and class III parameters to adjust the average to the target value. Class IV parameters may be set at the most economical levels since nothing is affected (Jadoun 2005).

To identify the parameters those affect the mechanical properties at weld zone during the welding operation the following variables are studied preliminary before the actual experiment. The parameters can be further classified as under:

(1)**Machine based parameters:** These parameters involve current, voltage, welding speed, gas flow rate, root gap, wire speed and automatic movement of torch

(2)**Work material based parameters:** These are the geometry of work piece, thickness, weldability, hardness and element chemical composition of work material

3.10.1 Welding Parameters

The regardless of the efficiency or variability, technology, parameters affect the quality and outcome of the weld. When these parameters are improperly configured or out of range for the equipment or materials, this can lead to a variety of the problems.

3.10.1.1 Welding current

Too much current as input parameter can lead to splatters and work-piece damage. In thin materials, it can lead to a widening of the material gap. Too little current can lead to sticking of the filler wire. This can also lead to heat damage and a much the larger weld affected area, as the high temperatures must be applied for much longer periods of the time in order to deposit the same amount of filling materials. The fixed current mode will vary the voltage in order to maintain a constant arc current.

3.10.1.2 Welding voltage

This parameter can be fixed or adjustable depending on the equipment. Some metals require a specific voltage range to be able to work. A high initial voltage allows for easy arc initiation and allows for a greater range of working tip distance. Too large a voltage, however, can lead to greater variability in work piece quality depending on the work piece distance and a greater variation in power and heat delivered to the work area.

3.10.1.3 Welding speed

The welding speed is an important parameter for GTAW. If the welding speed is increased the power or the heat input per unit length of weld is decreases therefore the less weld reinforcement results and the penetration of welding decreases. The welding speed or the travel speed is primarily control the bead size and penetration of weld. The excessive high

welding speed decreases wetting action the increases tendency of undercut the porosity and the uneven bead shapes while slower welding speed reduces the tendency to the porosity.

3.10.1.4 Gas flow and composition

The various welding or the shielding gasses are available including the mixtures of argon, carbon dioxide, oxygen, nitrogen, helium, hydrogen, nitric oxide, sulphur hexafluoride and dichlorodifluoromethane. The most importantly it also affects the finished weld penetration depth and subsurface profile, surface profile, composition, porosity, corrosion resistance, strength, ductility, hardness and brittleness of the weld zone.

3.10.1.5 Root gap

The welding technique and the features of the part will determine the quality of a weld. The root is formed by a weld pool that develops when welding starts, which in turn controls the degree of penetration. The material thickness, arc length root face and root gap are valuable determinants of this feature. The weld root can be directly inspected by particle inspection technique (penetrate or magnetic) and indirectly determined by radiography techniques. The strength of welded specimen depends on root gap; large strength for minimum gap, if root gap is increases than decrease the strength between pieces.

3.11 SELECTION OF PROCESS PARAMETERS BASED ON ISHIKAWA CAUSE EFFECT

The cause - effect diagrams can reveal key the relationships among the various variables and the possible causes provide the additional insight into process behaviour. An Ishikawa cause - effect diagram has been used for determining various input parameters that affects the desired quality characteristics of the final job. These parameters can be listed as follows:

- Material
- Welding equipment
- Environment
- People
- Power
- Procedure

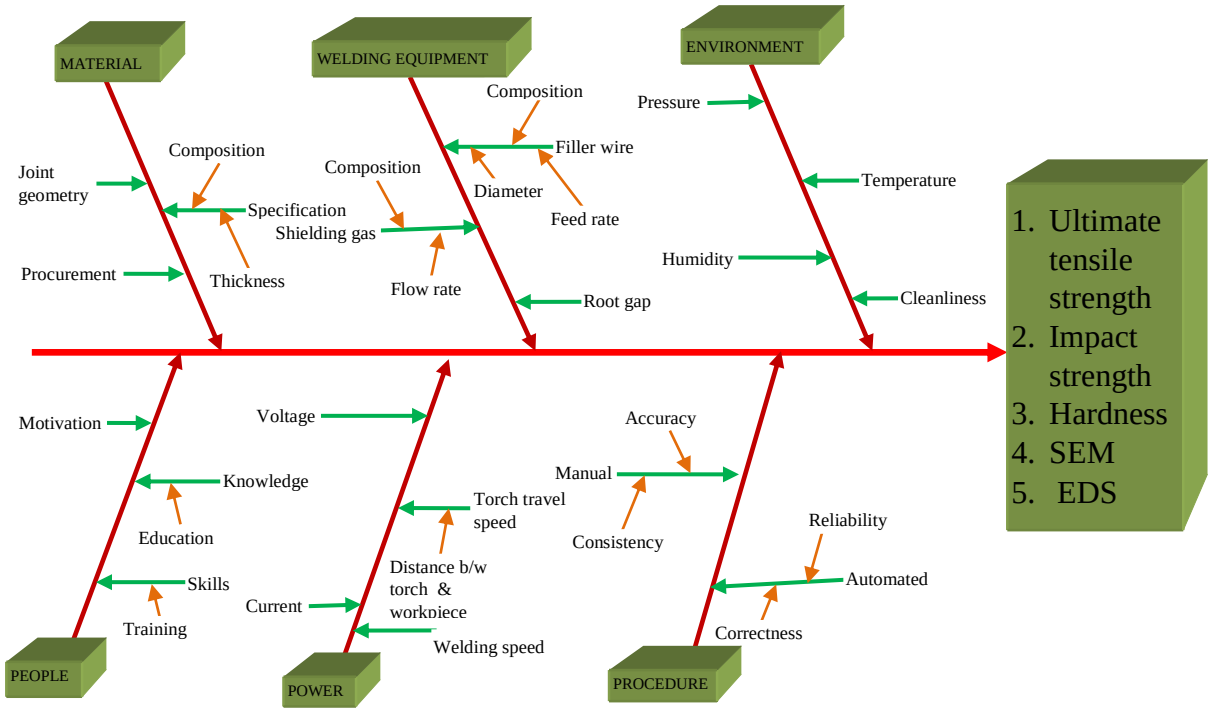


Fig. 3.15: Ishikawa cause - effect diagram for the GMAW and the GTAW processes (Jadoun 2005)

The processes parameters were selected by the help of the Ishikawa cause - effect diagram and the literature cited. The levels of the each parameter were chosen from the handbook and the data available in the different literature and the processes parameters.

3.12 INPUT CONTROL PARAMETERS

The welding current, welding voltage, welding speed, gas flow rate and root gap are selected as the control parameters or factors. These five parameters are selected because of their ease of the control and due to the limitations of available experimental setup. The parameters used for the actual experiment are given below in table 3.10.

Table 3.10: Process parameters or control factors used in GMAW and GTAW process

Process or control factors	GMAW	GTAW
Type of welding machine	GMAW PANA-AUTO KR II 400	TECHNO WELD MDX-300
Tungsten electrode diameter (mm)	-	3.5
Type of electrode	Consumable	Non-consumable
Filler rode/wire diameter (mm)	Ø1.6	Ø1.6
Voltage (Volts)	20-28	22-30
Current (Amps)	170-200	210-240
Welding speed (cm/min)	50-80	60-90
Heat input (kJ/mm)	2.25	1.76
Shielding gas	Argon & Helium	Argon & Helium
Gas flow rate (Lit/min)	15-23	12-20
Root gap (mm)	1.5-2.5	1.0-2.0

3.12.1 Constant Parameters for GMAW and GTAW Process

Type of parent material	Aluminium alloy 3003-H2 (IS-737)
Filler wire	ER4043
Thickness of parent material	5 mm
Thickness of filler wire	Ø1.6 mm
Joint geometry	simple butt joint

3.13 LEVELS OF VARIOUS CONTROL FACTORS

The short range of the control factors will have the minor effect on the responses parameters that is why a considerable range of the control parameters had been chosen. In this experimental study the each control factor used having three levels. The details of the each control factor level are as below in the Table 3.11.

3.13.1 Representation of Factors Levels

For conducting the final runs of the experiments all the five factors have been denoted by the specific letter and the notation used for the factors having their specific meaning as shown in the Table 3.11.

Table 3.11: All input control parameters and level

Si. No.	Factors	Level-1	Level-2	Level-3
1.	Welding current (A)	A1	A2	A3
2.	Welding voltage (B)	B1	B2	B3
3.	Welding speed (C)	C1	C2	C3
4.	Gas flow rate (D)	D1	D2	D3
5.	Root gap (E)	E1	E2	E3

Table 3.12: Values of input parameters for GMAW process (set of DOE)

Factors A for current	Factors B for voltage	Factors C for welding speed	Factors D for gas flow rate	Factors E for root gap
A1= 170 Amps	B1= 20 Volts	C1= 50 cm/min	D1= 15 Lit/min	E1= 1.5 mm
A2= 185 Amps	B2= 24 Volts	C2= 65 cm/min	D2= 19 Lit/min	E2= 2.0 mm
A3= 200 Amps	B3= 28 Volts	C3= 80 cm/min	D3= 23 Lit/min	E3= 2.5 mm

Table 3.13: The Process parameters and their values at different levels for Taguchi L_{27} orthogonal array design of experiment for GMAW process

Process parameters	Unit	Symbol	Level 1	Level 2	Level 3
Welding current	Amps	A	170	185	200
Welding voltage	Volts	B	20	24	28
Welding speed	cm/min	C	50	65	80
Gas flow rate	Lit/min	D	15	19	23
Root gap	mm	E	1.5	2.0	2.5

Table 3.14: Values of input parameters for GTAW process (set of DOE)

Factors A for current	Factors B for voltage	Factors C for speed	Factors D for gas flow rate	Factors E for root gap
A1= 210 Amps A2= 225 Amps A3= 240 Amps	B1= 22 Volts B2= 26 Volts B3= 30 Volts	C1= 60 cm/min C2= 75 cm/min C3= 90 cm/min	D1= 12 Lit/min D2= 16 Lit/min D3= 20 Lit/min	E1= 1.0 mm E2= 1.5 mm E3= 2.0 mm

Table 3.15: The Process parameters and their values at different levels for Taguchi L_{27} orthogonal array design of experiment for GTAW process

Process parameters	Unit	Symbol	Level1	Level2	Level3
Welding current	Amps	A	210	225	240
Welding voltage	Volts	B	22	26	30
Welding speed	cm/min	C	60	75	90
Gas flow rate	Lit/min	D	12	16	20
Root gap	mm	E	1.0	1.5	2.0

During the welding a manufacturer can control the various main welding parameters. It was observed that the main parameters levels chosen were in the operational range of the GMAW and GTAW processes. The different experimental runs were done by varying one of the welding parameters and keeping the others at constant values. The selection of levels for the main control parameters are given in Table 3.13 and 3.15. The three different levels were selected for the study of five main control parameters.

3.14 MEASUREMENT OF PERFORMANCE CHARACTERISTICS

Measurement of the performance characteristics (responses) like ultimate tensile strength (UTS), impact strength and hardness were performed as discussed below. In the present study the scanning electron microscope (SEM) and dispersion spectroscopy or the energy dispersive x- ray spectroscopy (EDS) are also discuss. The details of these response variables are given bellow in table 3.16.

Table 3.16: Responses or output and type for GMAW and GTAW process

Si. No.	Response	Unit	Response type
1.	Tensile strength	MPa	Continuous
2.	Impact strength	Joule	Continuous
3.	Hardness	HRB	Continuous
4.	Scanning electron microscope (SEM) and electron dispersion spectroscopy or the energy dispersive x – ray spectroscopy (EDS)		

3.15 STANDARD L_{27} ORTHOGONAL ARRAY

The standard format of L_{27} orthogonal array used for this experimental study is shown below in Table 3.17, taken from MINITAB-18 software tool.

Table 3.17: Taguchi's standard L_{27} orthogonal array for GMAW and GTAW process

Experiment No.	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1.	1	1	1	1	1
2.	1	1	1	1	2
3.	1	1	1	1	3
4.	1	2	2	2	1
5.	1	2	2	2	2
6.	1	2	2	2	3
7.	1	3	3	3	1
8.	1	3	3	3	2
9.	1	3	3	3	3
10.	2	1	2	3	1
11.	2	1	2	3	2
12.	2	1	2	3	3
13.	2	2	3	1	1
14.	2	2	3	1	2
15.	2	2	3	1	3
16.	2	3	1	2	1
17.	2	3	1	2	2
18.	2	3	1	2	3
19.	3	1	3	2	1
20.	3	1	3	2	2
21.	3	1	3	2	3
22.	3	2	1	3	1
23.	3	2	1	3	2
24.	3	2	1	3	3
25.	3	3	2	1	1
26.	3	3	2	1	2
27.	3	3	2	1	3

Table 3.18: Input parameters and GMAW process setting for each run

Experiment No. 1	Experiment No.2	Experiment No.3	Experiment No.4	Experiment No.5
A1 = 170	A1 = 170	A1 = 170	A1 = 170	A1 = 170
B1 = 20	B1 = 20	B1 = 20	B2 = 24	B2 = 24
C1 = 50	C1 = 50	C1 = 50	C2 = 65	C2 = 65
D1 = 15	D1 = 15	D1 = 15	D2 = 19	D2 = 19
E1 = 1.5	E2 = 2.0	E3 = 2.5	E1 = 1.5	E2 = 2.0
Experiment No.6	**Experiment No.7**	**Experiment No.8**	**Experiment No.9**	**Experiment No.10**
A1 = 170	A1 = 170	A1 = 170	A1 = 170	A2 = 185
B2 = 24	B3 = 28	B3 = 28	B3 = 28	B1 = 20
C2 = 65	C3 = 80	C3 = 80	C3 = 80	C2 = 65
D2 = 19	D3 = 23	D3 = 23	D3 = 23	D3 = 23
E3 = 2.5	E1 = 1.5	E2 = 2.0	E3 = 2.5	E1 = 1.5

Experiment No.11	Experiment No.12	Experiment No.13	Experiment No.14	Experiment No.15
A2 = 185	A2 = 185	A2 = 185	A2 = 185	A2 = 185
B1 = 20	B1 = 20	B2 = 24	B2 = 24	B2 = 24
C2 = 65	C2 = 65	C3 = 80	C3 = 80	C3 = 80
D3 = 23	D3 = 23	D1 = 15	D1 = 15	D1 = 15
E2 = 2.0	E3 = 2.5	E1 = 1.5	E2 = 2.0	E3 = 2.5
Experiment No.16	**Experiment No.17**	**Experiment No.18**	**Experiment No.19**	**Experiment No.20**
A2 = 185	A2 = 185	A2 = 185	A3 = 200	A3 = 200
B3 = 28	B3 = 28	B3 = 28	B1 = 20	B1 = 20
C1 = 50	C1 = 50	C1 = 50	C3 = 80	C3 = 80
D2 = 19	D2 = 19	D2 = 19	D2 = 19	D2 = 19
E1 = 1.5	E2 = 2.0	E3 = 2.5	E1 = 1.5	E2 = 2.0
Experiment No.21	**Experiment No.22**	**Experiment No.23**	**Experiment No.24**	**Experiment No.25**
A3 = 200	A3 = 200	A3 = 200	A3 = 200	A3 = 200
B1 = 20	B2 = 24	B2 = 24	B2 = 24	B3 = 28
C3 = 80	C1 = 50	C1 = 50	C1 = 50	C2 = 65
D2 = 19	D3 = 23	D3 = 23	D3 = 23	D1 = 15
E3 = 2.5	E1 = 1.5	E2 = 2.0	E3 = 2.5	E1 = 1.5

Experiment No.26	Experiment No.27
A3 = 200	A3 = 200
B3 = 28	B3 = 28
C2 = 65	C2 = 65
D1 = 15	D1 = 15
E2 = 2.0	E3 = 2.5

Table 3.19: Input parameters and GTAW process setting for each run

Experiment No. 1	Experiment No.2	Experiment No.3	Experiment No.4	Experiment No.5
A1 = 210	A1 = 210	A1 = 210	A1 = 210	A1 = 210
B1 = 22	B1 = 22	B1 = 22	B2 = 26	B2 = 26
C1 = 60	C1 = 60	C1 = 60	C2 = 75	C2 = 75
D1 = 12	D1 = 12	D1 = 12	D2 = 16	D2 = 16
E1 =1.0	E2 = 1.5	E3 = 2.0	E1 = 1.0	E2 = 1.5
Experiment No.6	**Experiment No.7**	**Experiment No.8**	**Experiment No.9**	**Experiment No.10**
A1 = 210	A1 = 210	A1 = 210	A1 = 210	A2 = 225
B2 = 26	B3 = 30	B3 = 30	B3 = 30	B1 = 22
C2 = 75	C3 = 90	C3 = 90	C3 = 90	C2 = 75
D2 = 16	D3 = 20	D3 = 20	D3 = 20	D3 = 20
E3 = 2.0	E1 = 1.0	E2 = 1.5	E3 = 2.0	E1 = 1.0
Experiment No.11	**Experiment No.12**	**Experiment No.13**	**Experiment No.14**	**Experiment No.15**
A2 = 225	A2 = 225	A2 = 225	A2 = 225	A2 = 225
B1 = 22	B1 = 22	B2 = 26	B2 = 26	B2 = 26
C2 = 75	C2 = 75	C3 = 90	C3 = 90	C3 = 90
D3 = 20	D3 = 20	D1 = 12	D1 = 12	D1 = 12
E2 = 1.5	E3 = 2.0	E1 = 1.0	E2 = 1.5	E3 = 2.0

Experiment No.16	Experiment No.17	Experiment No.18	Experiment No.19	Experiment No.20
A2 = 225	A2 = 225	A2 = 225	A3 = 240	A3 = 240
B3 = 30	B3 = 30	B3 = 30	B1 = 22	B1 = 22
C1 = 60	C1 = 60	C1 = 60	C3 = 90	C3 = 90
D2 = 16	D2 = 16	D2 = 16	D2 = 16	D2 = 16
E1 = 1.0	E2 = 1.5	E3 = 2.0	E1 = 1.0	E2 = 1.5
Experiment No.21	**Experiment No.22**	**Experiment No.23**	**Experiment No.24**	**Experiment No.25**
A3 = 240	A3 = 240	A3 = 240	A3 = 240	A3 = 240
B1 = 22	B2 = 26	B2 = 26	B2 = 26	B3 = 30
C3 = 90	C1 = 60	C1 = 60	C1 = 60	C2 = 75
D2 = 16	D3 = 20	D3 = 20	D3 = 20	D1 = 12
E3 = 2.0	E1 = 1.0	E2 = 1.5	E3 = 2.0	E1 = 1.0

Experiment No.26	Experiment No.27
A3 = 240	A3 = 240
B3 = 30	B3 = 30
C2 = 75	C2 = 75
D1 = 12	D1 = 12
E2 = 1.5	E3 = 2.0

3.16 CONDUCTING THE EXPERIMENT

Once the factors are assigned to a particular column of the selected orthogonal array the test strategy has been set and the physical preparation for performing the test is initiated. Some decisions need to be made concerning the order of test. The randomizing the order of performing the test of various trails should include some forms of randomization. The randomized trail order protects the experiment from any unknown and uncontrolled factors that may vary during the experiment and may influence the result.

3.16.1 Welded Samples

The experiments were conducted against each of the trial conditions on semiautomatic PANA-AUTO KR II 400 (GMAW) and Techno weld MDX 300 (GTAW) machine. In the present research work single butt joint was made as shown in Figure 3.16 and Figure 3.17.

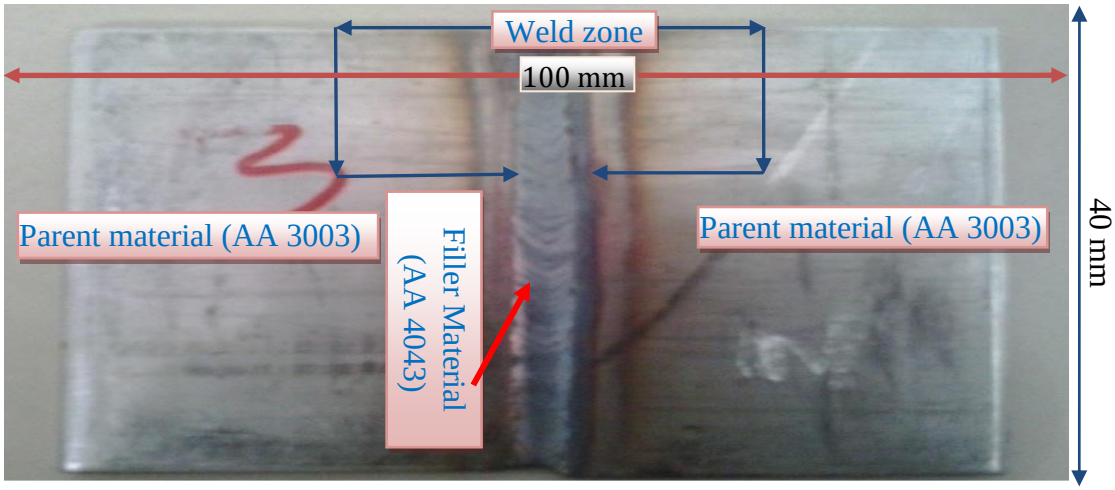


Fig. 3.16: Welded joint by GMAW

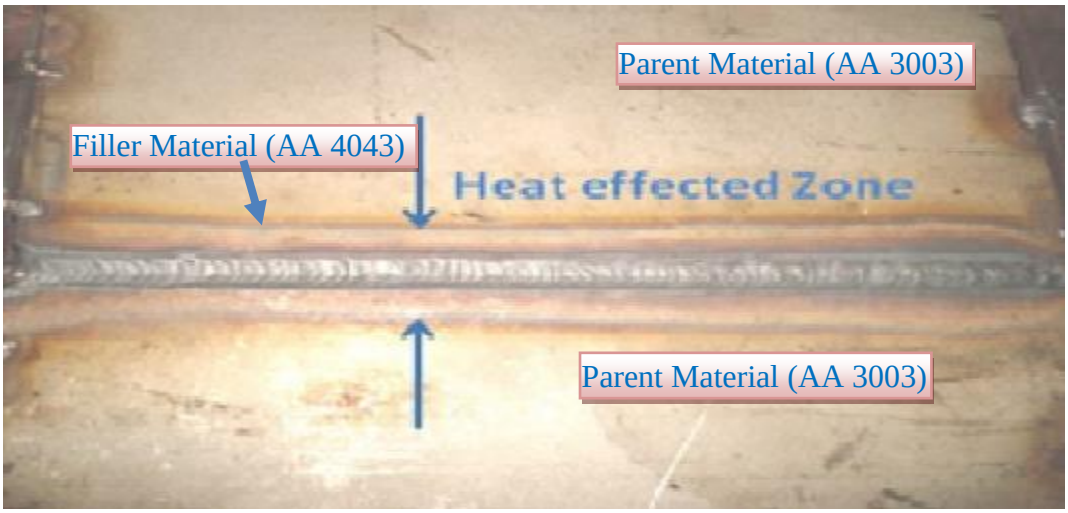


Fig. 3.17: Welded joint by GTAW study

3.16.2 Assignments of Main Welding Variables

To design the plan of experiments Taguchi uses a special set of orthogonal arrays (OA, L_{27}), which are always predefined. The full information of those factors that affect the process performance was found out by use of these standard arrays. The process parameters were assigned to the orthogonal array as shown in the Table 3.20 and 3.21.

Table 3.20: For the present investigation and the design matrix based on Taguchi L_{27} orthogonal array the design of experiment for the GMAW process

No. of Runs	Control factors				
	Welding current (Amps)	Welding voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)
1.	170	20	50	15	1.5
2.	170	20	50	15	2
3.	170	20	50	15	2.5
4.	170	24	65	19	1.5
5.	170	24	65	19	2
6.	170	24	65	19	2.5

7.	170	28	80	23	1.5
8.	170	28	80	23	2
9.	170	28	80	23	2.5
10.	185	20	65	23	1.5
11.	185	20	65	23	2
12.	185	20	65	23	2.5
13.	185	24	80	15	1.5
14.	185	24	80	15	2
15.	185	24	80	15	2.5
16.	185	28	50	19	1.5
17.	185	28	50	19	2
18.	185	28	50	19	2.5
19.	200	20	80	19	1.5
20.	200	20	80	19	2
21.	200	20	80	19	2.5
22.	200	24	50	23	1.5
23.	200	24	50	23	2
24.	200	24	50	23	2.5
25.	200	28	65	15	1.5
26.	200	28	65	15	2
27.	200	28	65	15	2.5

Table 3.21: For the present investigation and the design matrix based on Taguchi L_{27} orthogonal array design of experiment for the GTAW process

No. of Runs	Control Factors				
	Welding current (Amps)	Welding voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)
1.	210	22	60	12	1
2.	210	22	60	12	1.5
3.	210	22	60	12	2
4.	210	26	75	16	1
5.	210	26	75	16	1.5
6.	210	26	75	16	2
7.	210	30	90	20	1
8.	210	30	90	20	1.5
9.	210	30	90	20	2
10.	225	22	75	20	1
11.	225	22	75	20	1.5
12.	225	22	75	20	2
13.	225	26	90	12	1
14.	225	26	90	12	1.5
15.	225	26	90	12	2
16.	225	30	60	16	1
17.	225	30	60	16	1.5
18.	225	30	60	16	2
19.	240	22	90	16	1
20.	240	22	90	16	1.5
21.	240	22	90	16	2
22.	240	26	60	20	1
23.	240	26	60	20	1.5

24.	240	26	60	20	2
25.	240	30	75	12	1
26.	240	30	75	12	1.5
27.	240	30	75	12	2

3.17 TESTING PROCESS AND RESPONSE MEASUREMENT

Although there are the numbers of mechanical and physical tests for the GMAW and the GTAW processes which are necessary to determine the suitability of a metal some of the following important tests had been performed in the present investigation.

1. Ultimate Tensile Strength Testing
2. Impact Strength Testing
3. Hardness Testing
4. Scanning electron microscope (SEM)
5. Electron dispersion spectroscopy or the energy dispersive x – ray spectroscopy

These are measured the mechanical characteristics on Universal Testing Machine, Rockwell Hardness, Izod Impact testing machine, SEM and EDS testing machine respectively.

3.17.1Ultimate Tensile Strength Testing

The tensile tests are used to determine the ultimate tensile strength (UTS), has been carried out by universal testing machine setup available at department of mechanical engineering, Jamia Milia Islamia, University, Delhi. In the present investigation the tensile test is conducted as per the ASTM standard. The specimen configuration is shown in Figure 3.18. The tests are conducted on 100 kN servo hydraulic UTM machine under displacement mode of control Figure 3.18 (a and b). All tests were conducted at room temperature.

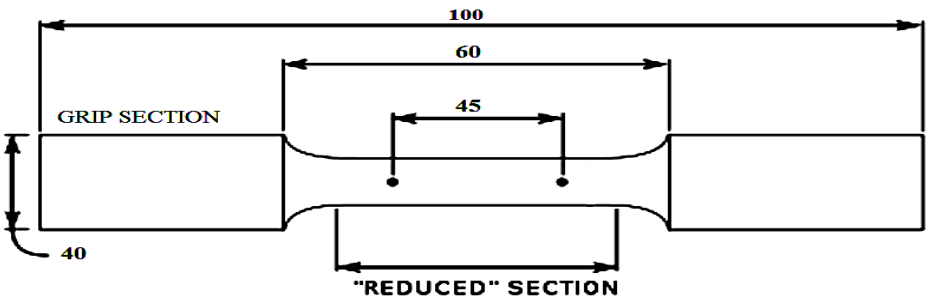


Fig. 3.18: Specimen geometry for tensile test according to ISO 527-2
(All dimensions are in mm)

Fig. 3.19: Universal testing machine (UTM)

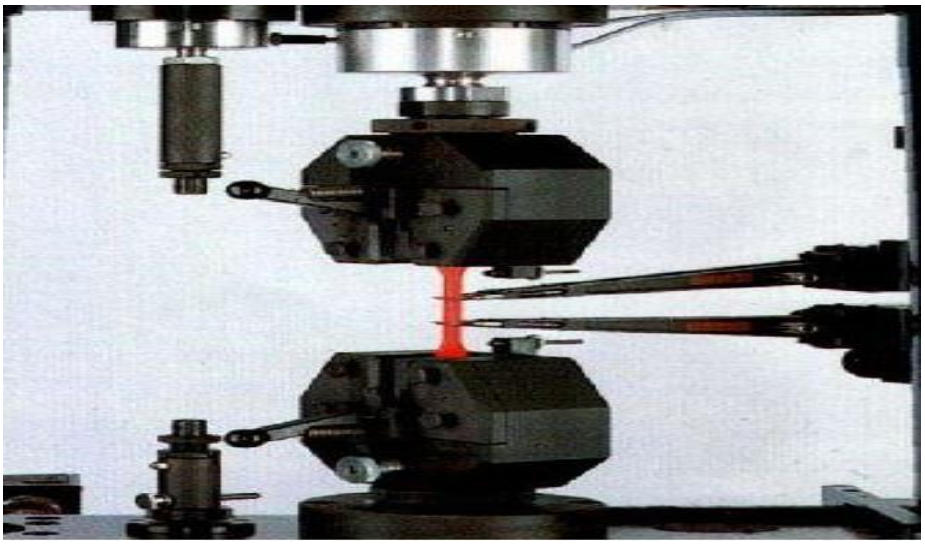


Fig. 3.20: Universal testing machine (UTM) with jaw

Technical specification of universal testing machine (UTM)

Type of machine:	servo hydraulic	Minimum test speed:	0.01 mm/min
Capacity:	Up to 100 kN	Maximum:	500 mm/min
Data acquisition:	As per ASTM E 1856	Test temperature:	Room temperature
Computer interface:	Via USB	Test humidity:	Normal
Application software:	Compatible with OS		

The specimen values of ultimate tensile strength for the GMAW and the GTAW processes as obtained by conducting experiments on UTM are shown in Table 3.22.

Fig. 3.21: Specimens after tensile testing at weld zone

Table 3.22: The experimental values of ultimate tensile strength on the GMAW process

No. of Exp.	Experiment No. 1	Experiment No.2	Experiment No.3	Ultimate tensile strength (mean value)
1.	127.712	137.942	141.401	135.685
2.	138.816	163.815	158.473	153.701
3.	171.597	167.497	184.286	174.460
4.	149.197	162.501	176.242	162.646
5.	180.541	174.183	191.374	182.032
6.	175.542	187.249	194.541	185.777
7.	178.427	187.243	168.264	177.978
8.	198.092	189.751	187.804	191.882
9.	211.052	213.812	190.246	205.036
10.	175.702	180.512	169.481	175.231
11.	170.542	162.843	177.671	170.352
12.	164.054	171.246	167.457	167.585
13.	181.241	177.914	174.571	177.908
14.	201.842	191.461	185.246	192.849
15.	186.246	181.764	175.468	181.159
16.	201.842	197.927	191.761	197.176
17.	192.751	185.538	179.854	186.047
18.	221.421	212.842	209.421	214.561
19.	203.735	196.267	191.548	197.183
20.	185.842	195.421	184.675	188.646
21.	187.457	180.576	184.276	184.103
22.	206.756	193.754	184.261	194.923
23.	227.469	218.467	210.912	218.949
24.	198.219	212.207	204.674	205.033
25.	221.402	214.276	198.768	211.482
26.	208.421	211.764	194.752	204.979
27.	221.792	216.542	208.467	215.600

Table 3.23: The AVG values of ultimate tensile strength at weld zone on the GMAW process

No. Run	Welding current (Amps)	Welding voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	UTS (mean value) (MPa)	S/N ratio
1.	170	20	50	15	1.5	135.685	42.65064
2.	170	20	50	15	2	153.701	43.73355
3.	170	20	50	15	2.5	174.460	44.83392
4.	170	24	65	19	1.5	162.646	44.2249
5.	170	24	65	19	2	182.032	45.20299

6.	170	24	65	19	2.5	185.777	45.37985
7.	170	28	80	23	1.5	177.978	45.00733
8.	170	28	80	23	2	191.882	45.6607
9.	170	28	80	23	2.5	205.036	46.23663
10.	185	20	65	23	1.5	175.231	44.87225
11.	185	20	65	23	2	170.352	44.62694
12.	185	20	65	23	2.5	167.585	44.48474
13.	185	24	80	15	1.5	177.908	45.00394
14.	185	24	80	15	2	192.849	45.70438
15.	185	24	80	15	2.5	181.159	45.16121
16.	185	28	50	19	1.5	197.176	45.89711
17.	185	28	50	19	2	186.047	45.39248
18.	185	28	50	19	2.5	214.561	46.63103
19.	200	20	80	19	1.5	197.183	45.8974
20.	200	20	80	19	2	188.646	45.51295
21.	200	20	80	19	2.5	184.103	45.30122
22.	200	24	50	23	1.5	194.923	45.79729
23.	200	24	50	23	2	218.949	46.80687
24.	200	24	50	23	2.5	205.033	46.23649
25.	200	28	65	15	1.5	211.482	46.50547
26.	200	28	65	15	2	204.979	46.23419
27.	200	28	65	15	2.5	215.600	46.67299

Table 3.24: The experimental values of ultimate tensile strength at weld zone on the GTAW

No. of Exp.	Experiment No. 1	Experiment No.2	Experiment No.3	Ultimate tensile strength (mean value)
1.	123.847	137.689	126.534	129.356
2.	133.847	147.683	176.534	152.688
3.	173.847	197.689	146.537	172.691
4.	164.845	145.653	169.987	160.161
5.	164.845	195.653	182.987	181.161
6.	166.845	179.653	177.987	174.828
7.	198.356	206.119	167.864	190.779
8.	258.356	186.119	177.864	207.446
9.	195.356	155.119	173.864	174.779
10.	152.161	208.845	163.674	174.893
11.	160.161	138.845	199.674	166.226
12.	188.161	167.845	189.674	181.893
13.	177.545	170.598	185.065	177.736
14.	179.545	185.598	209.065	191.402
15.	173.545	179.598	188.065	180.402
16.	204.544	200.321	195.021	199.962
17.	194.544	187.321	175.021	185.628
18.	198.544	257.321	191.021	215.628
19.	195.553	169.983	213.564	193.033
20.	193.553	179.983	188.564	187.366
21.	187.563	169.983	193.564	183.703
22.	185.643	197.326	196.098	193.022

23.	169.643	248.326	259.098	225.689
24.	175.643	198.326	200.098	191.355
25.	193.363	269.567	187.951	216.960
26.	209.363	189.567	204.951	201.293
27.	231.363	204.567	198.951	211.627

Table 3.25: The AVG values of ultimate tensile strength at weld zone on the GTAW process

No. Run	Welding current (Amps)	Welding voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	Ultimate tensile strength (mean value) (MPa)
1.	210	22	60	12	1	129.356
2.	210	22	60	12	1.5	152.688
3.	210	22	60	12	2	172.691
4.	210	26	75	16	1	160.161
5.	210	26	75	16	1.5	181.161
6.	210	26	75	16	2	174.828
7.	210	30	90	20	1	190.779
8.	210	30	90	20	1.5	207.446
9.	210	30	90	20	2	174.779
10.	225	22	75	20	1	174.893
11.	225	22	75	20	1.5	166.226
12.	225	22	75	20	2	181.893
13.	225	26	90	12	1	177.736
14.	225	26	90	12	1.5	191.402
15.	225	26	90	12	2	180.402
16.	225	30	60	16	1	199.962
17.	225	30	60	16	1.5	185.628
18.	225	30	60	16	2	215.628
19.	240	22	90	16	1	193.033
20.	240	22	90	16	1.5	187.366
21.	240	22	90	16	2	183.703
22.	240	26	60	20	1	193.022
23.	240	26	60	20	1.5	225.689
24.	240	26	60	20	2	191.355
25.	240	30	75	12	1	216.960
26.	240	30	75	12	1.5	201.293
27.	240	30	75	12	2	211.627

3.17.2 Impact Strength Testing

The Charpy test involves the use of a V-notched specimen and a machine to deliver an impact blow to the specimen. Testing was carried out with the specimens at room temperature. ASTM E23 standard methods for notched bar impact testing of metallic materials were followed for testing. The dimensions of the test specimen as per ASTM standards are shown in Figure 3.22:

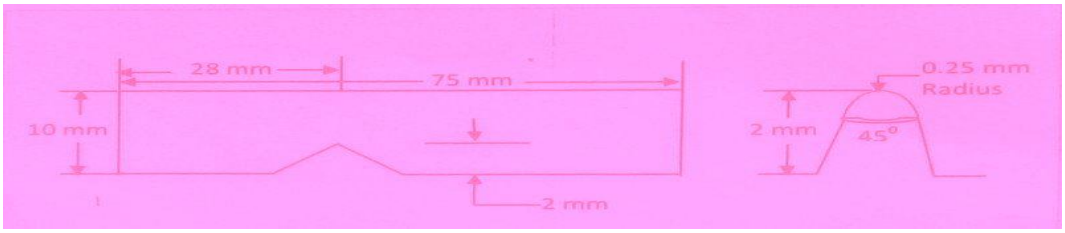


Fig. 3.22: Specimen geometry for impact test according to ASTM E23

The materials behave quite the differently when they are loaded suddenly than when they are loaded more slowly as in the ultimate tensile testing. The positioning of the specimen within the testing machine is critical. The Charpy specimen is held rigidly in a vice type fixture with the notched side facing the direction of impact.

The centreline of the notch was in the plane of the vice top. Once the specimen was in place the hammer was released from a preset height and allowed to strike the specimen thus fracturing it at the V-notch as shown in Figure 3.22. The striker continues its swing to the other side of the specimen up to a certain height. The difference between the two heights multiplied by the weight of the striker corresponds to the amount of energy that is absorbed in breaking.

Fig. 3.23: Schematic of a conventional pendulum charpy impact tester

After breaking the test piece, the height to which the pendulum rises is recorded by a slave friction pointer mounted on the dial, from which the absorbed energy amount is read. The results are expressed in energy lost per unit of thickness (such as ft·lb/in or J/cm) at the notch. The results are reported as energy lost per unit cross-sectional area at the notch (J/m^2 or $ft{\cdot}lb/in^2$).

Table 3.26: The experimental values of impact strength at weld zone on the GMAW process

No. of Exp.	Experiment No. 1	Experiment No.2	Experiment No.3	Impact strength (mean value)
1.	0.13501	0.10925	0.10124	0.11516
2.	0.11014	0.10146	0.10248	0.10469
3.	0.10954	0.10724	0.107502	0.10809
4.	0.10475	0.11278	0.10539	0.10764
5.	0.10549	0.10568	0.11031	0.10716

6.	0.10634	0.10451	0.11109	0.10731
7.	0.11067	0.10572	0.10452	0.10697
8.	0.10734	0.12829	0.11345	0.11636
9.	0.16705	0.21571	0.20514	0.19596
10.	0.10237	0.10281	0.10624	0.10380
11.	0.10248	0.31205	0.10263	0.17238
12.	0.10301	0.21347	0.31521	0.21056
13.	0.41352	0.24613	0.12541	0.26168
14.	0.10534	0.20136	0.10971	0.13880
15.	0.10027	0.19371	0.27543	0.18980
16.	0.10946	0.26721	0.41325	0.26330
17.	0.51735	0.42372	0.10304	0.34803
18.	0.10243	0.13752	0.10923	0.11639
19.	0.10813	0.51243	0.18309	0.26788
20.	0.10345	0.13428	0.10914	0.11562
21.	0.12003	0.10542	0.10604	0.11049
22.	0.14272	0.10205	0.12034	0.12170
23.	0.12031	0.10245	0.10672	0.10982
24.	0.51372	0.34026	0.10037	0.31811
25.	0.57612	0.19042	0.25409	0.34021
26.	0.64201	0.10972	0.41067	0.38746
27.	0.51607	0.19304	0.41067	0.37326

Table 3.27: The mean values of impact strength at weld zone on GMAW process

No. of Run	Welding current (Amps)	Welding Voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	Impact strength (mean value) (J/cm^2)
1.	170	20	50	15	1.5	0.11516
2.	170	20	50	15	2	0.10469
3.	170	20	50	15	2.5	0.10809
4.	170	24	65	19	1.5	0.10764
5.	170	24	65	19	2	0.10716
6.	170	24	65	19	2.5	0.10731
7.	170	28	80	23	1.5	0.10697
8.	170	28	80	23	2	0.11636
9.	170	28	80	23	2.5	0.19596
10.	185	20	65	23	1.5	0.10380
11.	185	20	65	23	2	0.17238
12.	185	20	65	23	2.5	0.21056
13.	185	24	80	15	1.5	0.26168
14.	185	24	80	15	2	0.13880
15.	185	24	80	15	2.5	0.18980
16.	185	28	50	19	1.5	0.26330
17.	185	28	50	19	2	0.34803
18.	185	28	50	19	2.5	0.11639
19.	200	20	80	19	1.5	0.26788
20.	200	20	80	19	2	0.11562
21.	200	20	80	19	2.5	0.11049
22.	200	24	50	23	1.5	0.12170
23.	200	24	50	23	2	0.10982

24.	200	24	50	23	2.5	0.31811
25.	200	28	65	15	1.5	0.34021
26.	200	28	65	15	2	0.38746
27.	200	28	65	15	2.5	0.37326

Table 3.28: The experimental values of impact strength at weld zone on the GTAW process

No. of Exp.	Experiment No. 1	Experiment No.2	Experiment No.3	Impact strength (mean value)
1.	0.10203	0.28208	0.10432	0.16281
2.	0.10203	0.19020	0.10910	0.13378
3.	0.10213	0.12170	0.10218	0.10867
4.	0.18255	0.10261	0.10269	0.12929
5.	0.15215	0.10211	0.10209	0.1187
6.	0.10215	0.10211	0.10209	0.10212
7.	0.14209	0.11015	0.10290	0.11838
8.	0.10209	0.11017	0.10290	0.10505
9.	0.15209	0.11018	0.10295	0.12174
10.	0.1030	0.11021	0.15026	0.12116
11.	0.10302	0.11021	0.15026	0.12117
12.	0.10302	0.11021	0.15026	0.12117
13.	0.10273	0.10280	0.10277	0.10277
14.	0.10281	0.10208	0.10521	0.10336
15.	0.14272	0.10200	0.10211	0.11561
16.	0.11479	0.12204	0.12052	0.11912
17.	0.11420	0.12207	0.12204	0.11944
18.	0.11408	0.12201	0.12274	0.11961
19.	0.12001	0.10201	0.10205	0.10802
20.	0.12001	0.10201	0.10205	0.10802
21.	0.12001	0.10201	0.10205	0.10802
22.	0.10233	0.12031	0.12103	0.11455
23.	0.10233	0.12031	0.12103	0.11455
24.	0.10233	0.12031	0.12103	0.11455
25.	0.11023	0.10207	0.10215	0.10481
26.	0.11023	0.10207	0.10215	0.10481
27.	0.11023	0.10207	0.10215	0.16281

Table 3.29: The mean values of impact strength at weld zone on the GTAW process

No. of Run	Welding current (Amps)	Welding voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	Impact strength (mean value) (J/cm^2)
1.	210	22	60	12	1	0.16281
2.	210	22	60	12	1.5	0.13378
3.	210	22	60	12	2	0.10867
4.	210	26	75	16	1	0.12929
5.	210	26	75	16	1.5	0.11878
6.	210	26	75	16	2	0.10212
7.	210	30	90	20	1	0.11838
8.	210	30	90	20	1.5	0.10505
9.	210	30	90	20	2	0.12174
10.	225	22	75	20	1	0.12116

11.	225	22	75	20	1.5	0.12117
12.	225	22	75	20	2	0.12117
13.	225	26	90	12	1	0.10277
14.	225	26	90	12	1.5	0.10336
15.	225	26	90	12	2	0.11561
16.	225	30	60	16	1	0.11912
17.	225	30	60	16	1.5	0.11944
18.	225	30	60	16	2	0.11961
19.	240	22	90	16	1	0.10802
20.	240	22	90	16	1.5	0.10802
21.	240	22	90	16	2	0.10802
22.	240	26	60	20	1	0.11455
23.	240	26	60	20	1.5	0.11455
24.	240	26	60	20	2	0.11455
25.	240	30	75	12	1	0.10481
26.	240	30	75	12	1.5	0.10481
27.	240	30	75	12	2	0.16281

3.17.3 Hardness Testing

The hardness is a measure of a materials resistance to localize the plastic deformation (for a small dent or scratch). The hardness testing involves a small indenter being forced into the surface of the material being tested under the controlled conditions of the load and the rate of application. The depth or size of the resulting indentation is measured which in turn is the related to a softer the material, hardness number, the larger and deeper the indentation and the lower the hardness index number.

The measured hardness is only the relative (rather than absolute) thus care must be taken when the comparing values determined by the different techniques. The macro-hardness (Rockwell) testing is the most commonly applied the materials test in the industry due to the several factors:

(1) The hardness testing is the simple to perform and does not require the highly skilled operators

(2) Through the use of different loads and the indenters and the hardness testing can be used for determining the hardness and the approximate strength of the most metals and alloys including the soft bearing materials and high strength steels

(3) The hardness readings can be taken in a few seconds with the minimal preparation

(4) For the Rockwell hardness testing no optical measurements is required all the readings are direct

The Rockwell hardness test consists of measuring the additional depth to which an indenter is forced by a major load beyond the depth of a previously applied the minor load.

The application of the minor load eliminates backlash in the load train and causes the indenter to break through the slight surface roughness and to crush particles of foreign matter thus the contributing too much the greater accuracy in the test.

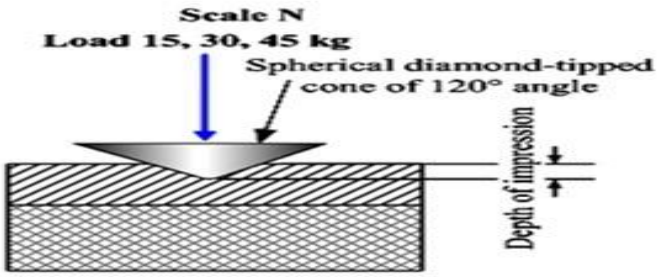


Fig. 3.24: Rockwell hardness testing system

The hardness testing was performed on the Rockwell hardness testing machine with ‘B’ scale. The photographic view of the Rockwell hardness testing machine is shown in Figure 3.25. The hardness is measured for three reading for the each runs or experiment. For the each run to measure the hardness the major load was 100 kgf and the minor load was 10 kgf.

Fig. 3.25: Rockwell hardness testing machine

According to Rockwell hardness tester the minor load is applied first and a reference or "set" position is established on the measuring device. Then the major load is applied at a prescribed the controlled rate. Without moving the work piece being tested the major load is removed and the Rockwell hardness number indicated on the dial gauge was recorded. The values of hardness were recorded at the weld zone only of AA3003. The Table 3.30 shows hardness values at different experiment runs.

Table 3.30: The experimental values of hardness at weld zone on GMAW process

No. of Exp.	Experiment No.1	Experiment No.2	Experiment No.3	Hardness (mean value)
1.	31.51	44.74	35.06	37.1033
2.	28.14	27.81	30.43	28.7933
3.	46.70	42.39	35.54	41.5433
4.	31.81	36.17	40.15	36.0433
5.	25.91	42.35	39.37	35.8766
6.	27.73	28.37	37.43	31.1766
7.	39.01	46.29	42.84	42.7133
8.	49.34	58.01	34.68	47.3433
9.	59.11	41.74	33.56	44.8033
10.	38.90	42.08	33.49	38.1566
11.	56.29	54.23	38.57	49.6966
12.	48.57	51.77	44.49	48.2766
13.	49.56	44.79	54.32	49.5566
14.	60.31	57.29	43.76	53.7866
15.	64.51	57.17	34.57	52.0833
16.	45.78	41.29	31.87	39.6466
17.	29.67	41.95	47.43	39.6833
18.	59.41	53.63	48.43	53.8233
19.	66.29	51.56	61.44	59.7633
20.	59.78	58.15	55.01	57.6466
21.	36.54	49.54	43.29	43.1233
22.	62.21	52.28	61.47	58.6533
23.	33.91	44.40	37.27	38.5266
24.	26.78	35.41	35.41	32.5333
25.	37.03	33.29	39.98	36.7666
26.	41.93	39.69	51.63	44.4166
27.	64.72	61.31	39.11	55.0466

Table 3.31: The mean values of hardness at weld zone on the GMAW process

No. of Run	Welding current (Amps)	Welding voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	Hardness (mean value) (HRB)
1.	170	20	50	15	1.5	37.1033
2.	170	20	50	15	2	28.7933
3.	170	20	50	15	2.5	41.5433
4.	170	24	65	19	1.5	36.0433
5.	170	24	65	19	2	35.8766
6.	170	24	65	19	2.5	31.1766
7.	170	28	80	23	1.5	42.7133
8.	170	28	80	23	2	47.3433
9.	170	28	80	23	2.5	44.8033
10.	185	20	65	23	1.5	38.1566
11.	185	20	65	23	2	49.6966
12.	185	20	65	23	2.5	48.2766
13.	185	24	80	15	1.5	49.5566
14.	185	24	80	15	2	53.7866
15.	185	24	80	15	2.5	52.0833

16.	185	28	50	19	1.5	39.6466
17.	185	28	50	19	2	39.6833
18.	185	28	50	19	2.5	53.8233
19.	200	20	80	19	1.5	59.7633
20.	200	20	80	19	2	57.6466
21.	200	20	80	19	2.5	43.1233
22.	200	24	50	23	1.5	58.6533
23.	200	24	50	23	2	38.5266
24.	200	24	50	23	2.5	32.5333
25.	200	28	65	15	1.5	36.7666
26.	200	28	65	15	2	44.4166
27.	200	28	65	15	2.5	55.0466

Table 3.32: The experimental values of hardness at weld zone on the GTAW process

No. of Exp.	Experiment No. 1	Experiment No.2	Experiment No.3	Hardness (mean value)
1.	68.71	66.53	67.84	67.6933
2.	67.01	63.89	69.40	66.7666
3.	67.91	65.89	63.74	65.8466
4.	65.67	67.23	68.95	67.2833
5.	65.67	64.63	61.95	64.0833
6.	67.67	66.23	62.95	65.6166
7.	60.76	64.52	69.44	64.9066
8.	69.44	64.52	65.44	65.5733
9.	63.76	68.52	67.44	66.5733
10.	68.99	64.87	68.98	67.6133
11.	69.99	65.87	63.98	66.6133
12.	67.99	69.87	64.98	67.6133
13.	68.76	69.34	70.15	69.4166
14.	68.76	69.34	70.15	69.4166
15.	68.76	69.34	72.15	70.0833
16.	67.89	74.91	71.77	71.5233
17.	67.89	68.91	66.77	67.8566
18.	67.89	68.91	69.77	68.8566
19.	70.05	71.66	68.43	70.0466
20.	70.05	64.66	63.49	66.0666
21.	71.05	69.66	69.43	70.0466
22.	63.95	64.56	64.76	64.4233
23.	65.95	64.56	68.76	66.4233
24.	69.95	65.56	69.76	68.4233
25.	72.34	67.87	73.71	71.3066
26.	66.34	68.76	76.74	70.6133
27.	74.34	67.87	75.78	72.6633

Table 3.33: The mean values of hardness at weld zone on the GTAW process

No. of Exp.	Welding current (Amps)	Welding voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	Hardness (HRB) (mean value)
1.	210	22	60	12	1	67.6933
2.	210	22	60	12	1.5	66.7666
3.	210	22	60	12	2	65.8466
4.	210	26	75	16	1	67.2833
5.	210	26	75	16	1.5	64.0833
6.	210	26	75	16	2	65.6166
7.	210	30	90	20	1	64.9066
8.	210	30	90	20	1.5	65.5733
9.	210	30	90	20	2	66.5733
10.	225	22	75	20	1	67.6133
11.	225	22	75	20	1.5	66.6133
12.	225	22	75	20	2	67.6133
13.	225	26	90	12	1	69.4166
14.	225	26	90	12	1.5	69.4166
15.	225	26	90	12	2	70.0833
16.	225	30	60	16	1	71.5233
17.	225	30	60	16	1.5	67.8566
18.	225	30	60	16	2	68.8566
19.	240	22	90	16	1	70.0466
20.	240	22	90	16	1.5	66.0666
21.	240	22	90	16	2	70.0466
22.	240	26	60	20	1	64.4233
23.	240	26	60	20	1.5	66.4233
24.	240	26	60	20	2	68.4233
25.	240	30	75	12	1	71.3066
26.	240	30	75	12	1.5	70.6133
27.	240	30	75	12	2	72.6633

3.17.4 Scanning Electron Microscopy

The scanning electron micrograph study generally performed by the scanning electron microscope (SEM) which uses electron to form an image with the high resolution or the magnification. In the present investigation SEM studies has been done to see the dispersion under the effect of filler material at the weld zone and the parent material. The images are obtained through microscopic investigation with LEO435VP. The SEM and EDS (EDX) have been carried out by Jeol-JSM-6510 setup available at department of Veterinary, GBPUA &T, Pantnagar.

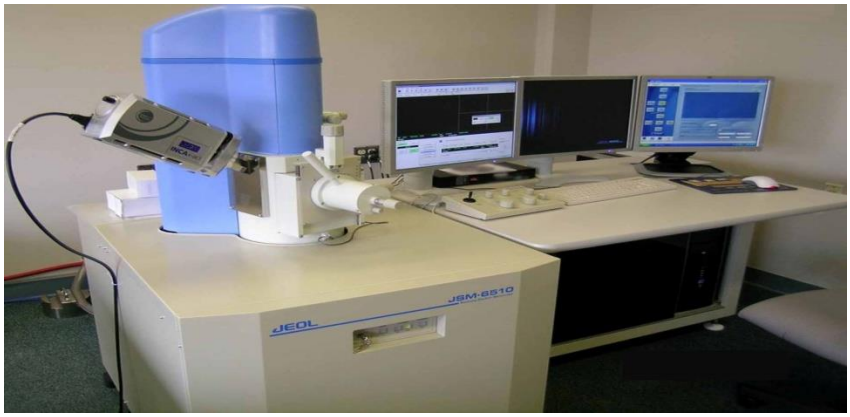


Fig. 3.26: SEM / EDS testing machine

Technical specification of SEM/EDS

Type of machine	: Jeol-JSM-6510
Resolution	: 3.0 mm (30kV)
Magnification	: 5x to 300,000x (Select for testing-500X)
Image mode	: Secondary electrons, backscattered electrons
Accelerating voltage	: 0.5 kV to 30 kV (Select for testing-22 kV)
Filament type	: W-type
Electron gun	: Fully automated, manual override
Objective lens	: Super conical
Rotation	: 360^0
Multi image display	: 2 images, 4 images

To obtain the scanning electrons micrographs square samples are cut from the crack surfaces at the weld zone, the parent material and the filler wire. The samples charging and then placed inside a chamber in which an electron beam is fall on the material. The accelerated voltage was 20 kV. The different images are taken at the various magnification ranges.

3.17.5 Electron Dispersion Spectroscopy

The energy dispersive spectroscopy (EDS) used to determine the elemental composition. The EDS also known as EDS Analysis, is a qualitative and semi-quantitative X-ray micro analytical technique that can provide information about the elemental or chemical composition of a sample as shown in above Figure 3.24. The EDS analysis is a very good at determining what elements are present in samples which are as small as one micrometer (40 micro-inches). The results are plotted with X-ray wavelength on the X-axis and intensity on the Y-axis with each peak labeled with its corresponding element.

3.18 DATA ANALYSIS

The numbers of technique have been done by the Taguchi to analyze the data obtained from the ranking method, observation method, column effects method, ANOVA, S/N ANOVA, interaction graph and plot the average response curves. The following techniques have been used in the present research work:

(1)Plot of the average response curves

(2)ANOVA for the raw data

(3)ANOVA for S/N data

The plot average response is a pictorial representation of the effect of the parameters on the response. The change in response characteristic with the change in the level of a parameter can easily be visualized from these curves. The typically ANOVA for orthogonal arrays are conducted in the same manner as other structured the experiments (Vineeta 2015).

The S/N ratio is treated as a response of the experiment which is a measure of the variation within a trial when the noise factors are present. A standard ANOVA can be conducted on the S/N ratio which will identify the significant parameters (mean and variation).

3.18.1 Statistical Analysis

It may be consists of the raw data analysis and the evaluation of signal to noise ratios (S/N ratio) which is described as follows:

3.18.1.1 Raw data analysis

I. Total levels and their ranges

The total value of the response at the each parameter is obtained by adding the results of all the trial conditions at the levels considered taking from Table 3.13 and Table 3.15 for both the processes. The average value is obtained by dividing total values of response and number of data points added. For the parameter welding current (A), the level total of the response is calculated as the following method:

A (1) = X1 + X2 + X3 + X4+X5+X6+X7+X8+X9 ……1

A (2) = X10 + X11 + X12 + X13+X14+X15+X16+X17+X18……2

A (3) = X19 + X20 + X21 + X22+X23+X24+X25+X26+X27 ……...3

The average value is obtained as:

$\overline{A}$ (1) = $\frac{A(1)}{3}$ ……4

$\overline{A}$ (2) = $\frac{A(2)}{3}$……5

$\overline{A}$ (3) = $\frac{A(3)}{3}$……6

Table 3.34: The general representation of response (standard values) table for the GMAW and the GTAW processes

No. of Run	Welding current (A)	Welding voltage (B)	Welding speed ©	Gas flow rate (D)	Root gap (E)	Response
1.	1	1	1	1	1	X1
2.	1	1	1	1	2	X2
3.	1	1	1	1	3	X3
4.	1	2	2	2	1	X4
5.	1	2	2	2	2	X5
6.	1	2	2	2	3	X6
7.	1	3	3	3	1	X7
8.	1	3	3	3	2	X8
9.	1	3	3	3	3	X9
10.	2	1	2	3	1	X10
11.	2	1	2	3	2	X11
12.	2	1	2	3	3	X12
13.	2	2	3	1	1	X13
14.	2	2	3	1	2	X14
15.	2	2	3	1	3	X15
16.	2	3	1	2	1	X16
17.	2	3	1	2	2	X17
18.	2	3	1	2	3	X18
19.	3	1	3	2	1	X19
20.	3	1	3	2	2	X20
21.	3	1	3	2	3	X21
22.	3	2	1	3	1	X22
23.	3	2	1	3	2	X23
24.	3	2	1	3	3	X24
25.	3	3	2	1	1	X25
26.	3	3	2	1	2	X26
27.	3	3	2	1	3	X27
Total						X

For the welding voltage (B) the level of total response is calculated as:

B (1) = X1+X2+X3+X10+X11+X12+X19+X20+21……7

B (2) = X4+X5+X6+X13+X14+X15+X22+X24+X25……8

B (3) = X7+X8+X9+X16+X17+X18+X25+X26+X27……9

The average of second parameter is obtained as:

$\overline{B}$ (1) = $\frac{B(1)}{3}$……10

$\overline{B}$ (2) = $\frac{B(2)}{3}$……11

$\overline{B}$ (3) = $\frac{B(3)}{3}$……12

Similarly for the welding speed (C) the level of total response is calculated as:

C (1) = X1+X2+X3+X16+X17+X18+X22+X23+X24……13

C (2) = X4+X5+X6+X10+X11+X12+X25+X26+X27……14

C (3) = X7+X8+X9+X13+X14+X15+X19+X20+X21……15

The average value of the third parameter is obtained as:

$\overline{C}$ (1) = $\frac{C(1)}{3}$……16

$\overline{C}$ (2) = $\frac{C(2)}{3}$……17

$\overline{C}$ (3) = $\frac{C(3)}{3}$……18

For the gas flow rate (D) the level of total response is calculated as:

D (1) =X1+X2+X3+X13+X14+X15+X25+X26+X27……19

D (2) = X4+X5+X6+X16+X17+X18+X19+X20+X21……...20

D (3) = X7+X8+X9+X10+X11+X12+X22+X23+X24……...21

The average value of the fourth parameter is obtained as:

$\overline{D}$ (1) = $\frac{D(1)}{3}$……..22

$\overline{D}$ (2) = $\frac{D(2)}{3}$……23

$\overline{D}$ (3) = $\frac{D(3)}{3}$……24

For the root gap (E) the level of total response is calculated as:

E (1) = X1+X4+X7+X10+X13+X16+X19+X22+X25……25

E (2) = X2+X5+X8+X11+X14+X17+X20+X23+X26……26

E (3) = X3+X6+X9+X12+X15+X18+X21+X24+X27……27

The average value of the fifth parameter is obtained as:

$\overline{E}$ = $\frac{E(1)}{3}$……..28

$\overline{E}$ = $\frac{E(2)}{3}$……..29

$\overline{E}$ = $\frac{E(3)}{3}$……..30

II. Main effect

The main effect of the parameter A when the parameter changed from the lower level to the upper level is given by:

The main effect of the parameter A when A changes from level 1 to level 2 = the difference in the average value of the response between level 2 and level 1 of parameter A

= $\overline{A}$ (2) – $\overline{(1)}$……31

The main effect of the parameter A when A changes from level 2 to level 3 = the difference in the average value of the response between level 3 and level 2 of parameter A

$= \overline{A}(3) - (\overline{2})$……32

Similarly, we can easily find out the main effect of the parameters B, C, D and E the parameters changed from the lower level to the upper level.

III. Analysis of variance (ANOVA)

The following steps are that are involved in it:

Step 1: The total of all the results (T) Here all the responses are added.

$T = X$…….33

Step 2: The correction factor (C.F.)

$C.F = T^2/N$…….34

Where,

N = the total number of experiments

Step 3: The total sum of squares (S_T)

$S_T = \sum_{i=1}^{n} X_i^2 - C.F$……35

Step 4: The sum of squares due to the parameter or factor sum of squares

$S_A = [\frac{A(1)^2}{N_{A1}} + \frac{A(2)^2}{N_{A2}} + \frac{A(3)^2}{N_{A3}}] - C.F$……..…….....36

Where,

N_{A1}, N_{A2} and N_{A3} are the number of trials with parameter A at level 1, 2 and 3 similarly we can find out S_B, S_C, S_D and S_E.

Step 5: Error sum of squares (S_e)

$S_e = S_T - (S_A+S_B+S_C+S_D+S_E)$……..……37

Step 6: The total and the parameter degree of freedom (DOF)

f_T = Total degree of freedom

= (Total number of trials - 1)

f_A = Degree of parameter A

= (Number of level of parameter A – 1)

Similarly,

f_B = Degree of parameter B

= (Number of level of parameter B - 1)

f_C = Degree of parameter C

= (Number of level of parameter C - 1)

f_D = Degree of parameter D

= (Number of level of parameter D - 1)

f_E = Degree of parameter E

= (Number of level of parameter E -1)

f_e = The error degree of freedom

$= f_T - (f_A + f_B + f_C + f_D + f_E)$……38

Step 7: Mean square of variance (V)

Variance due to parameter A

$V_A = \frac{S_A}{f_A}$……39

Similarly, Variance due to parameter B

$V_B = \frac{S_B}{f_B}$……40

Variance due to parameter C

$V_C = \frac{S_C}{f_C}$……41

Variance due to parameter D

$V_D = \frac{S_D}{f_D}$……42

Variance due to parameter E

$V_E = \frac{S_E}{f_E}$……43

Variance due to error

$V_e = \frac{S_e}{f_e}$……..44

Step 8: The Percentage contribution (P)

$P_A = \frac{S_A}{S_T}$……45

$P_B = \frac{S_B}{S_T}$……46

$P_C = \frac{S_C}{S_T}$……47

$P_D = \frac{S_D}{S_T}$……48

$P_E = \frac{S_E}{S_T}$……...49

The error of percentage contribution (e)

$P_e = \frac{S_e}{S_T}$……50

Step 9: F – Ratios

$F_A = \frac{V_A}{V_e}$……51

$$F_B = \frac{V_B}{V_e} \quad \ldots\ldots 52$$

$$F_C = \frac{V_C}{V_e} \quad \ldots\ldots 53$$

$$F_D = \frac{V_D}{V_e} \quad \ldots\ldots 54$$

$$F_E = \frac{V_E}{V_e} \quad \ldots\ldots 55$$

Step 10: Pooling

If calculated F- ratio in step 9 is less than F- ratio tabulated at 95% confidence level, the effect of parameter is pooled. The factor does not contribute to sum of squares within the confidence level. If a parameter is pooled, the sum of squares due to the parameter is added to the error sum of square and the ANOVA terms are modified. If parameter A is pooled, then

$$S_{e\,(Pooled)} = S_e + S_A \quad \ldots\ldots 56$$

$$f_{e\,(Pooled)} = f_e + f_A \quad \ldots\ldots 57$$

$$V_{e\,(pooled)} = \frac{S_{e(Pooled)}}{f_{e(Pooled)}} \quad \ldots\ldots 58$$

Step 11: Pure sum of square

If parameter A is significant

$$S'_A = S_A - (V_e \times f_A) \quad \ldots\ldots 59$$

Similarly, for B, C, D and E significant parameters pure sum of squares can be calculated with the help of equation No. 59. The subtracted amount of sum of square must be added to error sum of square in order to ensure that the total sum of squares is unchanged.

$$S'_e = S_e + (V_e \times f_A) \quad \ldots\ldots 60$$

Step 12: The modified percentage contribution

After pooling the percentage contribution of significant parameter is calculated.

$$P_A = \frac{S_A}{S_T} \quad \ldots\ldots 61$$

$$P_B = \frac{S_B}{S_T} \quad \ldots\ldots 62$$

$$P_C = \frac{S_C}{S_T} \quad \ldots\ldots 63$$

$$P_D = \frac{S_D}{S_T} \quad \ldots\ldots 64$$

$$P_E = \frac{S_E}{S_T} \quad \ldots\ldots 65$$

$$Pe = \frac{S_e}{S_T} \quad \ldots\ldots 66$$

The total percentage of contribution is calculated as:

$$P_T = P_A + P_B + P_C + P_D + P_E + P_e \quad \ldots\ldots 67$$

To check the percentage contribution and the significance levels of the parameters based on the signal to noise ratio (S/N) analysis of the same procedure is adopted as in the raw data analysis.

3.18.1.2 Evaluation of signal to noise (S/N) ratio

Signal is defined as the desirable value (mean) whereas noise is defined as the undesirable value (standard deviation). It represents the amount of the variation present in the performance characteristics. There can be various types of S/N ratios depending upon the objective of performance characteristics.

Here in the experiments the objective is the higher values of the tensile strength, impact strength and hardness. Therefore we have used larger-the-better type S/N ratio to transform the raw data and are as follows:

$$(S/N)_i = -10\log\left(\frac{1}{n}\sum_{n=1}^{1}\frac{1}{y_i^2}\right) \quad \ldots\ldots 68$$

Where,

y_i = The value of characteristics in an observation i and n is the number of observations or the number of repetitions.

3.19 PREDICTION OF MEAN

The optimum condition after determination the mean of the response (μ) at the optimum condition is predicted. This mean is the estimated only from the significant parameters which are identified by ANOVA. Let us suppose that the parameters A and B are significant factors and A2 B1 is the optimum condition. Then mean at the optimum condition (optimum value of the characteristics) is estimated as follows.

$$\mu = \overline{T} + (\overline{A}2 - \overline{T}) + (\overline{B}1 - \overline{T}) \quad \ldots\ldots 69$$

$$= \overline{A}2 + \overline{B}1 - \overline{T} \quad \ldots\ldots 70$$

Where,

$\overline{T}$ is the overall mean of the response and $\overline{A}2$ and $\overline{B}1$ are the average values of the responses at the second and first level of parameters A and B respectively. The predicted combination of the parameter levels (optimum treatment condition) may be the identical to one of those in the experiment. If this situation exists the most direct way of estimating the mean for that the treatment condition is to average all the results for the trials which are set at those particular levels (Jadoun 2005).

3.19.1 Determination of Confidence Interval around Estimated Mean

The estimate of the mean is only a point estimate based on the average of results obtained from the experiments. Statistically this provides a 50% chance of the true average being greater than 50% chance of the true average being less than mean (μ). The confidence interval is a major and a minor value between which the true average should fall at some stated percentage of the confidence. The confidence is the statistical sense means there is some chance of a mistake.

There are three different types of confidence intervals (CIs) that the Taguchi approach uses and the depending on the purpose of the estimate results.

(1) Near about the average for a particular treatment condition in the existing experiment

(2) Around the estimated average of a treatment condition the predicted from the experiment

(3) Near about the estimated average of a treatment condition used in a confirmation experiment to the verify prediction

I. Confidence interval one (CI_1) for existing experiment treatment condition

The method of computing a CI is traditional statistical technique (Jadoun 2005).

$$CI_1 = \sqrt{\frac{F_{\alpha;v1;v2} Vep}{n}} \quad \text{.....71}$$

Where,

$F_{\alpha;v1;v2}$ = F ratio is requiring for:

α = The risk

The confidence = 1- risk

v_1 = the degree of freedom (DOF) of the mean (always equals to 1)

v_2 = the degree of freedom (DOF) for the pooled error

V_{ep} = the variance of the error term, n = the number of tests under that condition

II. Confidence interval two (CI_2) for predicted treatment condition

The CI observing is modified (Jadoun 2005):

$$CI_2 = \sqrt{\frac{F_{\alpha;v1;v2} Vep}{n_{eff}}} \quad \text{.....72}$$

$$n_{eff} = \frac{N}{1+[\text{total degree of freedom associated with items used in } \mu \text{ estimate}]}$$

N = the total number of experiment run

III. Confidence interval three (CI_3) for predicted confirmation experiment

The confirmation experiment is used to verify that the factors and the levels chosen from an experiment cause a product or process to behave in the certain fashion. The difference between CI_2 and CI_3 is that CI_2 is for the entire population i.e. all the parts ever made under the specified conditions and CI_3 is only for a sample group made under the specified conditions. Because of the smaller size in the confirmation experiment CI_3 must be slighter wider. The expression for computing the confidence interval is given as (Jadoun 2005):

$$CI_3 = \sqrt{F\alpha_{v1:v2} V_{ep} \left[\frac{1}{n_{eff}} + \frac{1}{r}\right]} \quad \text{.....73}$$

r = Size of the sample for the confirmation experiment, $r \neq 0$

3.20 CONFIRMATION EXPERIMENT

The confirmation experiment is the final step in verifying the conclusion from the previous round of experimentation. The optimum conditions are set for the significant parameters (the insignificant parameters are set at economic levels) and a selected number of tests are run under constant specified conditions. The average of the confirmation experiment results is compared with the anticipated average based on the parameters and levels. The confirmation experiment is a crucial step and highly recommended to verify the experimental conclusions (Ross 1988).

Samples after welding are shown in Figure 3.27, Figure 3.28, Figure 3.29 and Figure 3.30. Samples after testing are shown in Figure 3.31, Figure 3.32 and Figure 3.33

Fig.3.27: Samples after GMAW

Fig.3.28: Samples after GTAW

Fig.3.29: Samples for tensile and impact testing after GMAW and GTAW

Fig.3.30: Samples of parent metal

Fig.3.31: Samples after impact testing

Fig.3.32: Samples of GMAW, GTAW and parent metal after tensile testing

Fig.3.33: Samples after hardness

Results and Discussion

4.1 RESULTS AND DISCUSSION

The analysis and discussion of results of Taguchi method based experiments are presented in this section. The effect of individual GMAW and GTAW process parameters selected on the performance characteristics (ultimate tensile strength, impact strength and hardness) is discussed. The experiments were conducted using L_{27} OA. The standard procedure suggested by Taguchi has been used for analyzing the results. The mean or the average values and S/N ratio of the quality/ performance characteristics for each parameter at different levels have been calculated from experimental data. For the graphical representation of the change in performance characteristics and that of S/N ratio with the variation in process parameters, the response curves have been plotted. These response curves have been used as an aid to visualize the parametric effects on the performance characteristics. The analysis of variance (ANOVA) for raw data and S/N data have been performed to identify the significant parameters and to quantify their effect on the performance characteristics. The pooled ANOVA and ANOVA (without pooling) are given also in this section. The most favorable conditions or optimal levels of process parameters have been established by analyzing response curves of S/N ratio associated with the raw data.

In this chapter after conducting the experiment with the different setting of input parameters and the values of the output variables have been measured and the plotted as per DOE approach. The analysis of the results obtained has been performed according to the standard procedure recommended by the taguchi method. The results obtained from the various tests performed during the present investigation such as ultimate tensile testing, impact testing, hardness testing, scanning electron microscope and the electron dispersion spectroscopy or the energy dispersive x – ray spectroscopy (EDS) are presented and discussed in the subsequent sections. An analysis on the basis of the means and S/N ratios are obtained using the MINITAB-18 software.

This chapter contains the analysis and discussion of the results from the data obtained through:

(1)Gas metal arc welding (GMAW) process

(2)Gas tungsten arc welding (GTAW) process

(3)Comparative analysis of GMAW, GTAW processes

4.2 EXPERIMENTAL DATA FOR ANOVA OF GAS METAL ARC WELDING

An analysis of variance is a statistical technique used to interpret an experimental data and make the necessary decision. The ANOVA is statically based decision tool for the detecting any difference in the average performance of group of the items tested. The ANOVA for the mean has been performed to identify the significant parameters to quantify their effect on the performance characteristics in the present investigation for the gas metal arc welding (GMAW) process. The experimental data for the mean data and S/N ratio of ultimate tensile strength, impact strength and hardness are given in Table 4.1, Table 4.2 and Table 4.3 for the GMAW process respectively.

Table 4.1: Experimental data of UTS and S/N ratio for GMAW

No. of Exp.	Ultimate tensile strength (UTS) at weld zone			Ultimate tensile strength (UTS) (mean value)	S/N ratio
	Experiment No. 1	Experiment No.2	Experiment No.3		
1.	127.712	137.942	141.401	135.685	42.65064
2.	138.816	163.815	158.473	153.701	43.73355
3.	171.597	167.497	184.286	174.460	44.83392
4.	149.197	162.501	176.242	162.646	44.2249
5.	180.541	174.183	191.374	182.032	45.20299
6.	175.542	187.249	194.541	185.777	45.37985
7.	178.427	187.243	168.264	177.978	45.00733
8.	198.092	189.751	187.804	191.882	45.6607
9.	211.052	213.812	190.246	205.036	46.23663
10.	175.702	180.512	169.481	175.231	44.87225
11.	170.542	162.843	177.671	170.352	44.62694
12.	164.054	171.246	167.457	167.585	44.48474
13.	181.241	177.914	174.571	177.908	45.00394
14.	201.842	191.461	185.246	192.849	45.70438
15.	186.246	181.764	175.468	181.159	45.16121
16.	201.842	197.927	191.761	197.176	45.89711
17.	192.751	185.538	179.854	186.047	45.39248
18.	221.421	212.842	209.421	214.561	46.63103
19.	203.735	196.267	191.548	197.183	45.8974
20.	185.842	195.421	184.675	188.646	45.51295
21.	187.457	180.576	184.276	184.103	45.30122
22.	206.756	193.754	184.261	194.923	45.79729
23.	227.469	218.467	210.912	218.949	46.80687
24.	198.219	212.207	204.674	205.033	46.23649
25.	221.402	214.276	198.768	211.482	46.50547
26.	208.421	211.764	194.752	204.979	46.23419
27.	221.792	216.542	208.467	215.600	46.67299
Average ($\mu_{\bar{T}}$)				187.1468	45.39517
Max.	227.469	218.467	210.912	218.949	46.80687
Min.	127.712	137.942	141.401	135.685	42.65064

Table 4.2: Experimental data of impact strength and S/N ratio for GMAW

No. of Exp.	Impact strength at weld zone			Impact strength (mean value)	S/N ratio
	Experiment No. 1	Experiment No.2	Experiment No.3		
1.	0.13501	0.10925	0.10124	0.11516	18.77346
2.	0.11014	0.10146	0.10248	0.10469	19.60162
3.	0.10954	0.10724	0.107502	0.10809	19.32397
4.	0.10475	0.11278	0.10539	0.10764	19.36053
5.	0.10549	0.10568	0.11031	0.10716	19.39935
6.	0.10634	0.10451	0.11109	0.10731	19.38693
7.	0.11067	0.10572	0.10452	0.10697	19.41476
8.	0.10734	0.12829	0.11345	0.11636	18.68393
9.	0.16705	0.21571	0.20514	0.19596	14.15636
10.	0.10237	0.10281	0.10624	0.10380	19.6755
11.	0.10248	0.31205	0.10263	0.17238	15.26993
12.	0.10301	0.21347	0.31521	0.21056	13.53235
13.	0.41352	0.24613	0.12541	0.26168	11.64437
14.	0.10534	0.20136	0.10971	0.13880	17.15200
15.	0.10027	0.19371	0.27543	0.18980	14.43392
16.	0.10946	0.26721	0.41325	0.26330	11.59076
17.	0.51735	0.42372	0.10304	0.34803	9.16750
18.	0.10243	0.13752	0.10923	0.11639	18.68144
19.	0.10813	0.51243	0.18309	0.26788	11.44109
20.	0.10345	0.13428	0.10914	0.11562	18.73909
21.	0.12003	0.10542	0.10604	0.11049	19.13302
22.	0.14272	0.10205	0.12034	0.12170	18.29395
23.	0.12031	0.10245	0.10672	0.10982	19.18584
24.	0.51372	0.34026	0.10037	0.31811	9.948272
25.	0.57612	0.19042	0.25409	0.34021	9.365059
26.	0.64201	0.10972	0.41067	0.38746	8.235313
27.	0.51607	0.19304	0.41067	0.37326	8.559771
Average ($\mu_{\bar{I}}$)				0.18588	15.63519
Max.	0.64201	0.51243	0.41325	0.38746	19.67550
Min.	0.10027	0.10146	0.10037	0.10380	8.235313

Table 4.3: Experimental data of hardness and S/N ratio for GMAW

No. of Exp.	Hardness at weld zone			Hardness (mean value)	S/N ratio
	Experiment No.1	Experiment No.2	Experiment No.3		
1.	31.51	44.74	35.06	37.1033	31.38826
2.	28.14	27.81	30.43	28.7933	29.18584
3.	46.70	42.39	35.54	41.5433	32.37003
4.	31.81	36.17	40.15	36.0433	31.13650
5.	25.91	42.35	39.37	35.8766	31.09624
6.	27.73	28.37	37.43	31.1766	29.87659
7.	39.01	46.29	42.84	42.7133	32.61127
8.	49.34	58.01	34.68	47.3433	33.50518
9.	59.11	41.74	33.56	44.8033	33.02621
10.	38.90	42.08	33.49	38.1566	31.63141
11.	56.29	54.23	38.57	49.6966	33.92655

12.	48.57	51.77	44.49	48.2766	33.67475
13.	49.56	44.79	54.32	49.5566	33.90204
14.	60.31	57.29	43.76	53.7866	34.61349
15.	64.51	57.17	34.57	52.0833	34.33398
16.	45.78	41.29	31.87	39.6466	31.96413
17.	29.67	41.95	47.43	39.6833	31.97216
18.	59.41	53.63	48.43	53.8233	34.61941
19.	66.29	51.56	61.44	59.7633	35.5287
20.	59.78	58.15	55.01	57.6466	35.21548
21.	36.54	49.54	43.29	43.1233	32.69425
22.	62.21	52.28	61.47	58.6533	35.36585
23.	33.91	44.40	37.27	38.5266	31.71523
24.	26.78	35.41	35.41	32.5333	30.24657
25.	37.03	33.29	39.98	36.7666	31.30909
26.	41.93	39.69	51.63	44.4166	32.95092
27.	64.72	61.31	39.11	55.0466	34.81462
Average ($\mu_{\bar{H}}$)				44.3178	32.76573
Max.	66.29	61.31	61.47	59.7633	35.52870
Min.	25.91	27.81	30.43	28.7933	29.18584

4.2.1 Data Analysis of Ultimate Tensile Strength for GMAW

The ultimate tensile strength (UTS) is the maximum stress that a material can withstand while being stretched or pulled before the failing or the breaking due to the applying tensile load. The data analysis selection of optimal settings, ANOVA, prediction of mean, determination of confidence interval, the effect of process parameters are presented in this section. The results of ultimate tensile strength and the results of S/N ratios obtained by software MINITAB-18 is given in Table 4.4 for the GMAW process.

Table 4.4: Experimental results and S/N ratios for UTS

No. of Run	Welding current (Amps)	Welding voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	Ultimate tensile strength (UTS) (MPa)	S/N ratio
1.	170	20	50	15	1.5	135.6850	42.6506
2.	170	20	50	15	2	153.7013	43.7335
3.	170	20	50	15	2.5	174.4600	44.8339
4.	170	24	65	19	1.5	162.6467	44.2249
5.	170	24	65	19	2	182.0327	45.2029
6.	170	24	65	19	2.5	185.7773	45.3798
7.	170	28	80	23	1.5	177.9780	45.0073
8.	170	28	80	23	2	191.8823	45.6607
9.	170	28	80	23	2.5	205.0367	46.2366
10.	185	20	65	23	1.5	175.2317	44.8722
11.	185	20	65	23	2	170.3520	44.6269
12.	185	20	65	23	2.5	167.5857	44.4847
13.	185	24	80	15	1.5	177.9087	45.0039
14.	185	24	80	15	2	192.8497	45.7043

15.	185	24	80	15	2.5	181.1593	45.1612
16.	185	28	50	19	1.5	197.1767	45.8971
17.	185	28	50	19	2	186.0477	45.3924
18.	185	28	50	19	2.5	214.5613	46.6310
19.	200	20	80	19	1.5	197.1833	45.8974
20.	200	20	80	19	2	188.6460	45.5129
21.	200	20	80	19	2.5	184.1030	45.3012
22.	2001	24	50	23	1.5	194.9237	45.7972
23.	200	24	50	23	2	218.9493	46.8068
24.	200	24	50	23	2.5	205.0333	46.2364
25.	200	28	65	15	1.5	211.4820	46.5054
26.	200	28	65	15	2	204.9790	46.2341
27.	200	28	65	15	2.5	215.6003	46.6729

The response table for the means or the raw data and signal to noise or S/N data at the five numbers of parameter levels are calculated from Table 4.4 and are shown in Table 4.5 and table 4.6 respectively. These results have been plotted as shown in Figure 4.1 and Figure 4.2 with the help of MINITAB-18 software.

Table 4.5: Raw or mean data response for ultimate tensile strength

Levels	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	174.4	171.9	186.7	183.1	181.1
2	184.8	189	186.2	188.7	187.7
3	202.3	200.5	188.5	189.7	192.6
Delta	28	28.6	2.3	6.6	11.5
Rank	2	1	5	4	3

The rank in Table 4.5 indicates that the increasing order in the first two columns and the rank also increasing order in the last three columns of the effect on the response is welding voltage, welding current, root gap, gas flow rate and welding speed.

Table 4.6: S/N response Table for ultimate tensile strength on GMAW Process

Level	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	44.77	44.66	45.33	45.17	45.1
2	45.31	45.5	45.36	45.49	45.43
3	46.11	46.03	45.5	45.53	45.66
Delta	1.34	1.37	0.17	0.36	0.56
Rank	2	1	5	4	3

The rank in Table 4.6 indicates that the increasing order in the first two columns and the rank also increasing order in the last three columns of the effect on the response is welding voltage, welding current, root gap, gas flow rate and welding speed, same as that obtained from above the raw data.

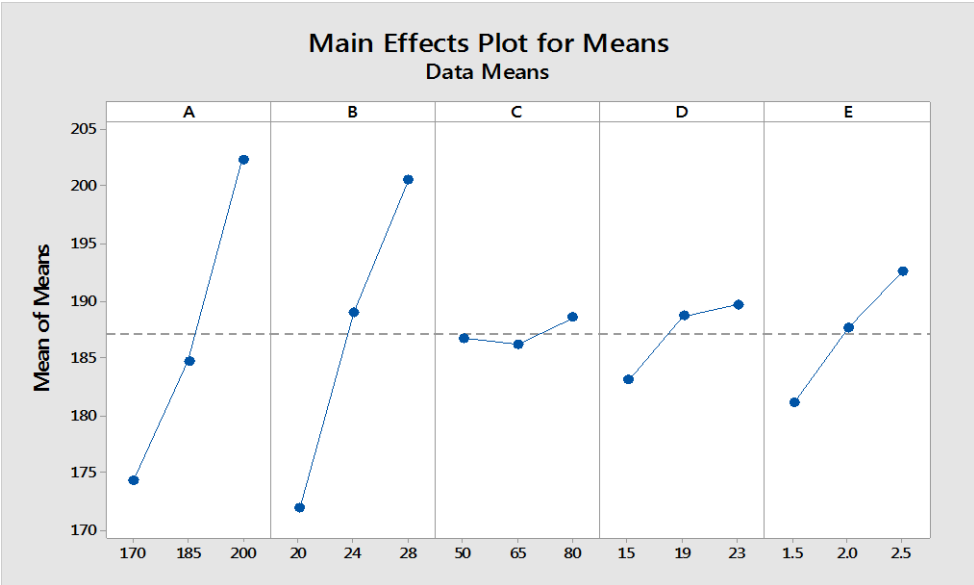


Fig. 4.1: Main effects plot of mean data for UTS on GMAW process

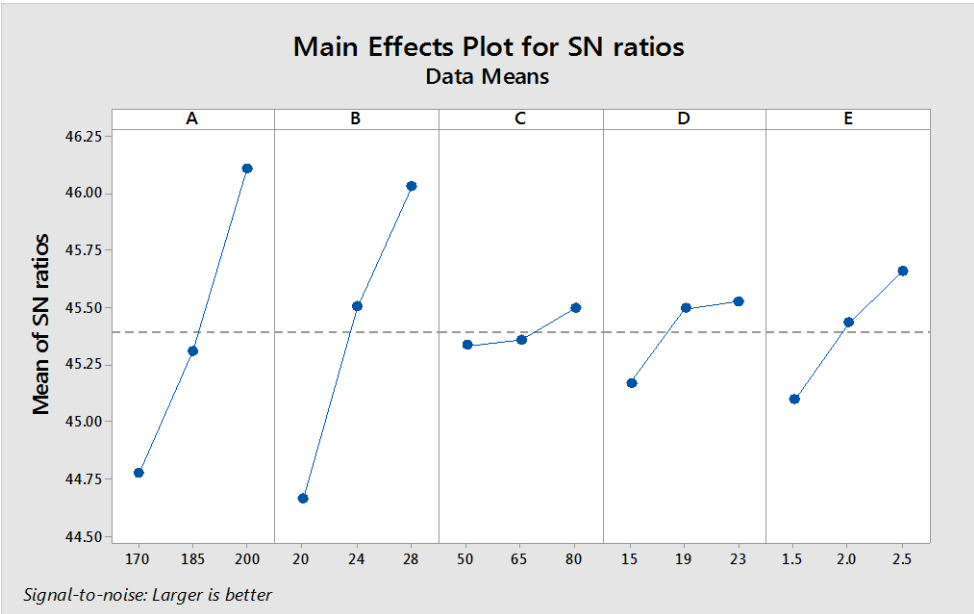


Fig. 4.2: Main effects plot of S/N ratios for UTS on GMAW process

From figure 4.1 and figure 4.2 it is clear that the optimal setting for input parameters for the said condition for UTS is A3 B3 C3 D3 E3. It means each parameter is at third level for this particularly.

4.2.2 Data Analysis of Impact Strength for GMAW

The impact test determines the behaviour of materials when subjected to the high rates of sudden loading, usually in bending tension or torsion. It measures the energy absorbed in breaking the specimen by a high blow or impact. The data analysis selection of optimal settings, ANOVA, prediction of mean, determination of confidence interval, the effect of

process parameters are presented in this section. The result of impact strength (IS) and the result of S/N ratios obtained by the software MINITAB-18 are given in the Table 4.7

Table 4.7: Experimental results and S/N ratios for impact strength for the GMAW

No. of Run	Welding current (Amps)	Welding Voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	Impact mean value	S/N ratio
1.	170	20	50	15	1.5	0.11516	18.77346
2.	170	20	50	15	2	0.10469	19.60162
3.	170	20	50	15	2.5	0.10809	19.32397
4.	170	24	65	19	1.5	0.10764	19.36053
5.	170	24	65	19	2	0.10716	19.39935
6.	170	24	65	19	2.5	0.10731	19.38693
7.	170	28	80	23	1.5	0.10697	19.41476
8.	170	28	80	23	2	0.11636	18.68393
9.	170	28	80	23	2.5	0.19596	14.15636
10.	185	20	65	23	1.5	0.10380	19.6755
11.	185	20	65	23	2	0.17238	15.26993
12.	185	20	65	23	2.5	0.21056	13.53235
13.	185	24	80	15	1.5	0.26168	11.64437
14.	185	24	80	15	2	0.13880	17.152
15.	185	24	80	15	2.5	0.18980	14.43392
16.	185	28	50	19	1.5	0.26330	11.59076
17.	185	28	50	19	2	0.34803	9.1675
18.	185	28	50	19	2.5	0.11639	18.68144
19	200	20	80	19	1.5	0.26788	11.44109
20	200	20	80	19	2	0.11562	18.73909
21.	200	20	80	19	2.5	0.11049	19.13302
22.	200	24	50	23	1.5	0.12170	18.29395
23.	200	24	50	23	2	0.10982	19.18584
24.	200	24	50	23	2.5	0.31811	9.948272
25.	200	28	65	15	1.5	0.34021	9.365059
26.	200	28	65	15	2	0.38746	8.235313
27.	200	28	65	15	2.5	0.37326	8.559771

The response table for the means or the raw data and signal to noise or S/N data at the five numbers of parameter levels are calculated from Table 4.7 and are shown in Table 4.8 and Table 4.9 respectively. These results have been plotted as shown in Figure 4.3 and Figure 4.4 with the help of MINITAB-18 software.

Table 4.8: Raw or mean data response for impact strength on the GMAW Process

Level	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	0.1188	0.1454	0.1784	0.2244	0.1876
2	0.2005	0.1625	0.2122	0.1715	0.1778
3	0.2383	0.2498	0.1671	0.1617	0.1922
Delta	0.1195	0.1044	0.0451	0.0626	0.0144
Rank	1	2	4	3	5

The rank in Table 4.8 indicates that the decreasing order in the first two columns and the rank fluctuate first increasing in the last two columns and decreasing in last column of the effect on the response is welding current, welding voltage, gas flow rate, welding speed and root gap.

Table 4.9: S/N response for impact strength on the GMAW process

Level	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	18.68	17.28	16.06	14.12	15.51
2	14.57	16.53	14.75	16.32	16.16
3	13.66	13.09	16.09	16.46	15.24
Delta	5.02	4.18	1.33	2.34	0.92
Rank	1	2	4	3	5

The rank in Table 4.9 indicates that the decreasing order in the first two columns and the rank increasing order in the two columns and decreasing in the last columns of the effect on the response is welding current, welding voltage, gas flow rate, welding speed and root gap, same as that obtained from above the raw data.

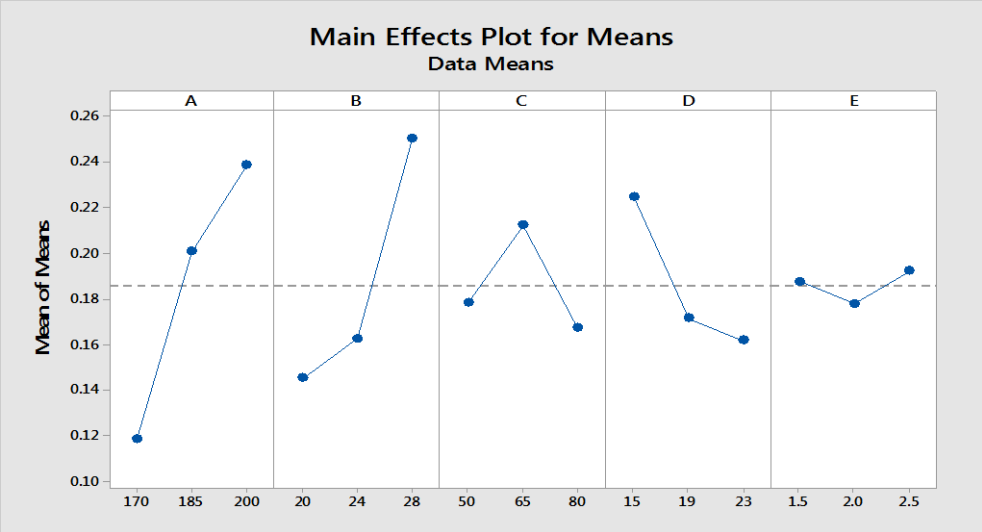


Fig.4.3: Main effects plot of mean data for impact strength on GMAW

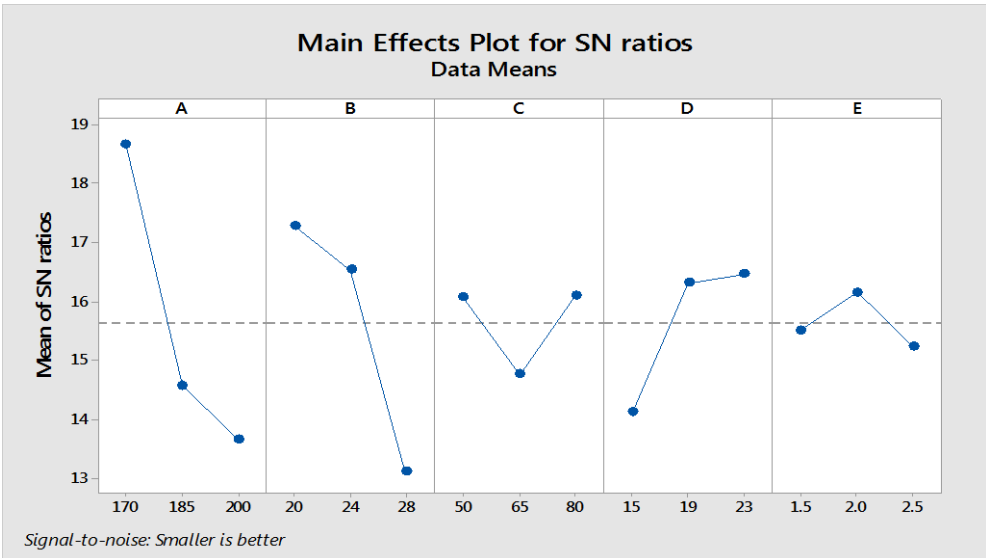


Fig. 4.4: Main effects plot of S/N ratios for impact strength on GMAW

Figure 4.3 and figure 4.4 shows that the optimal setting for input parameters for impact strength is A1 B1 C3 D3 E2.

4.2.3 Data Analysis of Hardness for GMAW

The hardness (HRB) of a material is the resistance to the penetration under a localized pressure or the resistance to the abrasion. The hardness tests provide an accurate, rapid and the economical way of determining the resistance of the materials to deformation. The data analysis selection of optimal settings, ANOVA, prediction of mean, determination of confidence interval, the effect of process parameters are presented in this section. The results of hardness (HRB) and the observations of S/N ratios obtained by the software MINITAB-18 is given in Table 4.10 on the GMAW process.

Table 4.10: Experimental results and S/N ratios for hardness test on GMAW process

Experiment No.	Welding current (A)	Welding voltage (V)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	Hardness (HRB) value	S/N ratio
1.	170	20	50	15	1.5	37.1033	31.38826
2.	170	20	50	15	2	28.7933	29.18584
3.	170	20	50	15	2.5	41.5433	32.37003
4.	170	24	65	19	1.5	36.0433	31.13650
5.	170	24	65	19	2	35.8766	31.09624
6.	170	24	65	19	2.5	31.1766	29.87659
7.	170	28	80	23	1.5	42.7133	32.61127
8.	170	28	80	23	2	47.3433	33.50518
9.	170	28	80	23	2.5	44.8033	33.02621
10.	185	20	65	23	1.5	38.1566	31.63141
11.	185	20	65	23	2	49.6966	33.92655
12.	185	20	65	23	2.5	48.2766	33.67475
13.	185	24	80	15	1.5	49.5566	33.90204
14.	185	24	80	15	2	53.7866	34.61349
15.	185	24	80	15	2.5	52.0833	34.33398
16.	185	28	50	19	1.5	39.6466	31.96413
17.	185	28	50	19	2	39.6833	31.97216
18.	185	28	50	19	2.5	53.8233	34.61941
19.	200	20	80	19	1.5	59.7633	35.5287
20.	200	20	80	19	2	57.6466	35.21548
21.	200	20	80	19	2.5	43.1233	32.69425
22.	200	24	50	23	1.5	58.6533	35.36585
23.	200	24	50	23	2	38.5266	31.71523
24.	200	24	50	23	2.5	32.5333	30.24657
25.	200	28	65	15	1.5	36.7666	31.30909
26.	200	28	65	15	2	44.4166	32.95092
27.	200	28	65	15	2.5	55.0466	34.81462

The above response table for the means or the raw data and signal to noise or S/N data at the five numbers of parameter levels are calculated from Table 4.10 and are shown in Table 4.11 and Table 4.12 respectively. These results have been plotted as shown in Figure 4.5 and Figure 4.6, as below with the help of MINITAB-18 software tool.

Table 4.11: Raw data response table for hardness on the GMAW process

Level	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	38.38	44.9	41.15	44.34	44.27
2	47.19	43.14	41.72	44.09	43.97
3	47.39	44.92	50.09	44.52	44.71
Delta	9.01	1.78	8.95	0.44	0.74
Rank	1	3	2	5	4

The rank in table 4.11 indicates that the decreasing order in the first two columns and the rank fluctuating decreasing and increasing in last three columns of the effect on the response is welding current, welding speed, welding voltage, gas flow rate and root gap.

Table 4.12: S/N response for hardness on the GMAW Process

Level	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	31.58	32.85	32.09	32.76	32.76
2	33.4	32.48	32.27	32.68	32.69
3	33.32	32.97	33.94	32.86	32.85
Delta	1.83	0.5	1.84	0.18	0.16
Rank	2	3	1	4	5

The rank in Table 4.12 indicates that the fluctuating decrease in the first three columns and the rank also decreasing order in the last two columns of the effect on the response is welding speed, welding current, welding voltage, gas flow rate and root gap, different order as that obtained from above the raw data. This can also be seen from figure 4.5 and figure 4.6.

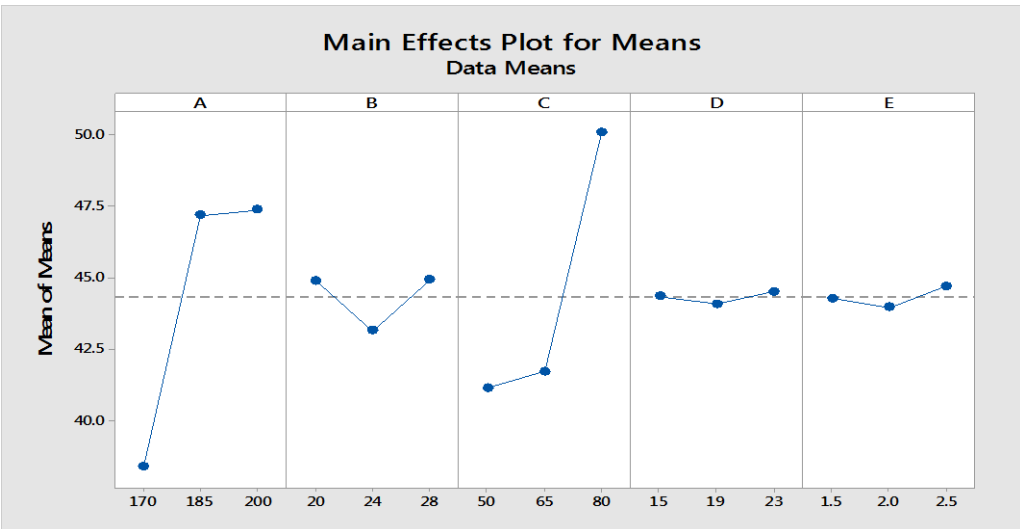


Fig. 4.5: Main effects plot for hardness of mean data on GMAW process

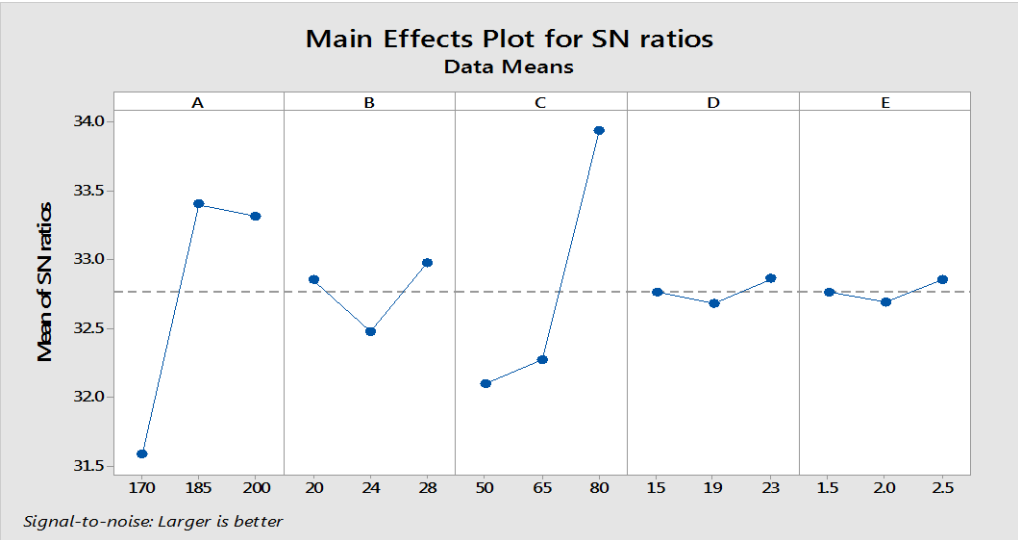


Fig. 4.6: Main effects plot of S/N ratios for hardness on GMAW process

Table 4.13: Factors effect for the average response of mean value on the GMAW process

Si. No.	Effective factors	Levels	Ultimate tensile strength (UTS)	Impact strength	Hardness
1.	Current	A1	174.4	0.1188	38.38
		A2	184.8	0.2005	47.19
		A3	202.3	0.2383	47.39
2.	Voltage	B1	171.9	0.1454	44.90
		B2	189.0	0.1625	43.14
		B3	200.5	0.2498	44.92
3.	Welding speed	C1	186.7	0.1784	41.15
		C2	186.2	0.2122	41.72
		C3	188.5	0.1671	50.09
4.	Gas flow rate	D1	183.1	0.2244	44.34
		D2	188.7	0.1715	44.09
		D3	189.7	0.1617	44.52
5.	Root gap	E1	181.1	0.1876	44.27
		E2	187.7	0.1778	43.97
		E3	192.6	0.1922	44.71

Table 4.14: Factors effect for S/N ratio on the GMAW process

Si. No.	Effective factors	Levels	Ultimate tensile strength (UTS)	Impact strength	Hardness
1.	Current	A1	44.77	18.68	31.58
		A2	45.31	14.57	33.40
		A3	46.11	13.66	33.32
2.	Voltage	B1	44.66	17.28	32.85
		B2	45.50	16.53	32.48
		B3	46.03	13.09	32.97
3.	Welding speed	C1	45.33	16.06	32.09
		C2	45.36	14.75	32.27
		C3	45.50	16.09	33.94
4.	Gas flow rate	D1	45.17	14.12	32.76
		D2	45.49	16.32	32.68
		D3	45.53	16.46	32.86
5.	Root gap	E1	45.10	15.51	32.76
		E2	45.43	16.16	32.69
		E3	45.66	15.24	32.85

4.2.4 Selection of Optimal Settings

The ultimate tensile strength (UTS) is larger-the-better type the quality characteristic for the process. Therefore the higher values of the UTS, hardness and minimum value of impact are considered to be optimal. It is the clear from Figure 4.1 for UTS, Figure 4.3 for impact and Figure 4.5 for hardness. Ultimate tensile strength (UTS) is the highest at the third level of welding current, third level of welding voltage, third level of welding speed, third level of gas flow rate and third level of root gap, the main effects of S/N ratios are also same as the highest at the above levels of factors at which the value of the UTS (means or raw) are the highest as shown in Table 4.13 (mean or raw) and in Table 4.14 (S/N ratio). Similarly, for impact is the lowest at the first level of welding current, first level of welding voltage, third level of welding speed, third level of gas flow rate and second level of root gap, the main effects of S/N ratios are also the lowest at the third level of welding current, third level of welding voltage, second level of welding speed, first level of gas flow rate and third level of root gap, at which the value of the impact strength (S/N ratio) are the lowest as shown in Table 4.13 (mean value) and in Table 4.14 (S/N ratio). For hardness is the highest at the third level of current, first level of voltage, third level of speed, third level of gas flow and third level of root gap, the main effect of S/N ratio are also the highest at the third level of current and others factors are same as above levels of factors at which the value of the hardness (S/N ratio) are the highest as shown in Table 4.13 (mean data) and in Table 4.14 (S/N ratio). The process parameters or factors and their selected the optimal levels are given below in the Table 4.15 on the GMAW process and the optimum input values for output response are given in Table 4.16.

Table 4.15: The optimum mean values on GMAW process

Si. No.	Input parameters	Optimum input values for output response					
		Ultimate tensile strength		Impact strength		Hardness	
		Value	Level	Value	Level	Value	Level
1.	Welding current (A)	200 Amps	3	200 Amps	3	200 Amps	3
2.	Welding voltage (B)	28 Volts	3	28 Volts	3	28 Volts	3
3.	Welding speed (C)	80 cm/min	3	65 cm/min	2	80 cm/min	3
4.	Gas flow rate (D)	23 Lit/min	3	15 Lit/min	1	23 Lit/min	3
5.	Root gap (E)	2.5 mm	3	2.5 mm	3	2.5 mm	3

Table 4.16: The optimum S/N values on GMAW process

Si. No.	Input parameters	Optimum input values for output response					
		Ultimate tensile strength		Impact strength		Hardness	
		Value	Level	Value	Level	Value	Level
1.	Welding current (A)	200 Amps	3	200 Amps	3	185 Amps	2
2.	Welding voltage (B)	28 Volts	3	28 Volts	3	28 Volts	3
3.	Welding speed (C)	80 cm/min	3	65 cm/min	2	80 cm/min	3
4.	Gas flow rate (D)	23 Lit/min	3	15 Lit/min	1	23 Lit/min	3
5.	Root gap (E)	2.5 mm	3	2.5 mm	3	2.5 mm	3

4.2.5 Summary of ANOVA for UTS using GMAW

The ANOVA is used to estimate the percentage contribution of all the five various process parameters for the gas metal arc welding (GMAW) process to the selected of performance characteristics. The total variation in the result is the sum of variation due to the various controlled factors and their interactions and due to the experimental error.

The ANOVA for raw data (ultimate tensile strength) and S/N (signal-to-noise) data has been performed as per the procedure given in section 3.15 (include in chapter materials and methods). The ANOVA based on the raw data identifies the parameters or the factors which affects the average response rather than the reducing variation. However the ANOVA (analysis of variance) based on the S/N ratio takes both these aspects into the account**.**

The ANOVA for the raw data or mean is presented in Tables 4.16. Since the degree of freedom (DOF) the calculated from S/N data for the numerator is 1 and that for the denominator is 2. Hence the limiting value at 95% confidence level of Fisher's constant from the F – table (appendix B) at F (1, 2) = 18.51.

It is clear from the Table 4.16 that F-value for all the parameters welding current and welding voltage are more than the limiting value, but for welding speed, gas flow rate and root gap the F value is less than the limiting value. Therefore welding current, welding voltage and root gap are the more significant than the welding speed and gas flow rate at the 95% confidence level.

The bar graph as shown in Figure 4.7 the percentage contribution (PC) of the process parameters affecting the average values of the raw data or mean values. Indicate that the maximum percentage contribution is of welding voltage i.e. 40.325 %.

Table 4.17: The ANOVA (without pooling) test summery of mean data for UTS

Source	DF	Seq SS	Adj SS	Adj MS/ Variance	F	P	P C (%)
Current	2	3596.3	3596.3	1798.15	15.67	0	37.887↑
Voltage	**2**	**3740.1**	**3740.07**	**1870.04**	**16.3**	0	**40.325↑↑**
Welding speed	2	27	27.03	13.51	0.12	0.89	4.269
Gas flow rate	2	226.3	226.33	113.16	0.99	0.394	6.258
Root gap	2	594.9	594.91	297.46	2.59	0.04	9.935
Residual Error	16	1835.7	1835.65	114.73			1.326
Total	26	10020.3					100

S = 10.7111, R-Sq = 81.68 %, R-Sq(adj) = 70.23 %
Order of significance 1: Current; 2: Voltage; 3: Root gap
SS: Sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

Table 4.18: The ANOVA (with pooling) test summery of mean data for UTS

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	2	3596.3	3364.1888	1798.15	15.4938	0	37.574↑
Voltage	**2**	**3740.1**	**3507.9888**	**1870.04**	**16.1133**	0	**39.009↑↑**
Welding speed	Pooled						
Gas flow rate							
Root gap	2	594.9	362.7888	297.46	2.5631	0.04	7.621
Residual Error	18	1835.7	2089	116.0556			
Total	24	10020.3					

SS: Sum of squares
SS`: Pure sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

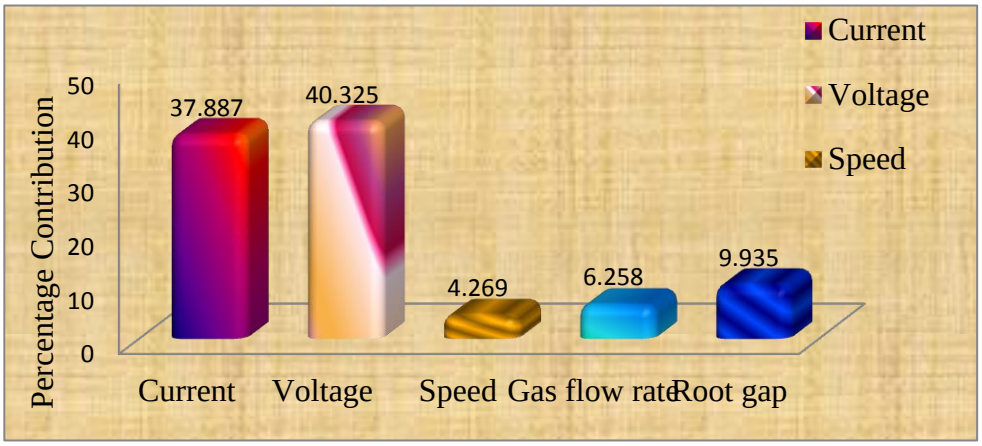


Fig. 4.7: Graph representing (without pooling) the percentage contribution of mean data for UTS

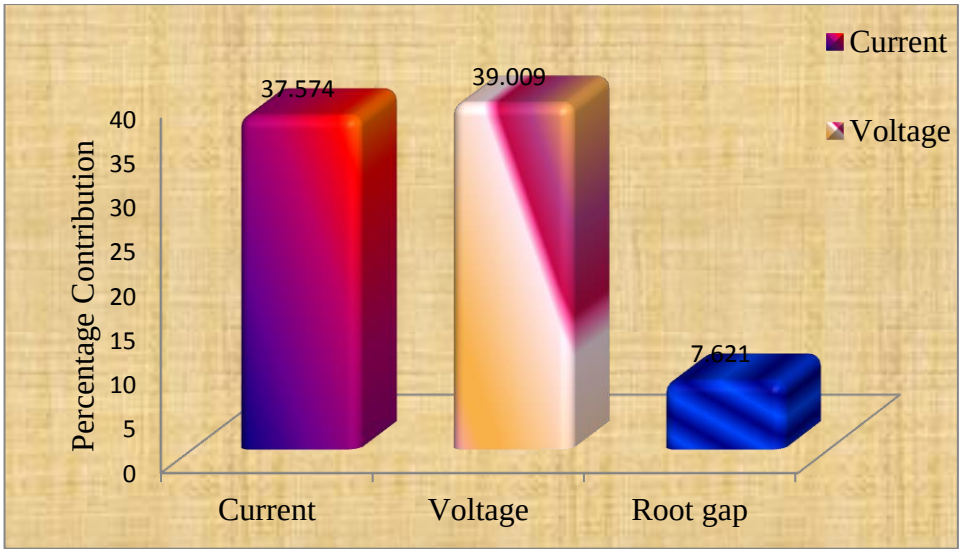


Fig. 4.8: Graph representing (with pooling) the percentage contribution of mean data for UTS

Table 4.19: ANOVA test summery (without pooling) of S/N data for UTS

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P C (%)
Current	2	8.1479	8.1479	4.07395	14.89	0	38.781↑
Voltage	**2**	**8.5923**	**8.5923**	**4.29616**	**15.7**	0	**40.678↑↑**
Welding speed	2	0.1467	0.1467	0.07337	0.27	0.768	4.626
Gas flow rate	2	0.7093	0.7093	0.35466	1.3	0.301	3.028
Root gap	2	1.4516	1.4516	0.72579	2.65	0.02	10.196
Residual Error	16	4.3784	4.3784	0.27365			2.691
Total	26	23.4262					100

S = 0.5231, R-Sq = 81.31 %, R-Sq(adj) = 69.63 %
Order of significance 1: Current; 2: Voltage; 3: Root gap
SS: Sum of squares
DOF: Degree of freedom
P: Percentage contribution
↑: Level of significance at 95% confidence level

Table 4.20: ANOVA test summery (with pooling) of S/N data for UTS on GMAW process

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	2	8.1479	7.5663	4.07395	14.0096	0	36.298↑
Voltage	**2**	**8.5923**	**8.0107**	**4.29615**	**14.7736**	0	**38.195↑↑**
Welding speed	Pooled						
Gas flow rate							
Root gap	2	1.4516	0.87	0.7258	2.4959	0.02	8.714
Residual Error	18	4.3784		0.2908			
Total	24	23.4262					

SS: Sum of squares
SS`: Pure sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

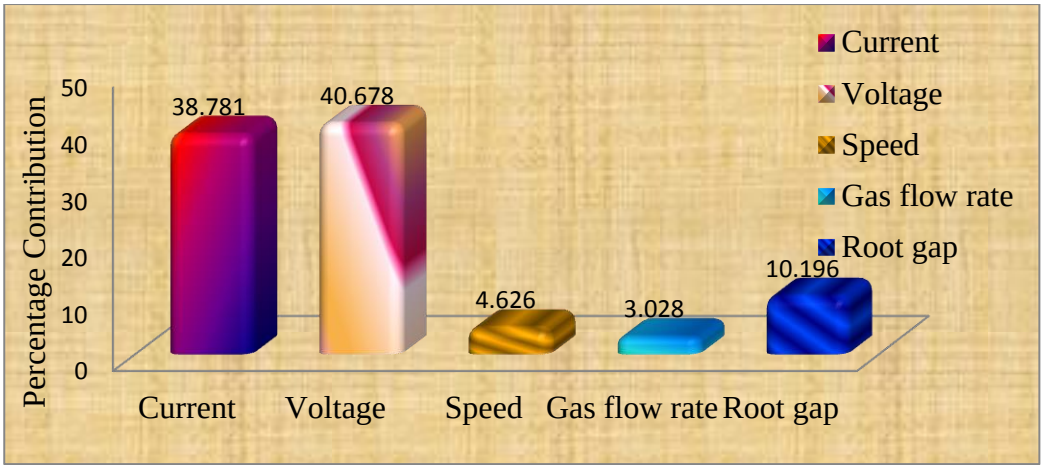


Fig. 4.9: Graph representing (without pooling) the percentage contribution of S/N ratios for UTS

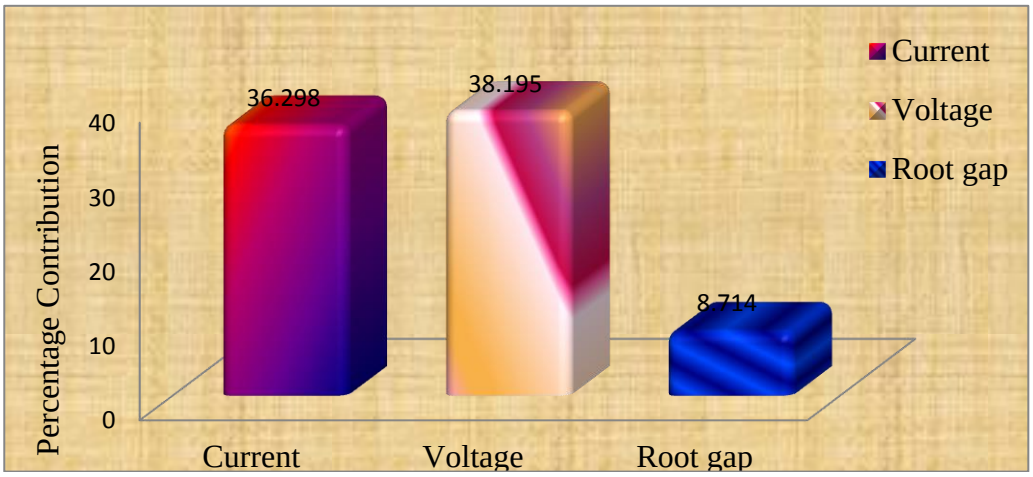


Fig. 4.10: Graph representing (with pooling) the percentage contribution of S/N ratios for UTS

According to article 4.2.5, it is clear from the Table 4.19 that the F value for the parameters of welding current and welding voltage are more than the limiting value but for welding speed, gas flow rate and root gap the F value is less than to the limiting value. Therefore, welding current, welding voltage and root gap are more significant than the welding speed and gas flow rate at 95% confidence level. The bar graph as shows in Figure 4.9 the percentage contribution of process parameters affecting the average values of S/N data. Indicate that maximum percentage contribution is of welding voltage i.e. 40.678 %.

4.2.6 Summary of ANOVA for Impact Strength using GMAW

According to article 4.2.5, it is clear from the Table 4.21 that F-value for all the parameters welding current and welding voltage are the more than the limiting value, but for welding speed, gas flow rate and root gap the F value are less than the limiting value. Therefore welding current and welding voltage gas flow rate are the more significant than the welding speed and root gap at the 95% confidence level. The bar graph as shown in Figure

4.11 the percentage contribution (PC) of the process parameters affecting the average values of the raw data or mean values. Indicate that the maximum percentage contribution is of welding current i.e. 33.486 %.

Table 4.21: The ANOVA test summery (without pooling) of mean data for impact strength

Source	DF	Seq SS	Adj SS	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**0.067126**	**0.067126**	**0.033563**	**6.01**	**0.011**	**33.486↑↑**
Voltage	2	0.056421	0.056421	0.028211	5.05	0.02	29.103↑
Welding speed	2	0.009928	0.009928	0.004964	0.89	0.43	10.065
Gas flow rate	2	0.020416	0.020416	0.010208	1.83	0.043	14.359
Root gap	2	0.000974	0.000974	0.000487	0.09	0.917	6.399
Residual Error	16	0.089352	0.089352	0.005584			5.588
Total	26	0.244217					100

S = 0.0747 R-Sq = 63.41 % R-Sq(adj) = 40.55 %
Order of significance 1: Current; 2: Voltage; 3: Gas flow rate
SS: Sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

Table 4.22: The ANOVA test summery (with pooling) of mean data for impact strength

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**0.067126**	**0.05599**	**0.027995**	**5.02603**	**0.011**	**28.927↑↑**
Voltage	2	0.056421	0.04529	0.022645	4.06553	0.02	24.545↑
Welding speed	Pooled						
Gas flow rate	2	0.020416	0.00928	0.00464	0.83304	0.043	9.799
Root gap	Pooled						
Residual Error	18	0.089352	0.100254	0.00557			
Total	24	0.244217					

SS: Sum of squares
SS`: Pure sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

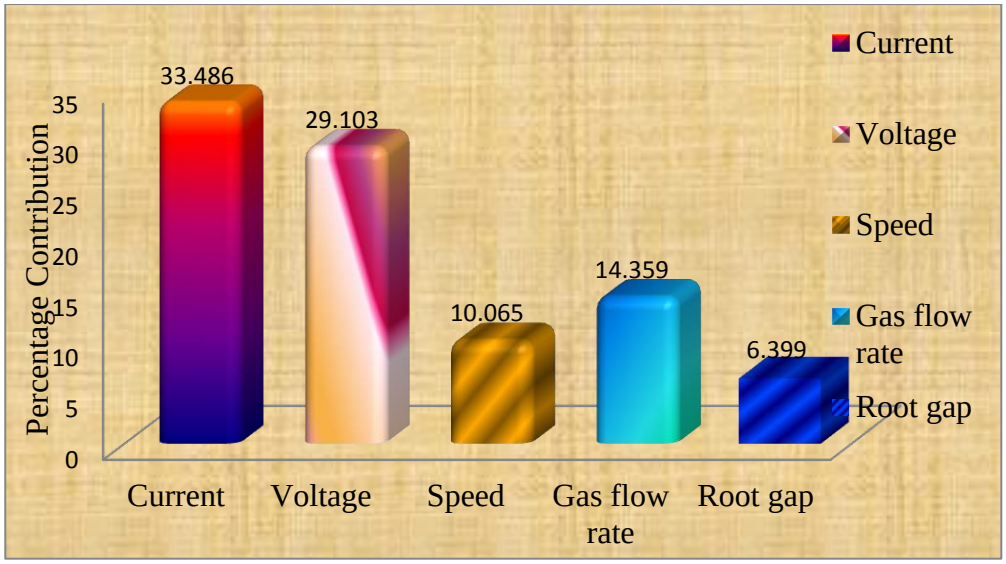


Fig. 4.11: Graph representing (without pooling) the percentage contribution of raw or mean data for impact strength

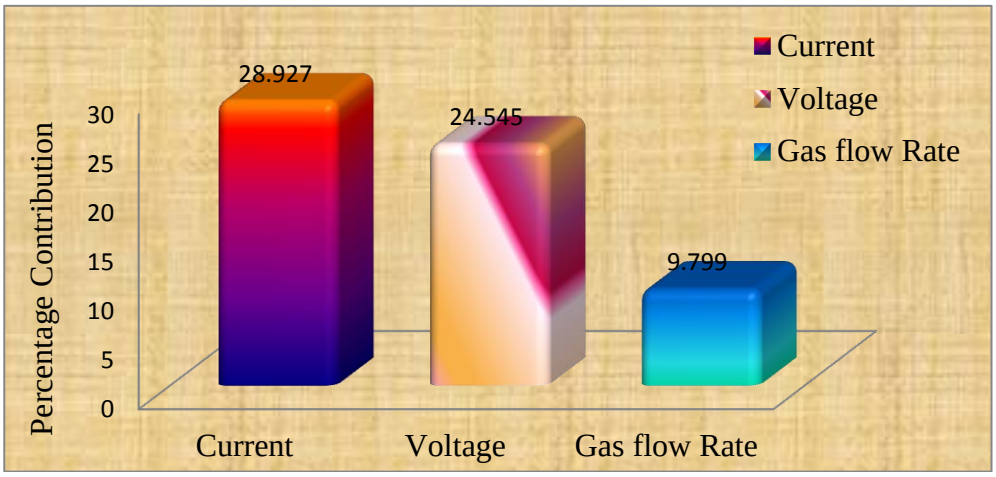


Fig. 4.12: Graph representing (with pooling) the percentage contribution of raw or mean data for impact strength

Table 4.23: ANOVA test summery (without pooling) of S/N data for impact strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P C (%)
Current	**2**	**128.76**	**128.76**	**64.38**	**5.51**	**0.015**	**35.568↑↑**
Voltage	2	89.593	89.593	44.796	3.84	0.043	27.878↑
Welding speed	2	10.489	10.489	5.245	0.45	0.646	9.327
Gas flow rate	2	31.038	31.038	15.519	1.33	0.045	14.887
Root gap	2	4.031	4.031	2.015	0.17	0.843	8.894
Residual Error	16	186.795	186.795	11.675			3.446
Total	26	450.707					100

S = 3.4168, R-Sq = 58.56 %, R-Sq(adj) = 32.65 %

Order of significance 1: Current; 2: Voltage; 3: Gas flow rate

SS: Sum of squares

DOF: Degree of freedom

P: Percentage contribution

↑: Level of significance at 95% confidence level

Table 4.24: ANOVA test summery (with pooling) of S/N data for impact strength

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**128.76**	**106.392**	**53.196**	**4.756**	**0.015**	**30.606↑↑**
Voltage	2	89.593	67.225	33.613	3.005	0.044	22.916↑
Welding speed	Pooled						
Gas flow rate	2	31.038	8.67	4.335	0.388	0.042	13.887
Root gap	Pooled						
Residual Error	18	186.795	201.315	11.184			
Total	24	450.707					

SS: Sum of squares
SS`: Pure sum of square
DOF: Degree of freedom
P: Percentage contribution
↑: Level of significance at 95% confidence level

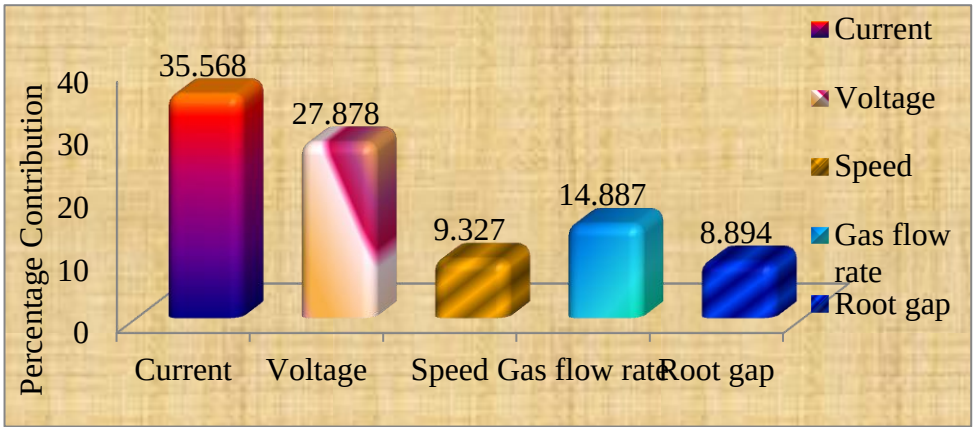


Fig. 4.13: Graph representing (without pooling) the percentage contribution of S/N ratios for impact strength

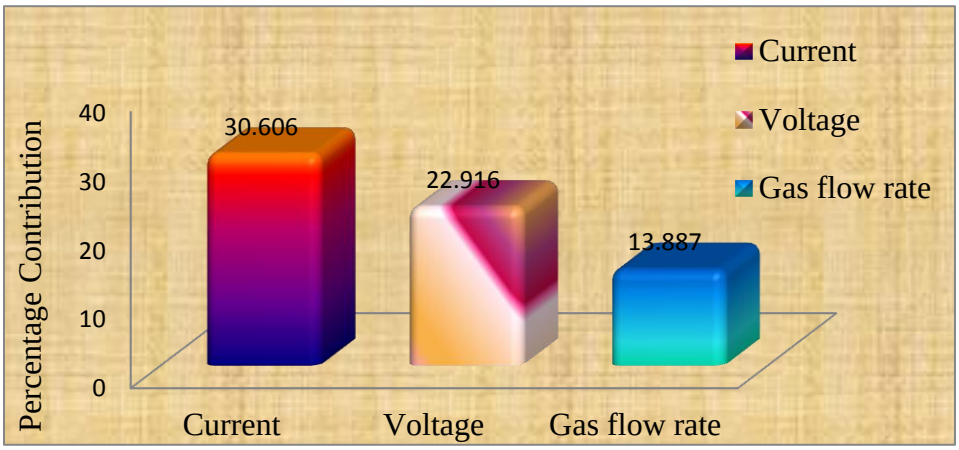


Fig. 4.14: Graph representing (with pooling) the percentage contribution of S/N ratios for impact strength

Since the degree of freedom calculated from the S/N data for the numerator is 1 and that for the denominator is 2. The limiting value at 95% confidence level of the Fisher's constant from the F table (appendix B) at F (1, 2) = 18.51. According to article 4.2.5, it is

clear from the Table 4.23 that the F value for the parameters of welding current and welding voltage are more than the limiting value but for welding speed, gas flow rate and root gap the F value is less than to the limiting value. Therefore welding current, welding voltage and gas flow rate are the more significant than the welding speed and root gap at 95% confidence level. The bar graph as shows in Figure 4.13 the percentage contribution of process parameters affecting the average values of S/N data. Indicate that the maximum percentage contribution is of welding current i.e. 35.568 %.

4.2.7 Summary of ANOVA for Hardness GMAW

The ANOVA is used to estimate the percentage contribution of all the five various process parameters for the gas metal arc welding (GMAW) process to the selected of performance characteristics. It is clear from the Table 4.25 that the F value for all the parameters welding current and welding speed are more than the limiting value, but for welding voltage, gas flow rate and root gap the F value is less than the limiting value. Therefore welding current and welding speed are the more significant than the welding voltage, gas flow rate and root gap at the 95% confidence level. The bar graph as shown in Figure 4.15 the percentage contribution (PC) of the process parameters affecting the average values of the raw data or mean values. Indicate that the maximum percentage contribution is of welding current i.e. 31.991 %.

Table 4.25: ANOVA test summery (without pooling) of means or raw value for hardness

Source	DF	Seq SS	Adj SS	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**476.58**	**476.58**	**238.291**	**3.68**	**0.022**	**31.991↑↑**
Voltage	2	180.81	180.81	9.407	0.15	0.049	17.102
Welding speed	2	451.43	451.43	225.714	3.48	0.035	30.725↑
Gas flow rate	2	0.86	0.86	0.431	0.01	0.993	8.043
Root gap	2	2.48	2.48	1.242	0.02	0.981	8.125
Residual Error	16	874.29	874.29	64.768			4.014
Total	26	1986.46					100

S = 8.0479 R-Sq = 47.83 % R-Sq(adj) = 15.23 %
Order of significance 1: Current; 2: Welding speed; 3: Voltage
SS: Sum of squares
DOF: Degree of freedom
P: Percentage contribution
↑: Level of significance at 95% confidence level

Table 4.26: ANOVA test summery (with pooling) of means or raw value for hardness

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**476.58**	**379.066**	**189.533**	**3.887**	**0.042**	**27.083↑↑**
Voltage	2	180.81	83.296	41.648	0.854	0.049	12.193
Welding speed	2	451.43	353.916	176.958	3.629	0.035	25.816↑
Gas flow rate	Pooled						
Root gap							
Residual Error	18	1036.29	1036.29	48.757			
Total	24	1986.46					

SS: Sum of squares
SS`: Pure sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

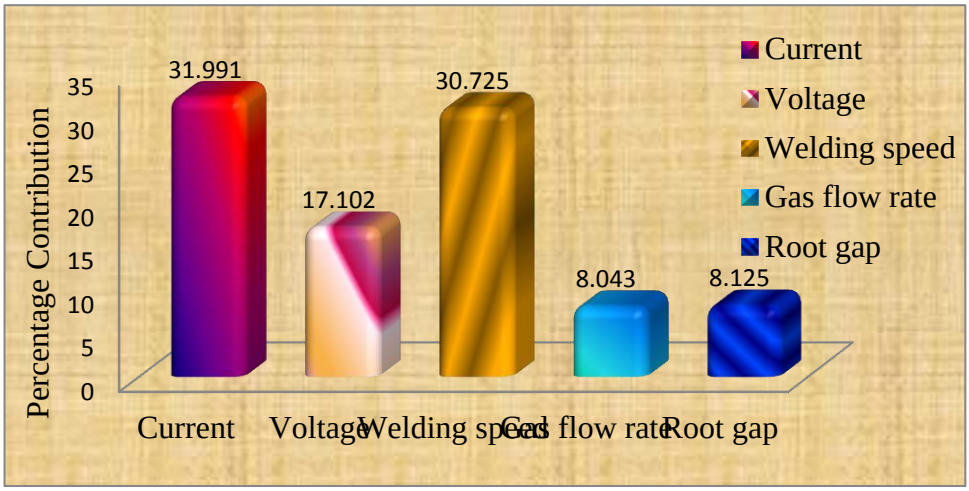


Fig. 4.15: Graph representing (without pooling) the percentage contribution of raw or mean data for hardness

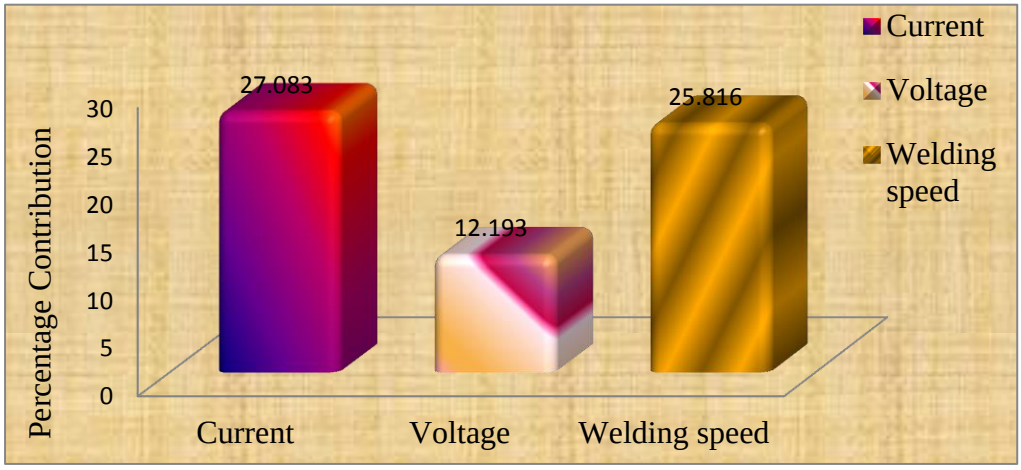


Fig. 4.16: Graph representing (with pooling) the percentage contribution of raw or mean data for hardness

Table 4.27: ANOVA test summery (without pooling) of S/N data for hardness

Source	DF	Seq SS	Adj SS	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**19.1008**	**19.1008**	**9.55041**	**3.86**	**0.033**	**32.229↑↑**
Voltage	2	4.2055	4.2055	0.60277	0.24	0.052	13.335
Welding speed	2	18.6521	18.6521	9.32605	3.77	0.041	31.659↑
Gas flow rate	2	0.1422	0.1422	0.07112	0.03	0.972	8.181
Root gap	2	0.1214	0.1214	0.06071	0.02	0.976	8.154
Residual Error	16	35.6133	35.6133	2.47583			5.442
Total	26	78.8354					100

S = 1.5735, R-Sq = 49.75 %, R-Sq(adj) = 18.35 %
Order of significance 1: Current; 2: Welding speed; 3: Voltage
SS: Sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

Table 4.28: ANOVA test summery (with pooling) of S/N data for hardness

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**19.1008**	**15.115**	**7.557**	**0.096**	**0.033**	**27.173↑↑**
Voltage	2	4.2055	0.219	0.1095	0.0014	0.052	8.278
Welding speed	2	18.6521	14.666	7.333	0.093	0.041	26.603↑
Gas flow rate	Pooled						
Root gap							
Residual Error	16	35.6133	35.877	1.993			
Total	26	78.8354					

SS: Sum of squares
SS`: Pure sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

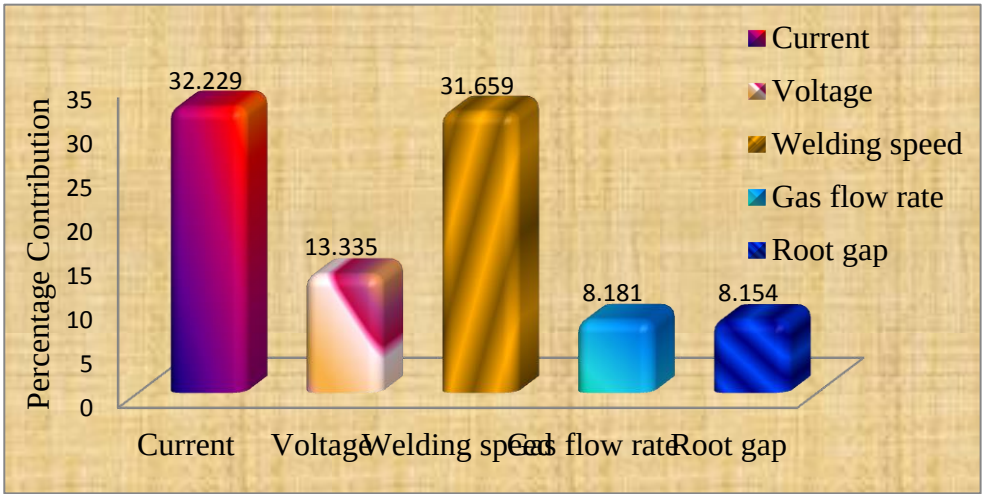


Fig. 4.17: Graph representing (without pooling) the percentage contribution of S/N ratios for hardness

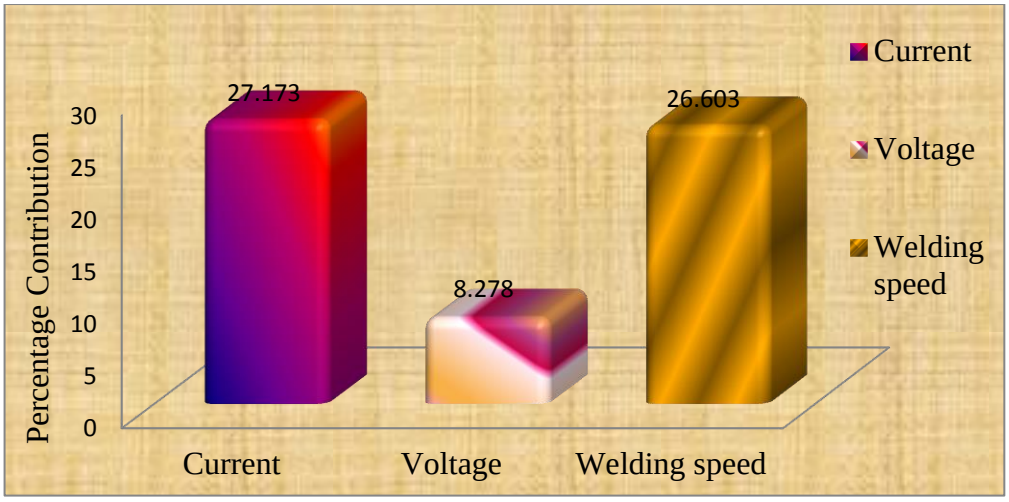


Fig. 4.18: Graph representing (with pooling) the percentage contribution of S/N ratios for the hardness

Since the degree of freedom calculated from the S/N data for the numerator is 1 and that for the denominator is 2. The limiting value at 95% confidence level of the Fisher's constant from the F table (appendix B) at F (1, 2) = 18.51. According to article 4.2.5, it is clear from the Table 4.27 that the F value for the parameters of welding current and welding speed are more than the limiting value but for welding voltage, gas flow rate and root gap the F value is less than to the limiting value. Therefore welding current and welding speed are more significant than the welding voltage, gas flow rate and root gap at 95% confidence level. The bar graph as shows in Fig 4.17 the percentage contribution of process parameters affecting the average values of S/N data. Indicate that the maximum percentage contribution is of welding voltage i.e. 32.229 %.

4.2.8 Effect of Input Parameters during GMAW Process

After the performing of experiment and analyzing all the results like ultimate tensile strength, impact strength and hardness for gas metal arc welding (GMAW) process the discussion for the effect of the different input factors or parameters on the output response variables is describe as below:

4.2.8.1 Effect of parameters on UTS

According to the Figure 4.7 that the input factors such as current and voltage affects the ultimate tensile strength (UTS) are very significantly. The different input parameters used in the experimentation can be ranked in Table 4.5 in order of increasing effect as welding speed, gas flow rate, root gap, current and voltage.

It is clear from the Figure 4.7 that the current and voltage affects the UTS significantly. The slop of welding speed, gas flow rate, root gap, current and voltage indicates

that increase in current, voltage, root gap, gas flow rate and welding speed increasing order and it is also practical that for the higher current and voltage there should be higher the root gap, gas flow rate and welding speed to melt the wire coming out continuously at higher speed. So that the basically for UTS the heat is required to melt the wire hence according to $\mathbf{H=I^2RT}$ (H= Heat, I=Current) and the current and the heat are directly proportional to welding speed. Similarly voltage and current are also related to the each other according to the equation **V=IR**. So that we can say that the each control factors is related to the each other partially or directly influencing UTS.

The analysis of variance the test results showed that the **A3 B3 C3 D3 E3** is the optimal factors or parameters setting for the ultimate tensile strength. In this investigation we concluded that the optimal input factor or parameter setting for current is 200 Amp, voltage is 28 V, welding speed is 80 cm/min, gas flow rate is 23 Lit/min and root gap is 2.5 mm while the welding of aluminium alloy 3003 as parent metal and ER4043 as filler wire on the GMAW machine as for as the ultimate tensile strength is concerned.

4.2.8.2 Effect of parameters on impact strength

According to Figure 4.11 that current and voltage affects the impact strength very significantly. The different input parameters used in the experimentation can be ranked in Table 4.8 in order of increasing effect as welding speed, gas flow rate, root gap, current and voltage.

It is clear from the Figure 4.11 that the current and voltage affects the impact strength significantly. The slop of welding speed, gas flow, root gap, current and voltage indicates that increase in current, voltage, gas flow rate, welding speed and root gap increasing order.

It is also practical that for the higher current and voltage there should be higher the root gap, gas flow rate and welding speed to melt the wire coming out continuously at higher speed. So that the basically for the impact strength the heat is required to melt the wire hence according to $\mathbf{H=I^2RT}$ (H= Heat, I=Current) and the current and the heat are directly proportional to welding speed. Similarly voltage and current are also related to the each other according to the equation **V=IR**. So that we can say that the each control factors is related to the each other partially or directly influencing the impact strength.

The analysis of variance the test results showed that the **A3 B3 C2 D1 E3** is the optimal factors or parameters setting for the impact strength. In this investigation we concluded that the optimal input factor or parameter setting for current is 200 Amp, voltage is 28 V, welding speed is 65 cm/min, gas flow rate is 15 Lit/min and root gap is 2.5 mm while

the welding of aluminium alloy 3003 as parent material and ER4043 as filler wire on the gas metal arc welding (GMAW) machine as for as the impact strength is concerned.

4.2.8.3 Effect of parameters on hardness

It can be seen for the Figure 4.15 that the current and voltage are the most significant parameters or factors that are affecting the hardness. The different input factors or parameters used in the experimentation can be ranked in order of increasing the effect as gas flow rate, root gap, voltage, welding speed and current.

According to the Figure 4.15 it can be conclude that the gas flow rate, root gap and voltage are less significant than welding speed and current. The higher current will result in quick melting of wire electrode. This allows the proper filling of the joint to be made hence increase the strength of the desired weld zone and also allows directional solidification of molten metal. The slope of the gas flow rate, root gap and voltage indicates that the gas flow rate and root gap are the almost equal, which may result in the shielding phenomenon. For the proper shielding of molten pool there should be sufficient amount of inner gas to keep away atmospheric gases from molten pool. Because if the atmospheric gases like oxygen (O_2) and nitrogen (N_2) reacts with the molten metal the results in oxides and nitrides which increase the brittleness hence increase the hardness. Like that the shielding phenomenon plays the important role for the weld zone hardness during the GMAW process.

The analysis of variance the experiment results for the hardness confirms the optimal parameters setting as **A3 B3 C2 D3 E3**. In this work we concluded that the optimal input factors or parameters setting for the current is 200 Amp, voltage is 28 V, welding speed is 65 cm/min, gas flow rate is 23 Lit/min and root gap is 2.5 mm during the welding of aluminium alloy grade 3003 as parent material and ER 4043 as filler wire on GMAW machine as for as the hardness is concerned.

4.2.9 Prediction of Mean for GMAW Process

The compute of the average or mean value is only a point estimate based on the mean or the average of the results observation from an experiment. It is therefore the customary to represent the value of the statistical factors as a range within which it is likely to the fall for a given level of confidence. This range the termed as the confidence interval (CI) in the other thing:

The confidence interval is a maximum and minimum value between which the true average should fall at the some stated percentage of confidence.

The Taguchi approach for predicting the mean performance characteristics and the determination of the confidence interval for the predicted average or the mean value has been applied. The mean or the average value of the performance characteristics observed through the confirmation experiments must be within the 95 % of the confidence interval (CI; $\alpha = 0.05$).

The observation for the mean value taken from the Table 4.1, Table 4.2 and Table 4.3 for the ultimate tensile strength, impact strength and hardness respectively overall population of average or the mean value.

The mean or average value for ultimate tensile strength is $\mu_{\bar{T}}$ **= 187.1468**

The mean or average value for impact strength is $\mu_{\bar{I}}$ **= 0.18588**

The mean or average value for hardness is $\mu_{\bar{H}}$ **= 44.3178**

According to the Table 4.14 the predicted optimum value of ultimate tensile strength is calculated as below:

The equation of optimum combination for ultimate tensile strength is $(\mu_T) = A_3 B_3 C_3 D_3 E_3$.

Hence

$$\boldsymbol{\mu_T = \mu_{\bar{T}} + (A_3 - \mu_{\bar{T}}) + (B_3 - \mu_{\bar{T}}) + (C_3 - \mu_{\bar{T}}) + (D_3 - \mu_{\bar{T}}) + (E_3 - \mu_{\bar{T}})}$$

Where,

A_3, B_3 and E_3 are taken optimum values from Table 4.15 due to the significant parameters

C_3 and D_3 are taken zero due to insignificant parameters

$\mu_{\bar{T}}$ = Overall mean of the response = 187.1468

μ_T = 202.3 + 200.5 + 192.6 – 2 x 187.1468

μ_T **= 221.1064**

Similarly,

For impact strength

$$\boldsymbol{\mu_I = \mu_{\bar{I}} + (A_3 - \mu_I) + (B_3 - \mu_{\bar{I}}) + (C_3 - \mu_{\bar{I}}) + (D_3 - \mu_{\bar{I}}) + (E_3 - \mu_{\bar{I}})}$$

μ_I **= 0.34074**

For hardness

$$\boldsymbol{\mu_H = \mu_{\bar{H}} + (A_3 - \mu_{\bar{H}}) + (B_3 - \mu_{\bar{H}}) + (C_3 - \mu_H) + (D_3 - \mu_{\bar{H}}) + (E_3 - \mu_{\bar{H}})}$$

μ_H **= 45.3944**

For the calculation of confidence interval ($CI_{ce\ (confirmation\ experiments)}$), with the help of the following equation has been used

$$\boldsymbol{CI_{CE} = \sqrt{Fa(1, fe)Ve\left[\left(\frac{1}{n_{eff}}\right) + \left(\frac{1}{R}\right)\right]}} \quad \text{.....1}$$

Where,

Fa(1, fe) = the F ratio at a confidence level of factor against DOF 1, and error degree of freedom *fe*

$$\boldsymbol{neff} = \frac{\boldsymbol{N}}{[\mathbf{1}+\boldsymbol{total\ DOFassociated\ in\ the\ estimation\ of\ mean}]} \text{.....}2$$

$\boldsymbol{neff}$ = for UTS, Impact strength and hardness during GMAW process

$$= \frac{81}{(1+10)} = 7.3636$$

Where, N = Total number of results = 27x3 = 81

- R = Sample size for confirmation experiment = 3
- Ve = Error variance = 114.73 (for tensile); = 11.675 (impact strength); = 2.4758 (hardness)
- fe = error degree of freedom = 2
- F0.05 (1, 2) = ...(Teken from the table value, from Roy 1990)

According to equation No. 1

$$\sqrt{18.51 \text{ x } 114.73 \left[\frac{1}{7.3636} + \frac{1}{3}\right]}$$

$(CI_{CE})UTS = \pm 31.5627$

Similarly, for impact strength and hardness

$(CI_{CE})impact = \pm 0.2202$; $(CI_{CE})hardness = \pm 23.7146$

Therefore, the predicted confidence interval for confirmation experiment is:

Table 4.29: Responses value of confidence interval for confirmation experiments

Tensile strength	**Impact strength**	**Hardness**
CI_{ce} (T) = $\pm$ 31.5627 The 95 % confidence level for µT is CI_{ce} (T) = $189.5437 \leq \mu_T \leq 252.6691$	CI_{ce} (I) = $\pm$ 0.2202 The 95 % confidence level for µI is CI_{ce} (I) = $0.12054 \leq \mu_I \leq 0.56094$	CI_{ce} (H) = $\pm$ 23.7146 The 95 % confidence level for µH is CI_{ce} (H) = $21.6798 \leq \mu_H \leq 69.109$

The predicted optimum values and the confidence interval have been tabulated in table as below. The experiments were conducted at the optimum setting of process parameters for all the response factors.

Table 4.30: The comparison of predicted values and the experimental values

Si. No.	Response	Predicted Value	Experimental value	Confidence interval for confirmation experiments (CI_{ce})
1.	Ultimate Tensile strength	221.1064	218.949	$189.5437 \leq \mu_T \leq 252.6691$
2.	Impact strength	0.34074	0.38746	$0.12054 \leq \mu_I \leq 0.56094$
3.	Hardness	45.3944	59.7633	$21.6798 \leq \mu_H \leq 69.109$

This predicted and the experiment values could be observed from the Table 4.30, that the values taken from the confirmation experiments were contained well within the confidence interval for all the response variables. Hence, the optimization results were validated.

4.3 EXPERIMENTAL DATA FOR ANOVA OF GTAW PROCESS

The experimental data for the mean data and S/N ratio of ultimate tensile strength, impact strength and hardness are given in Table 4.31, Table 4.32 and Table 4.33 for the GMAW respectively.

Table 4.31: Experimental data for ultimate tensile strength for the GTAW

No. of Exp.	Ultimate tensile strength at weld zone			Ultimate tensile strength (mean value)	S/N ratio
	Experiment No. 1	Experiment No.2	Experiment No.3		
1.	123.847	137.689	126.534	129.356	42.23573
2.	133.847	147.683	176.534	152.688	43.6761
3.	173.847	197.689	146.537	172.691	44.74539
4.	164.845	145.653	169.987	160.161	44.09114
5.	164.845	195.653	182.987	181.161	45.16129
6.	166.845	179.653	177.987	174.828	44.85222
7.	198.356	206.119	167.864	190.779	45.61061
8.	258.356	186.119	177.864	207.446	46.3381
9.	195.356	155.119	173.864	174.779	44.84979
10.	152.161	208.845	163.674	174.893	44.85545
11.	160.161	138.845	199.674	166.226	44.41398
12.	188.161	167.845	189.674	181.893	45.19632
13.	177.545	170.598	185.065	177.736	44.99551
14.	179.545	185.598	209.065	191.402	45.63893
15.	173.545	179.598	188.065	180.402	45.12483
16.	204.544	200.321	195.021	199.962	46.01895
17.	194.544	187.321	175.021	185.628	45.37287
18.	198.544	257.321	191.021	215.628	46.6741
19.	195.553	169.983	213.564	193.033	45.71263
20.	193.553	179.983	188.564	187.366	45.45382
21.	187.563	169.983	193.564	183.703	45.28232
22.	185.643	197.326	196.098	193.022	45.71214
23.	168.643	244.326	257.098	218.689	47.07021
24.	175.643	198.326	200.098	191.355	45.6368
25.	193.363	269.567	187.951	216.960	46.72759
26.	209.363	189.567	204.951	201.293	46.07657
27.	231.363	204.567	198.951	211.627	46.51142
Average ($\mu_{\bar{T}}$)				185.9891	45.33462
Max.	258.356	269.567	259.098	218.689	47.07021
Min.	123.847	137.689	126.534	129.356	42.23573

Table 4.32: Experimental data for impact strength for the GTAW

No. of Exp.	Impact strength at the weld zone			Impact Strength (mean value)	S/N ratio
	Experiment No. 1	Experiment No.2	Experiment No.3		
1.	0.10203	0.28208	0.10432	0.16281	15.76615
2.	0.10203	0.19020	0.10910	0.13378	17.47202
3.	0.10213	0.12170	0.10218	0.10867	19.2773
4.	0.18255	0.10261	0.10269	0.12929	17.76861
5.	0.15215	0.10211	0.10209	0.1187	18.50465
6.	0.10215	0.10211	0.10209	0.10212	19.81764
7.	0.14209	0.11015	0.10290	0.11838	18.53416
8.	0.10209	0.11017	0.10290	0.10505	19.57144
9.	0.15209	0.11018	0.10295	0.12174	18.2911
10.	0.10300	0.11021	0.15026	0.12116	18.33272
11.	0.10302	0.11021	0.15026	0.12117	18.33198
12.	0.10302	0.11021	0.15026	0.12117	18.33207
13.	0.10273	0.10280	0.10277	0.10277	19.76245
14.	0.10281	0.10208	0.10521	0.10336	19.71217
15.	0.14272	0.10200	0.10211	0.11561	18.73977
16.	0.11479	0.12204	0.12052	0.11912	18.48018
17.	0.11420	0.12207	0.12204	0.11944	18.45696
18.	0.11408	0.12201	0.12274	0.11961	18.44453
19.	0.12001	0.10201	0.10205	0.10802	19.32965
20.	0.12001	0.10201	0.10205	0.10802	19.32965
21.	0.12001	0.10201	0.10205	0.10802	19.32965
22.	0.10233	0.12031	0.12103	0.11455	18.81959
23.	0.10233	0.12031	0.12103	0.11455	18.81959
24.	0.10233	0.12031	0.12103	0.11455	18.81959
25.	0.11023	0.10207	0.10215	0.10481	19.59139
26.	0.11023	0.10207	0.10215	0.10481	19.59139
27.	0.11023	0.10207	0.10215	0.16131	15.3215
Average ($\mu_{\bar{I}}$)				0.117929	18.62935
Max.	0.18255	0.28208	0.15026	0.16281	19.81764
Min.	0.10203	0.10200	0.10205	0.10212	15.76615

Table 4.33: Experimental data for hardness for the GTAW

No. of Exp.	Hardness at the weld zone			Hardness (mean value)	S/N ratio
	Experiment No.1	Experiment No.2	Experiment No.3		
1.	68.71	66.53	67.84	67.6933	36.61092
2.	67.01	63.89	69.40	66.7666	36.49119
3.	67.91	65.89	63.74	65.8466	36.37068
4.	65.67	67.23	68.95	67.2833	36.55815
5.	65.67	64.63	61.95	64.0833	36.1349
6.	67.67	66.23	62.95	65.6166	36.34028
7.	60.76	64.52	69.44	64.9066	36.24579
8.	69.44	64.52	65.44	65.5733	36.33455
9.	63.76	68.52	67.44	66.5733	36.46601
10.	68.99	64.87	68.98	67.6133	36.60065

11.	69.99	65.87	63.98	66.6133	36.47122
12.	67.99	69.87	64.98	67.6133	36.60065
13.	68.76	69.34	70.15	69.4166	36.82928
14.	68.76	69.34	70.15	69.4166	36.82928
15.	68.76	69.34	72.15	70.0833	36.91229
16.	67.89	74.91	71.77	71.5233	37.08895
17.	67.89	68.91	66.77	67.8566	36.63185
18.	67.89	68.91	69.77	68.8566	36.75892
19.	70.05	71.66	68.43	70.0466	36.90775
20.	70.05	64.66	63.49	66.0666	36.39965
21.	71.05	69.66	69.43	70.0466	36.90775
22.	63.95	64.56	64.76	64.4233	36.18086
23.	65.95	64.56	68.76	66.4233	36.44641
24.	69.95	65.56	69.76	68.4233	36.70408
25.	72.34	67.87	73.71	71.3066	37.06260
26.	66.34	68.76	76.74	70.6133	36.97773
27.	74.34	67.87	75.78	72.6633	37.22631
Average ($\mu_{\bar{H}}$)				67.9018	36.63291
Max.	74.34	74.91	76.74	72.6633	37.22631
Min.	60.76	63.89	61.95	64.0833	36.1349

4.3.1 Data Analysis of Ultimate Tensile Strength for GTAW

The ultimate tensile strength (UTS) is the maximum stress that a metal can withstand while being the stretched or the pulled before the failing or the breaking due to the applying the tensile load or force. The analysis of data selection of the optimal settings for the ANOVA the prediction of mean, the determination of confidence interval and the effect of process parameters are presented in this section. The result of the UTS and the S/N ratios obtained by MINITAB-18 is given in Table 4.34.

Table 4.34: Experimental results and S/N ratios of UTS for the GTAW process

No. of Run	Welding current (Amps)	Welding voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	Ultimate tensile (MPa)	S/N Ratio
1.	210	22	60	12	1	129.356	42.2357
2.	210	22	60	12	1.5	152.688	43.6761
3.	210	22	60	12	2	172.691	44.7453
4.	210	26	75	16	1	160.161	44.0911
5.	210	26	75	16	1.5	181.161	45.1612
6.	210	26	75	16	2	174.828	44.8522
7.	210	30	90	20	1	190.779	45.6106
8.	210	30	90	20	1.5	207.446	46.3381
9.	210	30	90	20	2	174.779	44.8497
10.	225	22	75	20	1	174.893	44.8554
11.	225	22	75	20	1.5	166.226	44.4139
12.	225	22	75	20	2	181.893	45.1963
13.	225	26	90	12	1	177.736	44.9955

14.	225	26	90	12	1.5	191.402	45.6389
15.	225	26	90	12	2	180.402	45.1248
16.	225	30	60	16	1	199.962	46.0189
17.	225	30	60	16	1.5	185.628	45.3728
18.	225	30	60	16	2	215.628	46.6741
19.	240	22	90	16	1	193.033	45.7126
20.	240	22	90	16	1.5	187.366	45.4538
21.	240	22	90	16	2	183.703	45.2823
22.	240	26	60	20	1	193.022	45.7121
23.	240	26	60	20	1.5	225.689	47.0702
24.	240	26	60	20	2	191.355	45.6368
25.	240	30	75	12	1	216.96	46.7275
26.	240	30	75	12	1.5	201.293	46.0765
27.	240	30	75	12	2	211.627	46.5114

The response table for the means or the raw data and signal to noise or S/N data at the five numbers of the input parameter levels are compute from Table 4.34 and are shown in Table 4.35 and Table 4.36 respectively. These results have been plotted as shown in Figure 4.19 and Figure 4.20 with the help of MINITAB-18 software tool.

Table 4.35: Raw data response for ultimate tensile strength at weld zone on GTAW process

Level	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	171.5	171.3	185.1	181.6	181.8
2	186	186.2	185.4	186.8	188.8
3	200.4	200.5	187.4	189.6	187.4
Delta	28.9	29.1	2.3	8	7
Rank	2	1	5	3	4

The rank in the Table 4.35 indicates that the increasing in initial two columns and the fluctuating in the last three columns, the effect on the responses are welding voltage, welding current, gas flow rate, root gap and welding speed.

Table 4.36: S/N response table for ultimate tensile strength on the GTAW process

Level	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	44.62	44.62	45.24	45.08	45.11
2	45.37	45.36	45.32	45.4	45.47
3	46.02	46.02	45.45	45.52	45.43
Delta	1.4	1.4	0.21	0.44	0.36
Rank	1	2	5	3	4

The rank in the Table 4.36 indicates that the fluctuating order of the effects on the response are welding current, welding voltage, gas flow rate, root gap and welding speed.

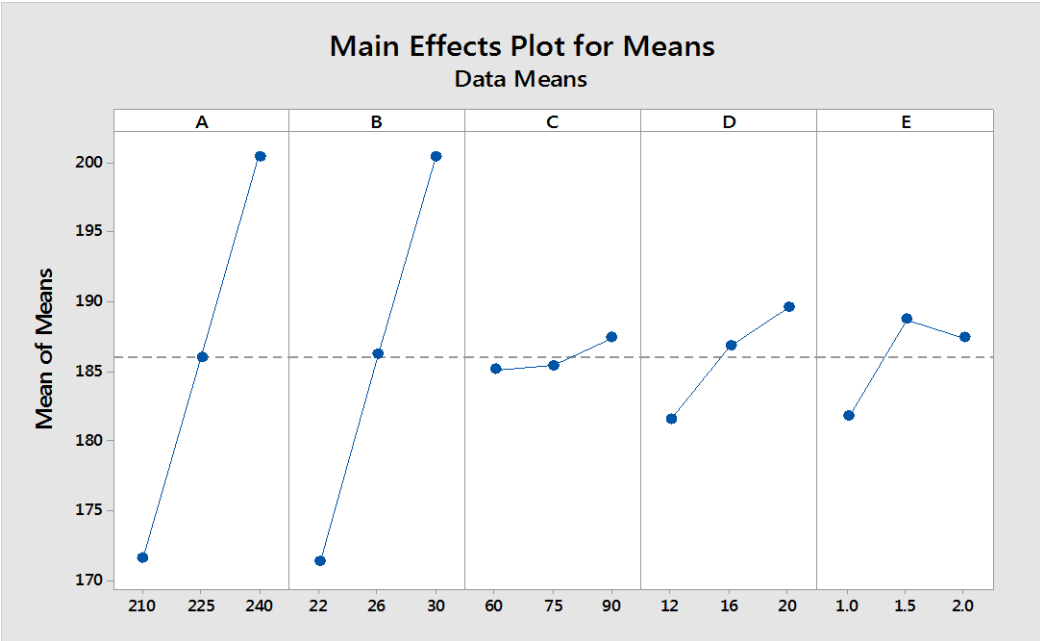


Fig. 4.19: Main effects plot of means data for UTS on the GTAW

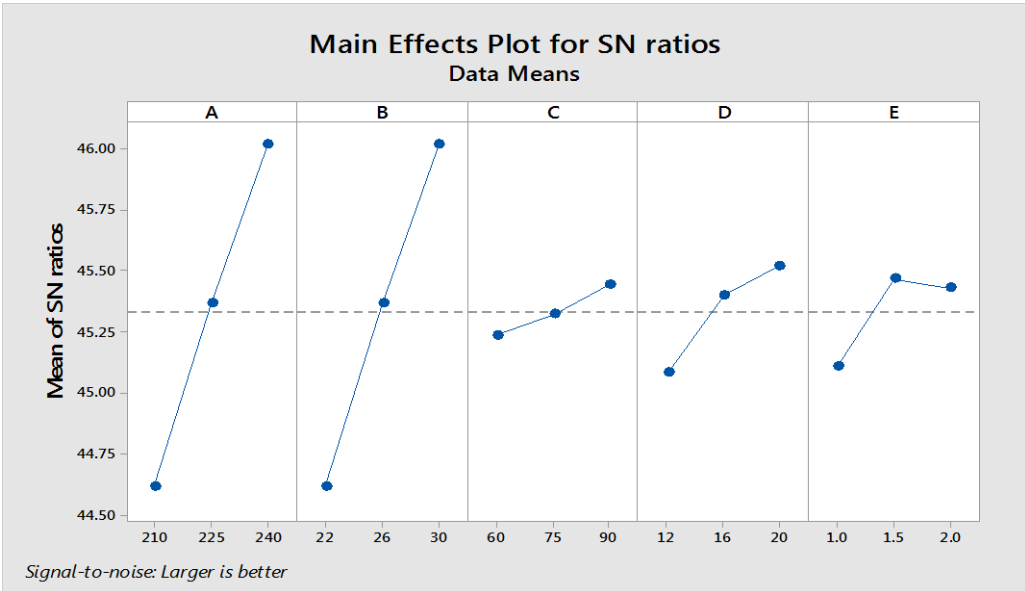


Fig. 4.20: Main effects plot of S/N ratios for UTS on the GTAW

4.3.2 Data Analysis of Impact Strength for GTAW

The impact test determines the behaviour of the materials when the subjected to the high rates of sudden loading usually in the tension. It calculates the energy absorbed during breaking the specimen by a high blow or impact. The selection of optimal settings for the data analysis, ANOVA, prediction of mean, determination of confidence interval and the effect of process parameters are presented in this section. The results of impact strength and the results of S/N ratios obtained by the software MINITAB-18 is given in Table 4.37.

Table 4.37: Experimental results of impact and S/N ratios for the GTAW

No. of Run	Welding current (Amps)	Welding voltage (Volts)	Welding speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	Impact mean value	S/N Ratio
1.	210	22	60	12	1	0.16281	15.76615
2.	210	22	60	12	1.5	0.13378	17.47202
3.	210	22	60	12	2	0.10867	19.2773
4.	210	26	75	16	1	0.12929	17.76861
5.	210	26	75	16	1.5	0.11878	18.50465
6.	210	26	75	16	2	0.10212	19.81764
7.	210	30	90	20	1	0.11838	18.53416
8.	210	30	90	20	1.5	0.10505	19.57144
9.	210	30	90	20	2	0.12174	18.2911
10.	225	22	75	20	1	0.12116	18.33272
11.	225	22	75	20	1.5	0.12117	18.33198
12.	225	22	75	20	2	0.12117	18.33207
13.	225	26	90	12	1	0.10277	19.76245
14.	225	26	90	12	1.5	0.10336	19.71217
15.	225	26	90	12	2	0.11561	18.73977
16.	225	30	60	16	1	0.11912	18.48018
17.	225	30	60	16	1.5	0.11944	18.45696
18.	225	30	60	16	2	0.11961	18.44453
19.	240	22	90	16	1	0.10802	19.32965
20.	240	22	90	16	1.5	0.10802	19.32965
21.	240	22	90	16	2	0.10802	19.32965
22.	240	26	60	20	1	0.11455	18.81959
23.	240	26	60	20	1.5	0.11455	18.81959
24.	240	26	60	20	2	0.11455	18.81959
25.	240	30	75	12	1	0.10481	19.59139
26.	240	30	75	12	1.5	0.10481	19.59139
27.	240	30	75	12	2	0.16131	15.32150

The response table for the means or the raw data and signal to noise or S/N data at the five numbers of input parameter levels are calculated from Table 4.37 and are shown in Table 4.38 and Table 4.39 respectively. These results have been plotted as shown in Figure 4.21 and Figure 4.22, with the help of MINITAB-18 software.

Table 4.38: Raw data response table of impact strength for the GTAW

Level	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	0.1223	0.1214	0.123	0.1222	0.1201
2	0.1159	0.1128	0.1207	0.1147	0.1143
3	0.1156	0.1195	0.1101	0.1169	0.1194
Delta	0.0067	0.0086	0.0129	0.0074	0.0058
Rank	4	2	1	3	5

The rank in Table 4.38 indicates that the increasing order in the first three colum and the rank decreasing order in the last two colum of the effect on the response are welding speed, welding voltage, gas flow rate, welding current and root gap.

Table 4.39: S/N response table of impact strength for the GTAW

Level	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	18.33	18.39	18.26	18.41	18.49
2	18.73	18.97	18.45	18.83	18.87
3	18.82	18.53	19.18	18.65	18.54
Delta	0.49	0.58	0.92	0.42	0.38
Rank	3	2	1	4	5

The rank in Table 4.39 indicates that the increasing order in the first three columns and decreasing in the last two columns of the effect on the response are welding speed, welding voltage, welding current, gas flow rate and root gap.

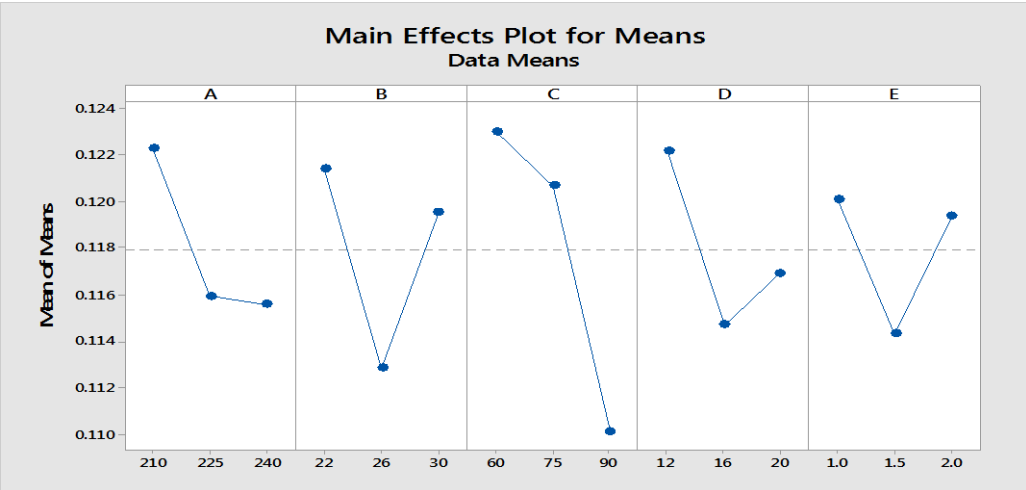


Fig.4.21: Main effects plot of means data for impact strength on the GTAW

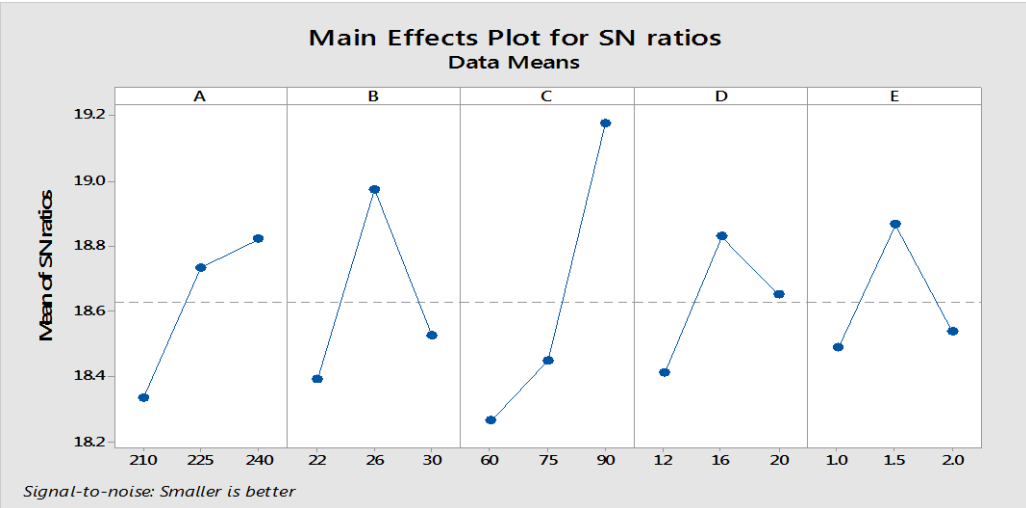


Fig. 4.22: Main effects plot of S/N ratio for impact strength on the GTAW

4.3.3 Data Analysis of Hardness for GTAW

The hardness (HRB) of a material is the resistance to the penetration under a localized pressure or the resistance to the abrasion. The hardness tests provide an accurate, rapid and the economical way of determining the resistance of the materials to the deformation. The selection of optimal settings for the data analysis, ANOVA, prediction of mean, determination of confidence interval and the effect of process parameters are presented in this section. The results of hardness (HRB) and the observations of the S/N ratios obtained by the software MINITAB-18 is given in Table 4.35 for the GTAW.

Table 4.40: Experimental results of hardness test and S/N ratios for the GTAW

No. of Run	Current (A)	Voltage (V)	W speed (cm/min)	Gas flow rate (Lit/min)	Root gap (mm)	Hardness (HRB) at weld zone	S/N Ratio
1.	210	22	60	12	1	67.6933	36.61092
2.	210	22	60	12	1.5	66.7666	36.49119
3.	210	22	60	12	2	65.8466	36.37068
4.	210	26	75	16	1	67.2833	36.55815
5.	210	26	75	16	1.5	64.0833	36.1349
6.	210	26	75	16	2	65.6166	36.34028
7.	210	30	90	20	1	64.9066	36.24579
8.	210	30	90	20	1.5	65.5733	36.33455
9.	210	30	90	20	2	66.5733	36.46601
10.	225	22	75	20	1	67.6133	36.60065
11.	225	22	75	20	1.5	66.6133	36.47122
12.	225	22	75	20	2	67.6133	36.60065
13.	225	26	90	12	1	69.4166	36.82928
14.	225	26	90	12	1.5	69.4166	36.82928
15.	225	26	90	12	2	70.0833	36.91229
16.	225	30	60	16	1	71.5233	37.08895
17.	225	30	60	16	1.5	67.8566	36.63185
18.	225	30	60	16	2	68.8566	36.75892
19.	240	22	90	16	1	70.0466	36.90775
20.	240	22	90	16	1.5	66.0666	36.39965
21.	240	22	90	16	2	70.0466	36.90775
22.	240	26	60	20	1	64.4233	36.18086
23.	240	26	60	20	1.5	66.4233	36.44641
24.	240	26	60	20	2	68.4233	36.70408
25.	240	30	75	12	1	71.3066	37.0626
26.	240	30	75	12	1.5	70.6133	36.97773
27.	240	30	75	12	2	72.6633	37.22631

The above response table for the means or the raw data and signal to noise or S/N data at the five numbers of parameter levels are calculated from Table 4.40 and are shown in

Table 4.41 and Table 4.42 respectively. These results have been plotted as shown in Figure 4.23 and Figure 4.24, with the help of MINITAB-18 software.

Table 4.41: Raw data response table for hardness on the GTAW process

Level	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	66.04	67.59	67.53	69.31	68.25
2	68.78	67.24	68.16	67.93	67.05
3	68.89	68.87	68.01	66.46	68.41
Delta	2.85	1.63	0.62	2.85	1.37
Rank	1	3	5	2	4

The rank in Table 4.41 indicates that the decreasing order in the first three columns and also the decreasing order in the last two columns of the effect on the response are welding current, gas flow rate, welding voltage, root gap and welding speed.

Table 4.42: S/N response table for hardness on the GTAW Process

Level	Welding current (A)	Welding voltage (B)	Welding speed (C)	Gas flow rate (D)	Root gap (E)
1	36.39	36.6	36.59	36.81	36.68
2	36.75	36.55	36.66	36.64	36.52
3	36.76	36.75	36.65	36.45	36.7
Delta	0.36	0.21	0.08	0.36	0.17
Rank	1	3	5	2	4

The rank in Table 4.42 indicates that the decreasing order in the first three columns and the rank also decreasing order in the last two columns of the effect on the response are welding current, gas flow rate, welding voltage, root gap, welding speed, as the same order that obtained from above raw data.

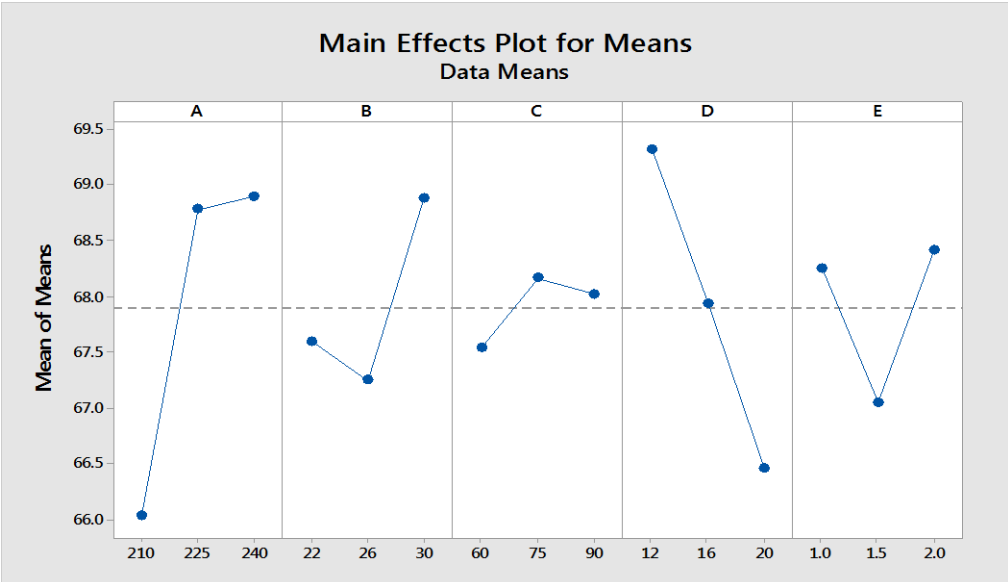


Fig.4.23: Main effects plot of means data for hardness on the GTAW

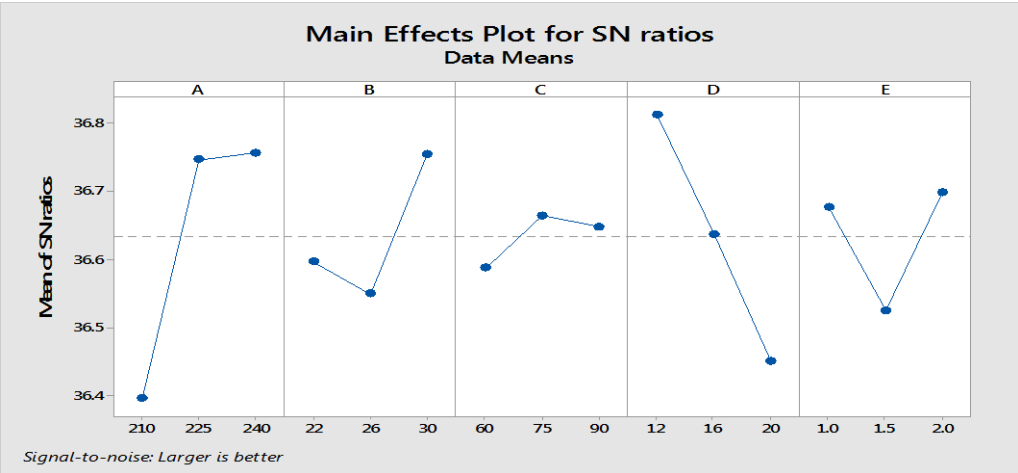


Fig. 4.24: Main effects plot of S/N ratios for hardness on the GTAW

Table 4.43: Factor effects for the average response of mean value on the GTAW

Si. No.	Effective factors	Levels	Ultimate tensile strength	Impact strength	Hardness
1.	Current	A1	171.5	0.1223	64.04
		A2	186	0.1159	68.78
		A3	200.4	0.1156	68.89
2.	Voltage	B1	171.3	0.1214	67.59
		B2	186.2	0.1128	67.24
		B3	200.5	0.1195	68.87
3.	Welding speed	C1	185.1	0.1230	67.53
		C2	185.4	0.1207	68.16
		C3	187.4	0.1101	68.01
4.	Gas flow rate	D1	181.6	0.1222	69.31
		D2	186.8	0.1147	67.93
		D3	189.6	0.1169	66.46
5.	Root gap	E1	181.8	0.1201	68.25
		E2	188.8	0.1143	67.05
		E3	187.4	0.1194	68.41

Table 4.44: Factor effects of S/N ratio on the GTAW

Si. No.	Factors effect	Levels	Ultimate tensile strength	Impact strength	Hardness
1.	Current	A1	44.62	18.33	36.39
		A2	45.37	18.73	36.75
		A3	46.02	18.82	36.76
2.	Voltage	B1	44.62	18.39	36.6
		B2	45.36	18.97	36.55
		B3	46.02	18.53	36.75
3.	Welding speed	C1	45.24	18.26	36.59
		C2	45.32	18.45	36.66
		C3	45.45	19.18	36.65
4.	Gas flow rate	D1	45.08	18.41	36.81
		D2	45.4	18.83	36.64
		D3	45.52	18.65	36.45
5.	Root gap	E1	45.11	18.49	36.68
		E2	45.47	18.87	36.52
		E3	45.43	18.54	36.7

4.3.4 Selection of Optimal Settings

The ultimate tensile strength (UTS) is larger-the-better type the quality characteristic for the process. Therefore the higher values of the UTS, hardness and minimum value of impact are considered to be optimal. It is the clear from Figure 4.19 for UTS, Figure 4.21 for impact and Figure 4.23 for hardness. Ultimate tensile strength (UTS) is the highest at the third level of welding current, third level of welding voltage, third level of welding speed, third level of gas flow rate and second level of root gap, the main effects of S/N ratios are also same as the highest at the above levels of factors at which the value of the UTS (means or raw) are the highest as shown in Table 4.35 (mean or raw) and in Table 4.36 (S/N ratio). Similarly, for impact is the lowest at the third level of welding current, second level of welding voltage, third level of welding speed, second level of gas flow rate and second level of root gap, the main effects of S/N ratios are also the lowest at the first level of welding current, first level of welding voltage, first level of welding speed, first level of gas flow rate and first level of root gap, at which the value of the impact strength (S/N ratio) are the lowest as shown in Table 4.38 (mean value) and in Table 4.39 (S/N ratio). For hardness is the highest at the third level of current, third level of voltage, second level of speed, first level of gas flow and third level of root gap, the main effect of S/N ratio are also same as the highest at the above levels of factors at which the value of the UTS (means or raw) at which the value of the hardness (S/N ratio) are the highest as shown in Table 4.41 (mean data) and in Table 4.42 (S/N ratio). The process parameters or factors and their selected the optimal levels of mean and S/N ratios are given in the Table 4.45 and Table 4.46.

Table 4.45: The optimum values from Table 4.35, Table.4.38 and Table.4.41 for the gas tungsten arc welding (GTAW) process

Si. No.	Input parameters	Optimum input values for output response					
		Ultimate tensile strength		Impact strength		Hardness	
		Value	Level	Value	Level	Value	Level
6.	Welding current (A)	240 Amp	3	240 Amp	3	240 Amp	3
7.	Welding voltage (B)	30 Volt	3	26 Volt	2	30 Volt	3
8.	Welding speed (C)	90 cm/min	3	90 cm/min	3	75 cm/min	2
9.	Gas flow rate (D)	20 Lit/min	3	16 Lit/min	2	12 Lit/min	1
10.	Root gap (E)	1.5 mm	2	1.5 mm	2	2.0 mm	3

Table 4.46: The optimum S/N values on GTAW process

Si. No.	Input parameters	Optimum input values for output response					
		Ultimate tensile strength		Impact strength		Hardness	
		Value	Level	Value	Level	Value	Level
1.	Welding current (A)	240 Amp	3	210 Amp	1	240 Amp	3
2.	Welding voltage (B)	30 Volt	3	22 Volt	1	30 Volt	3
3.	Welding speed (C)	90 cm/min	3	60 cm/min	1	75 cm/min	2
4.	Gas flow rate (D)	20 Lit/min	3	12 Lit/min	1	12 Lit/min	1
5.	Root gap (E)	1.5 mm	2	1.0 mm	1	2.0 mm	3

4.3.5 Summary of ANOVA of UTS using GTAW

The ANOVA is used to the estimate the percentage contribution of all the five various process parameters for the GTAW process to the selected performance characteristics. The total variation in the result is the sum of variation due to various controlled factors and their interactions and due to an experimental error.

It is clear from the Table 4.47, that the F value for all the parameters welding current, welding voltage and gas flow rate is more than the limiting value but welding speed and root gap the F value is less than limiting value. Therefore welding current, welding voltage and gas flow rate are more significant than the welding speed and root gap at 95% confidence level. The bar graph as shown in Figure 4.25, the percentage contribution of process parameters significantly affecting average values of raw data indicates that maximum percentage contribution is of welding voltage i.e. 38.084 %.

Table 4.47: The ANOVA test summery (without pooling) of mean or raw data for UTS on the GTAW

Source	DF	Seq SS	Adj SS	Adj MS/ Variance	F	P	P C (%)
Current	2	3760.2	3760.15	1880.08	9.84	0.002	37.537↑↑
Voltage	**2**	**3821.5**	**3821.5**	**1910.75**	**10**	**0.002**	**38.084↑**
Welding speed	2	27.6	27.57	13.79	0.07	0.931	4.246
Gas flow rate	2	297	296.96	148.48	0.78	0.045	6.648
Root gap	2	248.7	248.66	124.33	0.65	0.535	6.218
Residual Error	16	3057	3056.97	191.06			6.267
Total	26	11211.8					100

S = 13.8225, R-Sq = 72.73 %, R-Sq(adj) = 55.69 %
Order of significance 1:Voltage; 2: Current; 3: Gas flow rate
SS: Sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

Table 4.48: The ANOVA test summery (with pooling) of mean or raw data for UTS on the GTAW

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	2	3760.2	3389.834	1694.917	9.153	0.002	34.234↑↑
Voltage	**2**	**3821.5**	**3451.134**	**1725.567**	**9.318**	**0.002**	**34.781↑**
Welding speed	Pooled						
Gas flow rate	2	297	73.366	36.683	1.198	0.045	4.654
Root gap	Pooled						
Residual Error	18	3057	3333.3	185.183			
Total	24	11211.8					

SS: Sum of squares
SS`: Pure sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

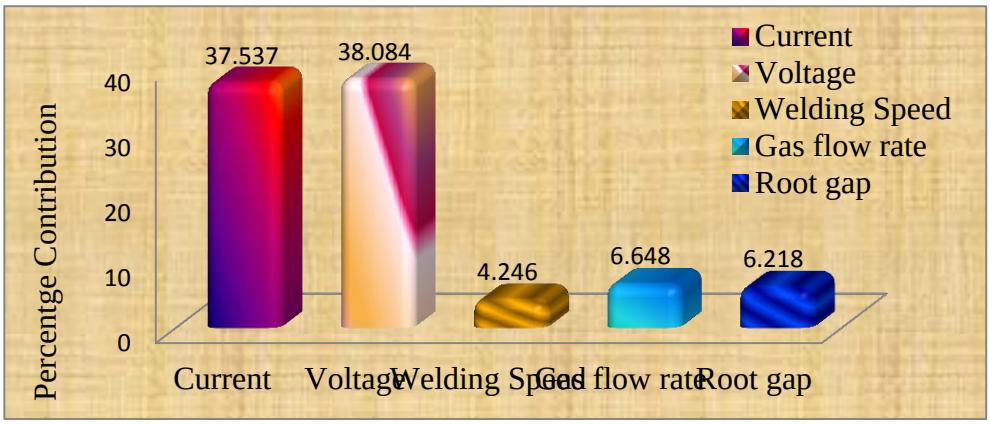


Fig. 4.25: Graph representing (without pooling) the percentage contribution of raw or mean data for UTS

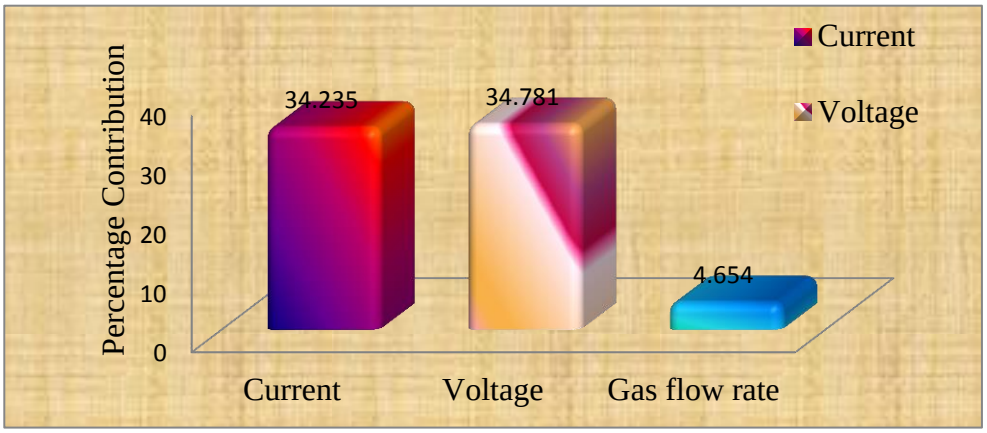


Fig. 4.26: Graph representing (with pooling) the percentage contribution of raw or mean data for UTS

Table 4.49: ANOVA test summery (without pooling) of S/N data for UTS on GTAW

Source	DF	Seq SS	Adj SS	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**8.8654**	**8.8654**	**4.43271**	**9.88**	**0.002**	**37.177↑↑**
Voltage	2	8.8439	8.8439	4.42193	9.85	0.002	37.096↑
Welding speed	2	0.1957	0.1957	0.09785	0.22	0.806	4.732
Gas flow rate	2	0.9289	0.9289	0.46447	1.04	0.045	7.476
Root gap	2	0.7077	0.7077	0.35384	0.79	0.471	6.648
Residual Error	16	7.1802	7.1802	0.44876			5.871
Total	26	26.7218					100

S = 0.6699, R-Sq = 73.13 %, R-Sq(adj) = 56.34 %
Order of significance 1: Current; 2: Voltage; 3: Gas flow rate
SS: Sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

Table 4.50: ANOVA test summery (with pooling) of S/N data for UTS on GTAW

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**8.8654**	**7.967**	**3.984**	**8.873**	**0.002**	**33.815↑↑**
Voltage	2	8.8439	7.946	3.973	8.848	0.002	33.736↑
Welding speed	Pooled						
Gas flow rate	2	0.9289	0.131	0.115	0.134	0.045	4.491
Root gap	Pooled						
Residual Error	18	7.1802	8.084	0.44876			
Total	24	26.7218					

SS: Sum of squares
SS`: Pure sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

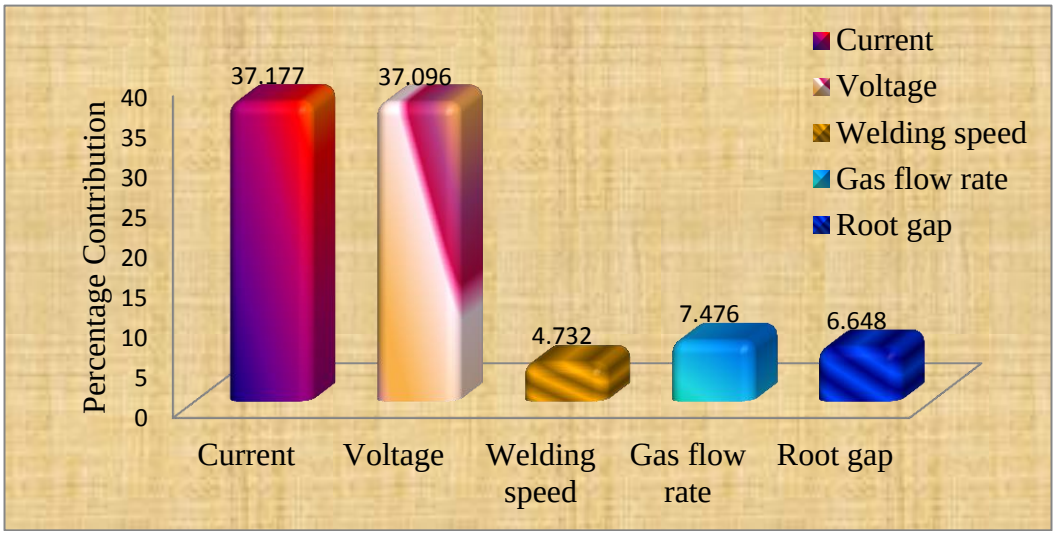


Fig. 4.27: Graph representing (without pooling) the percentage contribution of S/N ratios for UTS on the GTAW

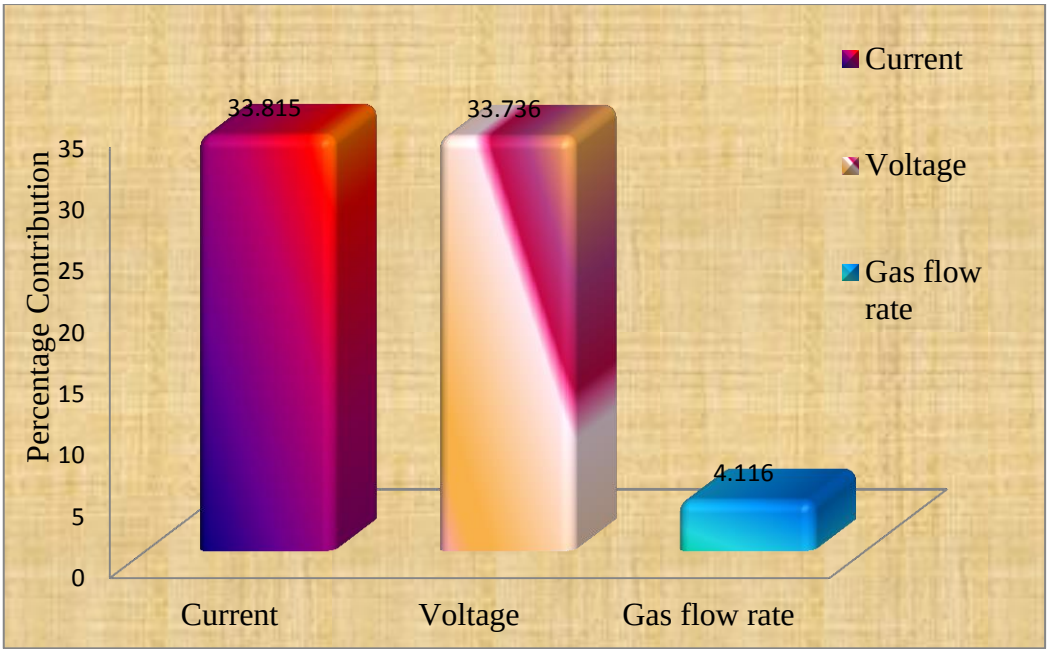


Fig. 4.28: Graph representing (with pooling) the percentage contribution of S/N ratios for UTS on the GTAW

It is clear from the article 4.2.5, and the Table 4.49 that the F value for the parameters of welding current, welding voltage and gas flow rate are more than the limiting value but for welding speed and root gap the F value is less than to the limiting value. Therefore welding current, welding voltage and gas flow rate are more significant than the welding speed and root gap at 95% confidence level. The bar graph as shows in Figure 4.27 the percentage contribution of process parameters affecting the average values of S/N data. Indicate that the maximum percentage contribution is of welding current i.e. 37.177 %.

4.3.6 Summary of ANOVA of Impact Strength using GTAW

It is clear from the Table 4.51 that F-value for all the parameters welding current and welding voltage are the more than the limiting value, but for welding speed, gas flow rate and root gap F value are less than the limiting value. Therefore welding current and welding voltage are the more significant than the welding speed, gas flow rate and root gap at the 95% confidence level. The bar graph as shown in Figure 4.29 the percentage contribution (PC) of the process parameters affecting the average values of the raw data or mean values. Indicate that the maximum percentage contribution is of welding speed i.e. 30.985 %.

Table 4.51: ANOVA test summery (without pooling) of mean or raw data for impact strength for the GTAW

Source	DF	Seq SS	Adj SS	Adj MS/ Variance	F	P	P C (%)
Current	2	0.000257	0.000257	0.000129	0.49	0.045	22.904
Voltage	2	0.000366	0.000366	0.000183	0.7	0.023	25.631↑
Welding speed	**2**	**0.000851**	**0.000851**	**0.000425**	**1.63**	**0.016**	**30.985↑↑**
Gas flow rate	2	0.000263	0.000263	0.000132	0.51	0.613	8.376
Root gap	2	0.000178	0.000178	0.000089	0.34	0.716	6.917
Residual Error	16	0.004169	0.004169	0.000261			5.187
Total	26	0.006084					100

S = 0.0161 R-Sq = 31.47 % R-Sq (adj) = 00.00 %
Order of significance 1: Welding speed; 2: Voltage; 3 Current
SS: Sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

Table 4.52: ANOVA test summery (with pooling) of mean or raw data for impact strength on the GTAW process

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	2	0.000257	0.000255	0.000126	0.498	0.045	18.191
Voltage	2	0.000366	0.000146	0.000073	0.285	0.023	21.399↑
Welding speed	**2**	**0.000851**	**0.000339**	**0.000169**	**0.662**	**0.016**	**25.872↑↑**
Gas flow rate	Pooled						
Root gap							
Residual Error	18	0.004169	0.00461	0.000256			
Total	24	0.006084					

SS: Sum of squares
SS`: Pure sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

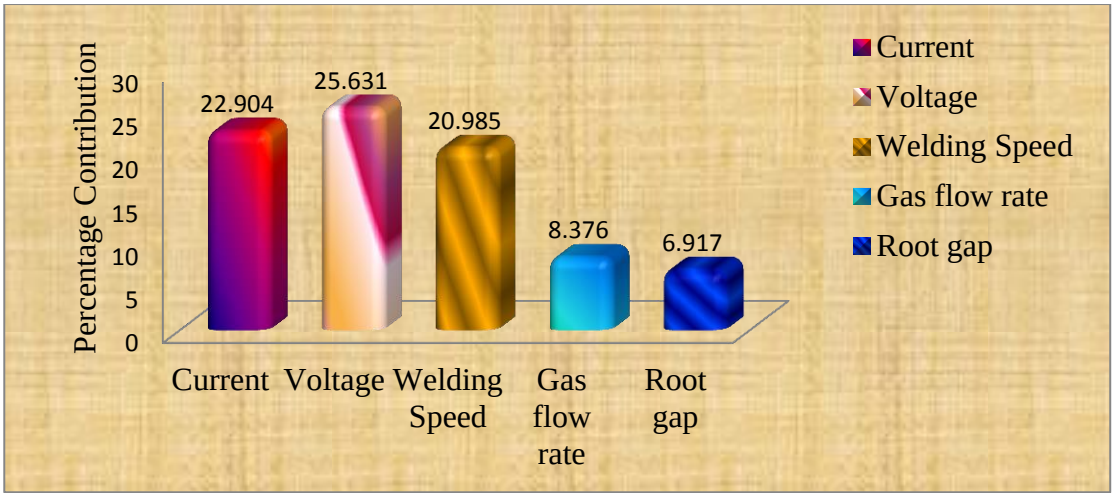


Fig. 4.29: Graph representing (without pooling) the percentage contribution of raw or mean data for impact strength on the GTAW process

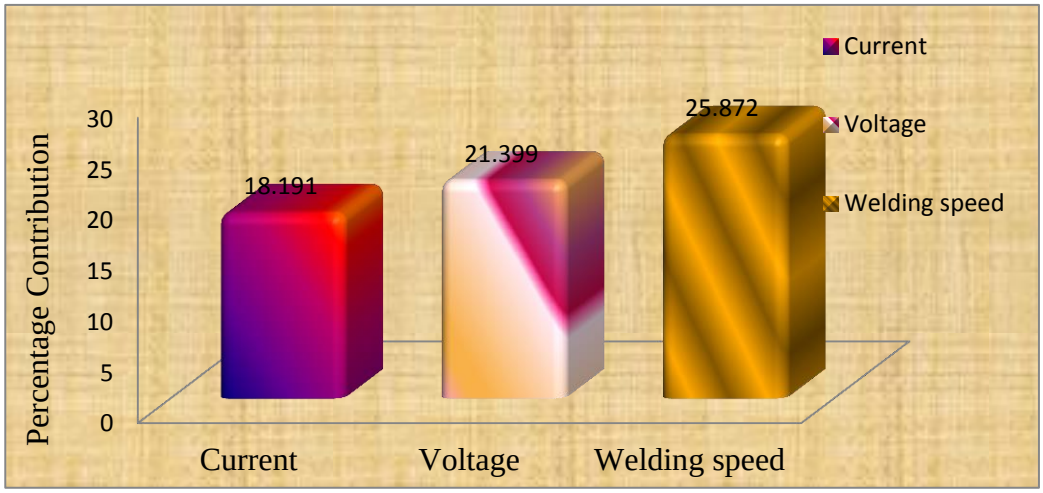


Fig. 4.30: Graph representing (with pooling) the percentage contribution of raw or mean data for impact strength

Table 4.53: ANOVA test summery (without pooling) of S/N data for impact strength

Source	DF	Seq SS	Adj SS	Adj MS/ Variance	F	P	P C (%)
Current	2	1.2161	1.2161	0.6081	0.51	0.050	23.368
Voltage	2	1.6851	1.6851	0.8425	0.71	0.041	28.082↑
Welding speed	**2**	**4.2174**	**4.2174**	**2.1087**	**1.78**	**0.022**	**32.247↑↑**
Gas flow rate	2	0.8008	0.8008	0.4004	0.34	0.718	6.912
Root gap	2	0.7635	0.7635	0.3817	0.32	0.728	6.741
Residual Error	16	18.9021	18.9021	1.1814			2.65
Total	26	27.585					100

S = 1.0869, R-Sq = 31.48 %, R-Sq(adj) = 0.00 %
Order of significance 1: Welding speed; 2: Voltage; 3: Current
SS: Sum of squares
DOF: Degree of freedom
P: Percentage contribution
↑: Level of significance at 95% confidence level

Table 4.54: ANOVA test summery (with pooling) of S/N data for impact strength

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	2	1.2161	1.058	0.529	0.465	0.050	18.835
Voltage	2	1.6851	0.589	0.295	0.259	0.041	23.135↑
Welding speed	**2**	**4.2174**	**1.943**	**0.972**	**0.855**	**0.022**	**29.044↑↑**
Gas flow rate	Pooled						
Root gap							
Residual Error	18	18.9021	20.466	1.137			
Total	24	27.585					

SS: Sum of squares
SS`: Pure sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

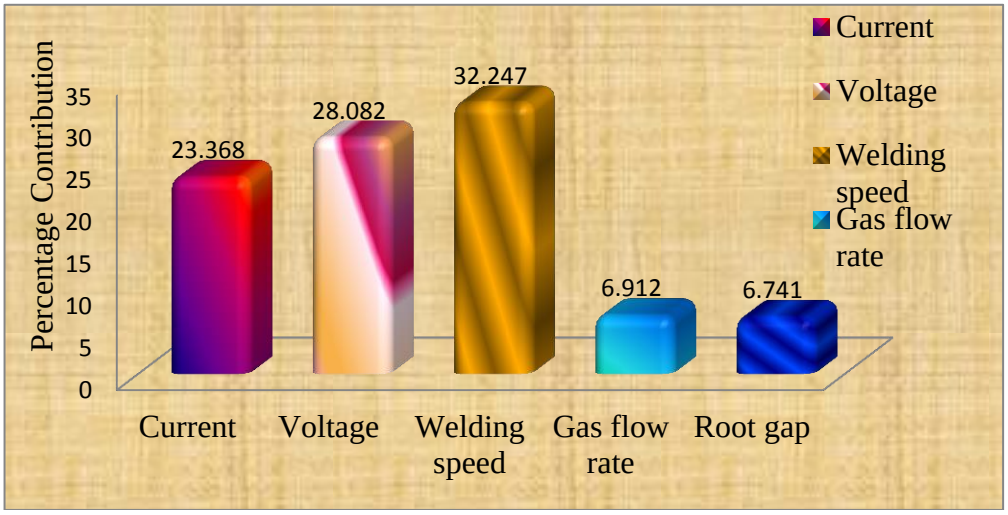


Fig. 4.31: Graph representing (without pooling) the percentage contribution of S/N ratios for impact strength on the GTAW process

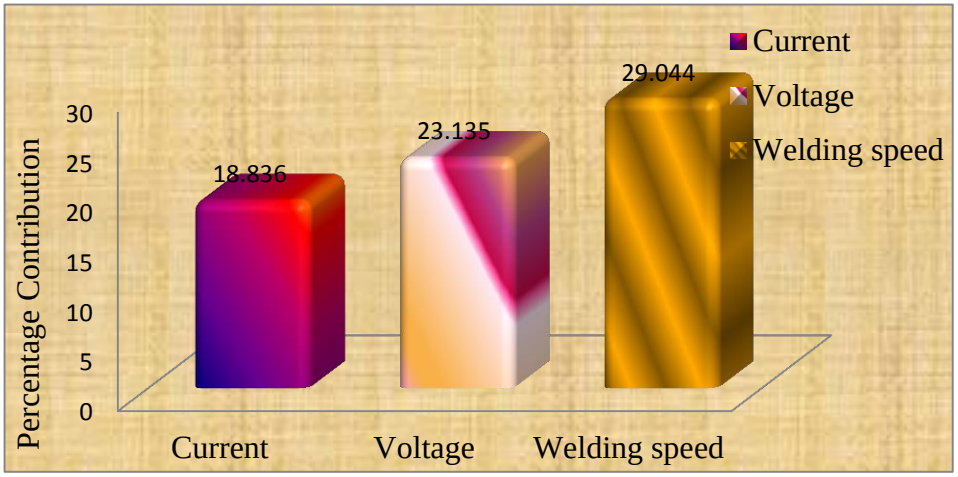


Fig. 4.32: Graph representing (with pooling) the percentage contribution of S/N ratios for impact strength

It is clear from the Table 4.53 that the F value for the parameters of welding speed, welding voltage and welding current are more than the limiting value but for gas flow rate and root gap the F value is less than to the limiting value. Therefore welding speed, welding voltage and welding current are more significant than the gas flow rate and root gap at 95% confidence level. The bar graph as shows in Figure 4.31, the percentage contribution of process parameters affecting the average values of S/N data. Indicate that the maximum percentage contribution is of welding speed i.e. 32.247 %.

4.3.7 Summary of ANOVA of Hardness using GTAW

It is clear from the Table 4.55 that the F value for all the parameters welding current, welding voltage and root gaps are more than the limiting value, but for welding speed and gas flow rate F value is less than the limiting value. Therefore welding current, gas flow rate and welding voltage are the more significant than the welding speed and root gap at the 95% confidence level. The bar graph as shown in Figure 4.33 the percentage contribution (PC) of the process parameters affecting the average values of the raw data or mean values. Indicate that the maximum percentage contribution is of welding current i.e. 37.157 %.

Table 4.55: ANOVA test summery (without pooling) of means or raw data for hardness

Source	DF	Seq SS	Adj SS	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**46.949**	**46.949**	**23.4743**	**13.86**	**0**	**37.157↑↑**
Voltage	2	13.326	13.326	6.6632	3.93	0.043	13.263
Welding speed	2	1.909	1.909	0.9546	0.56	0.58	1.470
Gas flow rate	2	36.544	36.544	18.2719	10.79	0.001	30.144↑
Root gap	2	10.017	10.017	5.0084	2.96	0.051	10.714
Residual Error	16	21.102	27.102	1 6.693			6.252
Total	26	129.847					100

S = 1.3015 R-Sq = 80.05 % R-Sq(adj) = 67.58 %
Order of significance 1: Current; 2: Gas flow rate, 3: Voltage;4: Root gap
SS: Sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

Table4.56: ANOVA test summery (with pooling) of means or raw data for hardness

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**46.949**	**43.725**	**21.863**	**13.562**	**0**	**36.187↑↑**
Voltage	2	13.326	10.102	5.051	3.133	0.043	12.436
Welding speed	Pooled						
Gas flow rate	2	36.544	33.32	16.66	10.335	0.001	28.528↑
Root gap	2	10.017	6.793	3.397	2.107	0.051	9.001
Residual Error	18	27.102	29.011	1.612			
Total	24	135.847					

SS: Sum of squares
SS`: Pure sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

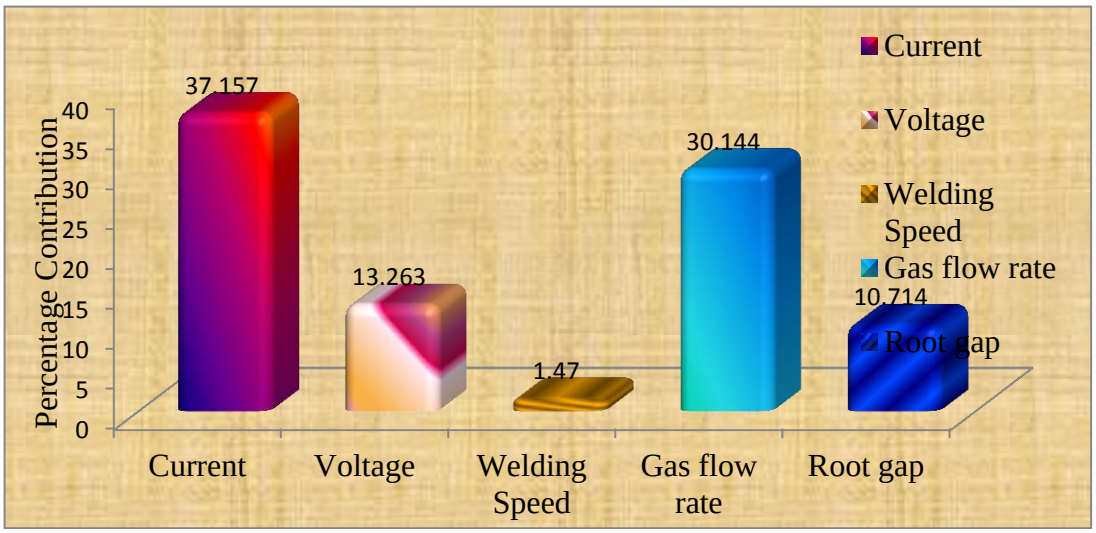


Fig. 4.33: Graph representing (without pooling) the percentage contribution of raw or mean data for hardness

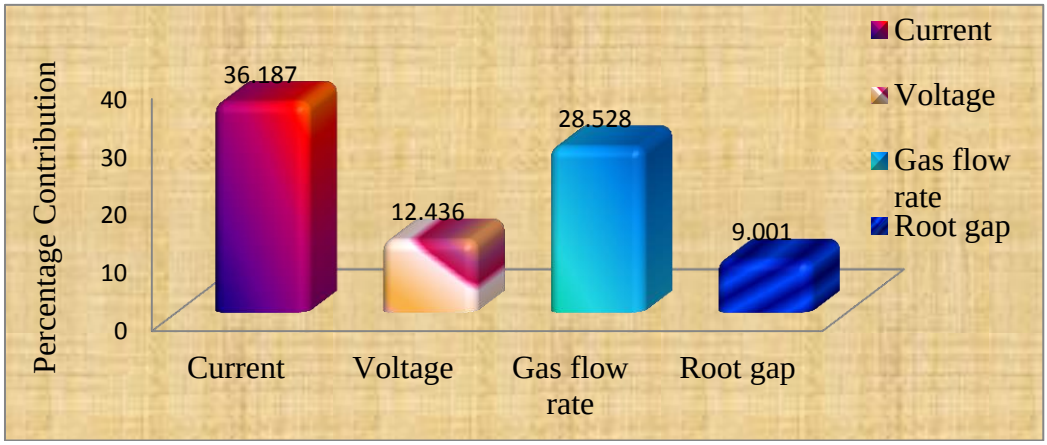


Fig. 4.34: Graph representing (with pooling) the percentage contribution of raw or mean data for hardness

Table 4.57: ANOVA test summery (without pooling) of S/N data for hardness

Source	DF	Seq SS	Adj SS	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**0.76641**	**0.76641**	**0.38321**	**13.66**	**0**	**34.721↑↑**
Voltage	2	0.21041	0.21041	0.1052	3.75	0.046	19.532
Welding speed	2	0.02943	0.02943	0.01472	0.52	0.602	1.322
Gas flow rate	2	0.59061	0.59061	0.29531	10.53	0.001	26.765↑
Root gap	2	0.16215	0.16215	0.08108	2.89	0.054	16.346
Residual Error	16	0.44888	0.44888	0.02806			1.314
Total	26	2.2079					100

S = 0.1675, R-Sq = 79.67 %, R-Sq(adj) = 66.96 %
Order of significance 1: Current; 2: Gas flow rate: 3: Voltage; 4: Root gap
SS: Sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

Table 4.58: ANOVA test summery (with pooling) of S/N data for hardness

Source	DF	Seq SS	SS`	Adj MS/ Variance	F	P	P C (%)
Current	**2**	**0.76641**	**0.7132**	**0.3566**	**13.406**	**0**	**32.302↑↑**
Voltage	2	0.21041	0.1572	0.0786	2.955	0.046	17.119
Welding speed	Pooled						
Gas flow rate	2	0.59061	0.5374	0.2687	10.102	0.001	24.339↑
Root gap	2	0.16215	0.1089	0.0545	2.049	0.054	14.932
Residual Error	18	0.44888	0.4783	0.0226			
Total	24	2.2079					

SS: Sum of squares
SS`: Pure sum of squares
DOF: Degree of freedom
P C: Percentage contribution
↑: Level of significance at 95% confidence level

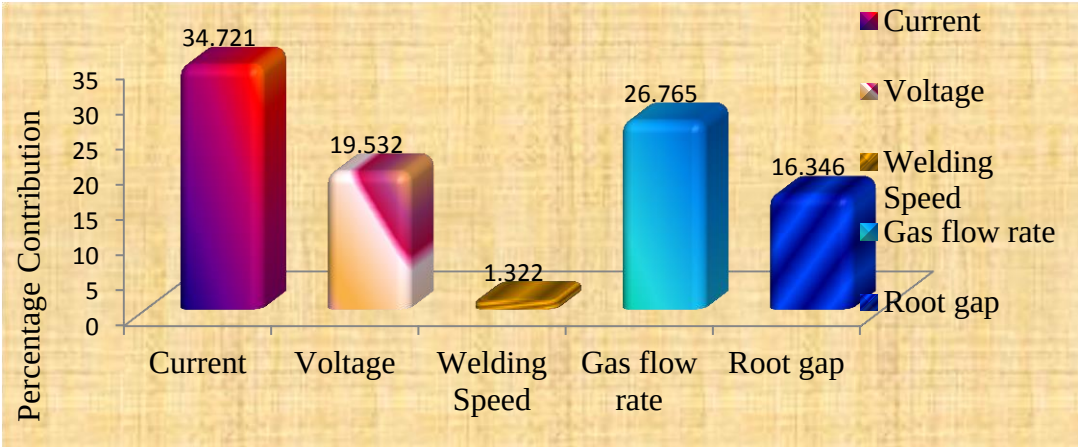


Fig. 4.35: Graph representing (without pooling) the percentage contribution of S/N ratios for hardness

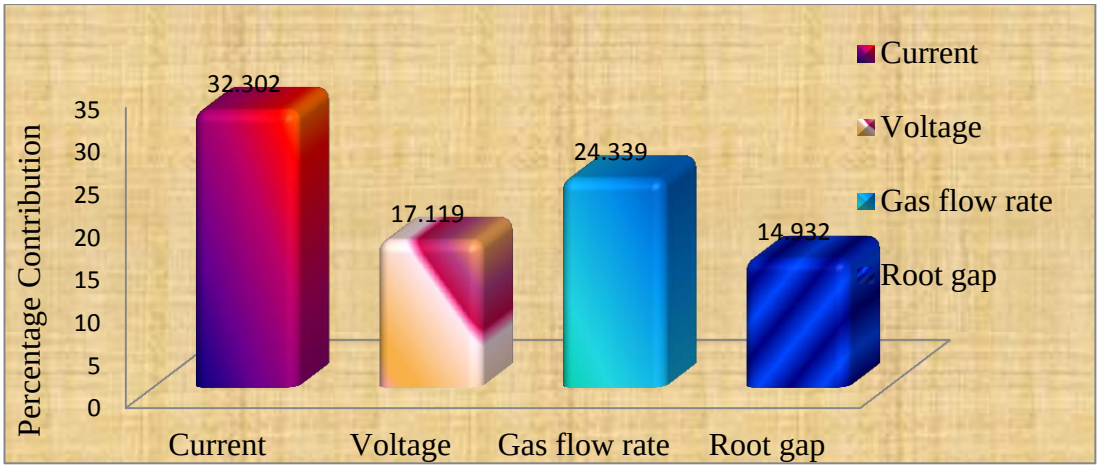


Fig. 4.36: Graph representing (with pooling) the percentage contribution of S/N ratios for hardness

It is clear from the Table 4.55 that the F value for the parameters of welding current, gas flow rate and welding voltage are more than the limiting value but for welding speed and root gap the F value is less than to the limiting value. Therefore welding current, gas flow rate and welding voltage are more significant than the welding speed and root gap at 95% confidence level. The bar graph as shows in Figure 4.33 the percentage contribution of process parameters affecting the average values of S/N data. Indicate that the maximum percentage contribution is of welding voltage i.e. 34.721 %.

4.3.8 Effect of Input Parameters during GTAW Process

After all the experiment performing and the analyzing all results like as ultimate tensile strength, impact strength and hardness for GTAW process the discussion for the effect of the different input factors or parameters on the output response variables is describe.

4.3.8.1 Effect of parameters on UTS

According to the Figure 4.25 and Figure 4.27 for mean and S/N values that current and voltage affects the tensile strength very significantly. The different input parameters used in the experimentation can be ranked in Table 4.47 and Table 4.49 for mean and S/N values respectively, in order of increasing effect of mean value and S/N value as voltage, current, gas flow rate, root gap and speed and welding speed, voltage, gas flow rate, current and root gap respectively.

It is clear from the Figure 4.25, that the current and voltage affects the tensile strength significantly. The slop of voltage, current, gas flow rate, root gap and speed indicates that increase in current, voltage, root gap, gas flow rate and welding speed increasing order and it is also practical that for the higher current and voltage there should be higher the root gap,

gas flow rate and welding speed to melt the wire coming out continuously at higher speed. So that the basically for the tensile strength the heat is required to melt the wire hence according to $\mathbf{H=I^2RT}$ (H= Heat, I=Current) and the current and the heat are directly proportional to welding speed. Similarly voltage and current are also related to the each other according to the equation **V=IR**. So that we can say that the each control factors is related to the each other partially or directly influencing the tensile strength.

The analysis of variance the test results showed that the $\mathbf{A_3\ B_3\ C_3\ D_3\ E_2}$ is the optimal factors or parameters setting for the tensile strength. In this investigation we concluded that the optimal input factor or parameter setting for current is 240 Amp, voltage is 30 V, welding speed is 90 cm/min, gas flow rate is 20 Lit/min and root gap is 1.5 mm while the welding of aluminium alloy 3003 as parent material and ER4043 as filler wire on the gas tungsten arc welding (GTAW) as for as the tensile strength is concerned.

4.3.8.2 Effect of Parameters on Impact Strength

According to the Figure 4.29 (mean value) and Fig. 4.31 (S/N value) that the welding speeds only affects the impact strength very significantly. The different input parameters used in the experimentation can be ranked in Table 4.51 and Table 4.53 in order of increasing effect of mean and S/N values as welding speed, voltage, gas flow rate, current and root gap and speed, voltage, current, gas flow rate and root gap respectively. It is clear from the Figure 4.29 that the welding speed only affects the impact strength significantly.

The slop of welding speed, voltage, gas flow rate, current and root indicates that increase in current, voltage, gas flow rate, welding speed and root gap increasing order and it is also practical that for the higher current and voltage there should be higher according to the Table 4.51 and Table 4.53 the current melt the wire coming out continuously at higher speed. So that the basically for the impact strength the heat is required to melt the wire hence according to $\mathbf{H=I^2RT}$ (H= Heat, I=Current) and the current and the heat are directly proportional to welding speed. Similarly voltage and current are also related to the each other according to the equation **V=IR**. So that we can say that the each control factors is related to the each other partially or directly influencing the impact strength.

The analysis of variance the test results showed that the $\mathbf{A_1\ B_1\ C_1\ D_1\ E_1}$ is the optimal factors or parameters setting for the impact strength. In this investigation we concluded that the optimal input factor or parameter setting for current is 210 Amp, voltage is 22 V, welding speed is 60 cm/min, gas flow rate is 12 Lit/min and root gap is 1.0 mm while the welding of

aluminium alloy 3003 as parent material and ER4043 as filler wire on the gas tungsten arc welding (GTAW) machine as for as the impact strength is concerned.

4.3.8.3 Effect of Parameters on Hardness

It can be seen for the Figure 4.33 and Figure 4.35 that the current, gas flow rate and voltage are the most significant parameters or factors that are affecting the hardness. The different input factors or parameters used in the experimentation can be ranked in order of increasing the effect as current, gas flow rate, voltage, root gap and welding speed.

According to the Figure 4.33 it can be conclude that the current, gas flow rate and voltage are more significant than the remaining input parameters. The higher current will result in quick melting of wire electrode. This allows the proper filling of the joint to be made hence increase the strength of the desired weld zone and also allows directional solidification of molten metal. The slope of the gas flow rate, root gap and voltage indicates that the gas flow rate and root gap are the almost equal, which may result in the shielding phenomenon. For the proper shielding of molten pool there should be sufficient amount of inner gas to keep away atmospheric gases from molten pool. Because if the atmospheric gases like oxygen (O_2) and nitrogen (N_2) reacts with the molten metal the results in oxides and nitrides which increase the brittleness hence increase the hardness. Like that the shielding phenomenon plays the important role for the weld zone hardness during the GTAW process. The analysis of variance experiment results for the hardness confirms the optimal parameters setting as $\mathbf{A_3}$ $\mathbf{B_3}$ $\mathbf{C_2}$ $\mathbf{D_1}$ $\mathbf{E_3}$. In this work we concluded that the optimal input factors or parameters setting for the current is 240 Amp, voltage is 30 V, welding speed is 75 cm/min, gas flow rate is 12 Lit/min and root gap is 2.0 mm during the welding of aluminium alloy grade 3003 as parent material and ER 4043 as filler wire on GTAW machine as for as the hardness is concerned.

4.3.9 Prediction of Mean for GTAW Process

The Taguchi approach for predicting the mean performance characteristics and the determination of the confidence interval for the predicted average or the mean value has been applied. The mean or the average value of the performance characteristics observed through the confirmation experiments must be within the 95 % of the confidence interval ($CI;\ \alpha = 0.05$).

The observation for the mean value taken from the Table 4.30, Table 4.31 and Table 4.32 for the tensile strength, impact strength and hardness respectively overall population of average or the mean value.

The mean or average value for tensile strength is $\mu_{\overline{T}}$ **= 185.9891**

The mean or average value for impact strength is $\mu_{\bar{I}}$ **= 0.117929**

The mean or average value for hardness is $\mu_{\bar{H}}$ **= 67.9018**

According to the table 4.30, the predicted optimum value of UTS is calculated as below:

The equation of optimum combination for ultimate tensile strength is **($\mu_{\bar{T}}$)** = $\mathbf{A_3\, B_3\, C_3\, D_3\, E_2}$.

Hence, $\boldsymbol{\mu_T} = \boldsymbol{\mu_{\bar{T}}} + (\boldsymbol{A_3} - \boldsymbol{\mu_{\bar{T}}}) + (\boldsymbol{B_3} - \boldsymbol{\mu_{\bar{T}}}) + (\boldsymbol{C_3} - \boldsymbol{\mu_{\bar{T}}}) + (\boldsymbol{D_3} - \boldsymbol{\mu_{\bar{T}}}) + (\boldsymbol{E_3} - \boldsymbol{\mu_{\bar{T}}})$

Where,

A_3, B_3 and D_3 are taken optimum values from Table 4.44, due to the significant parameters

C_3 and E_3 are taken zero due to insignificant parameters

$\boldsymbol{\mu_{\bar{T}}}$ = Overall mean of the response = 185.9891

μ_T = 200.4 + 200.5 + 189.6 – 2 x 185.9891

$\boldsymbol{\mu_T}$ **= 218.523**

Similarly, For impact strength $\boldsymbol{\mu_I}$ **= 0.1309,** and For hardness $\boldsymbol{\mu_H}$ **= 71.775**

For the calculation of confidence interval ($CI_{CE\ (confirmation\ experiments)}$), with the help of the following equation has been used for GTAW process.

$$\boldsymbol{CI_{CE}} = \sqrt{\boldsymbol{Fa(1, fe)Ve}\left[\left(\frac{1}{n_{eff}}\right) + \left(\frac{1}{R}\right)\right]} \quad \text{.....1}$$

Where, *Fa(1, fe)* = the F ratio at a confidence level of factor against DOF 1, and error degree of freedom *fe*

$$\boldsymbol{neff} = \frac{\boldsymbol{N}}{[\boldsymbol{1+total\ DOFassociated\ in\ the\ estimation\ of\ mean}]} \text{.....2}$$

$\boldsymbol{neff}$ = for UTS, Impact strength and hardness during GTAW process

$= \frac{81}{1+10} = 7.3636$

Where, N = Total number of results = 27x3 = 81

- R = Sample size for confirmation experiment = 3
- Ve = Error variance = 191.06 (for tensile), = 0.000261 (for impact), = 16.693 (for hardness)
- fe = degree of freedom = 2
- F0.05 (1, 2) = ...(Teken from the table value, from Roy 1990)

According to equation No. 1, $neff = \sqrt{18.51 \text{ x } 191.06\left[\frac{1}{7.3636} + \frac{1}{3}\right]}$

(CI_{CE})UTS = $\pm$40.7306

Similarly, for impact strength and hardness

(CI_{CE})impact = $\pm$0.1176 and (CI_{CE})hardness = $\pm$12.0394

Therefore, the predicted confidence interval for confirmation experiment is:

Table 4.59: Responses value of confidence interval for confirmation experiments

Tensile strength	Impact strength	Hardness
CI_{CE} (T) = $\pm$ 40.7306 The 95 % confidence level for μT is CI_{CE} (T) = 177.792$\leq \mu_T \leq$ 259.254	CI_{CE} (I) = $\pm$ 0.1176 The 95 % confidence level for μI is CI_{CE} (I) = $0.0133 \leq \mu_I \leq 0.2485$	CI_{CE} (H) = $\pm$ 12.0394 The 95 % confidence level for μH is CI_{CE} (H) = $59.736 \leq \mu_H \leq 84.814$

The predicted optimum values and the confidence interval have been tabulated in Table 4.60. The experiments were conducted at the optimum setting of process parameters for all the response factors.

Table 4.60: The comparison of predicted values and the experimental values for GTAW

Si. No.	Response	Predicted Value	Experimental value (Max)	Confidence interval for confirmation experiments (CI_{ce})
1.	Ultimate tensile strength	218.523	218.689	$177.792 \leq \mu_T \leq 259.254$
2.	Impact strength	0.1309	0.16281	$0.0133 \leq \mu_I \leq 0.2485$
3.	Hardness	71.775	72.6633	$59.736 \leq \mu_H \leq 84.814$

This predicted and experiment values could be observed from the above table that the values taken from the confirmation experiments were contained well within the confidence interval for all the response variables. Hence, the optimization results were validated.

4.4 GMAW, GTAW PROCESSES AND PARENT METAL

The parameters optimum setting for GMAW and GTAW joining processes

Table 4.61: Optimal parametric setting for GMAW and GTAW

Optimum setting for GMAW joining process					
Si. No.	Output responses	Input variables	Optimum values	Optimum equation	S/N properties
1.	Ultimate tensile strength	Current	200	$A_3B_3C_3D_3E_3$	Larger-is-better (Maximum)
		Voltage	28		
		W speed	80		
		GFR	23		
		Root gap	2.5		
2.	Impact strength	Current	170	$A_1B_1C_3D_3E_2$	Smaller-is-better (Minimum)
		Voltage	20		
		W speed	80		
		GFR	23		
		Root gap	2.0		
3.	Hardness	Current	200	$A_3B_3C_2D_3E_3$	Larger-is-better (Maximum)
		Voltage	28		
		W speed	65		
		GFR	23		
		Root gap	2.5		

Optimum setting on GTAW joining process					
4.	Ultimate tensile strength	Current	240	$\mathbf{A_3B_3C_3D_3E_2}$	Larger-is-better (Maximum)
		Voltage	30		
		W speed	90		
		GFR	20		
		Root gap	1.5		
5.	Impact strength	Current	240	$\mathbf{A_3B_2C_3D_2E_2}$	Smaller-is-better (Minimum)
		Voltage	26		
		W speed	90		
		GFR	16		
		Root gap	15		
6.	Hardness	Current	240	$\mathbf{A_3B_3C_2D_1E_3}$	Larger-is-better (Maximum)
		Voltage	30		
		W speed	75		
		GFR	12		
		Root gap	2.0		

Table 4.62: Percentage contribution of all input parameters for GMAW and GTAW

Ultimate tensile strength					
Si. No.	Variable parameters	GMAW Process		GTAW Process	
		Percentage contribution (% P C)		Percentage contribution (% P C)	
		Raw or Mean values	S/N Ratio	Raw or Mean values	S/N Ratio
1.	Current	37.887	40.678	37.537	37.177
2.	Voltage	40.325	40.678	38.084	37.096
3.	Welding speed	4.269	4.626	4.246	4.732
4.	Gas flow rate	6.258	3.028	6.648	7.476
5.	Root gap	9.935	2.691	6.218	6.648
Impact strength					
6.	Current	33.486	35.568	22.904	23.368
7.	Voltage	29.103	27.878	25.631	28.082
8.	Welding speed	10.065	9.327	30.985	32.247
9.	Gas flow rate	14.359	14.887	8.376	6.912
10.	Root gap	6.399	8.894	6.917	6.741
Hardness					
11.	Current	31.991	32.229	37.157	34.721
12.	Voltage	17.102	13.335	13.263	19.532
13.	Welding speed	30.725	31.659	1.470	1.322
14.	Gas flow rate	8.043	8.181	30.144	26.765
15.	Root gap	8.125	8.154	10.714	16.346

4.4.1 Responses of Mean Data and S/N Ratios between GMAW and GTAW

The mean value (raw data) and the signal to noise (S/N) ratio at weld zone or bead are determined with the help of using software MINITAB-18. Larger-the-better characteristic are used for ultimate tensile strength and hardness. Smaller-the-better characteristic is used for impact strength for the both processes. All the responses values of raw and S/N data are mentioned in the Table 4.63 and Table 4.64 respectively.

Table 4.63: The mean of responses between GMAW and GTAW

No. of Run	GMAW			GTAW		
	At weld zone			At weld zone		
	Ultimate tensile strength	Impact strength	Hardness	Ultimate tensile strength	Impact strength	Hardness
1.	135.685	0.11516	37.1033	129.356	0.16281	67.6933
2.	153.701	0.10469	28.7933	152.688	0.13378	66.7666
3.	174.460	0.10809	41.5433	172.691	0.10867	65.8466
4.	162.646	0.10764	36.0433	160.161	0.12929	67.2833
5.	182.032	0.10716	35.8766	181.161	0.1187	64.0833
6.	185.777	0.10731	31.1766	174.828	0.10212	65.6166
7.	177.978	0.10697	42.7133	190.779	0.11838	64.9066
8.	191.882	0.11636	47.3433	207.446	0.10505	65.5733
9.	205.036	0.19596	44.8033	174.779	0.12174	66.5733
10.	175.231	0.10380	38.1566	174.893	0.12116	67.6133
11.	170.352	0.17238	49.6966	166.226	0.12117	66.6133
12.	167.585	0.21056	48.2766	181.893	0.12117	67.6133
13.	177.908	0.26168	49.5566	177.736	0.10277	69.4166
14.	192.849	0.13880	53.7866	191.402	0.10336	69.4166
15.	181.159	0.18980	52.0833	180.402	0.11561	70.0833
16.	197.176	0.26330	39.6466	199.962	0.11912	71.5233
17.	186.047	0.34803	39.6833	185.628	0.11944	67.8566
18.	214.561	0.11639	53.8233	215.628	0.11961	68.8566
19.	197.183	0.26788	59.7633	193.033	0.10802	70.0466
20.	188.646	0.11562	57.6466	187.366	0.10802	66.0666
21.	184.103	0.11049	43.1233	183.703	0.10802	70.0466
22.	194.923	0.12170	58.6533	193.022	0.11455	64.4233
23.	218.949	0.10982	38.5266	225.689	0.11455	66.4233
24.	205.033	0.31811	32.5333	191.355	0.11455	68.4233
25.	211.482	0.34021	36.7666	216.960	0.10481	71.3066
26.	204.979	0.38746	44.4166	201.293	0.10481	70.6133
27.	215.600	0.37326	55.0466	211.627	0.16281	72.6633
Average	187.1468	0.18588	44.3178	185.9891	0.11792	67.9018
Max	218.949	0.38746	59.7633	225.689	0.16281	72.6633
Min	135.685	0.10380	28.7933	129.356	0.10212	64.0833

Table 4.64: The S/N ratio of the responses between GMAW and GTAW process

No. of Run	GMAW			GTAW		
	At weld zone			At weld zone		
	Ultimate tensile strength	Impact strength	Hardness	Ultimate tensile strength	Impact strength	Hardness
1.	42.65064	18.77346	31.38826	42.23573	15.76615	36.61092
2.	43.73355	19.60162	29.18584	43.6761	17.47202	36.49119
3.	44.83392	19.32397	32.37003	44.74539	19.2773	36.37068
4.	44.2249	19.36053	31.13650	44.09114	17.76861	36.55815
5.	45.20299	19.39935	31.09624	45.16129	18.50465	36.1349
6.	45.37985	19.38693	29.87659	44.85222	19.81764	36.34028
7.	45.00733	19.41476	32.61127	45.61061	18.53416	36.24579
8.	45.6607	18.68393	33.50518	46.3381	19.57144	36.33455
9.	46.23663	14.15636	33.02621	44.84979	18.2911	36.46601
10.	44.87225	19.6755	31.63141	44.85545	18.33272	36.60065
11.	44.62694	15.26993	33.92655	44.41398	18.33198	36.47122
12.	44.48474	13.53235	33.67475	45.19632	18.33207	36.60065
13.	45.00394	11.64437	33.90204	44.99551	19.76245	36.82928
14.	45.70438	17.15200	34.61349	45.63893	19.71217	36.82928
15.	45.16121	14.43392	34.33398	45.12483	18.73977	36.91229
16.	45.89711	11.59076	31.96413	46.01895	18.48018	37.08895
17.	45.39248	9.1675	31.97216	45.37287	18.45696	36.63185
18.	46.63103	18.68144	34.61941	46.6741	18.44453	36.75892
19.	45.8974	11.44109	35.5287	45.71263	19.32965	36.90775
20.	45.51295	18.73909	35.21548	45.45382	19.32965	36.39965
21.	45.30122	19.13302	32.69425	45.28232	19.32965	36.90775
22.	45.79729	18.29395	35.36585	45.71214	18.81959	36.18086
23.	46.80687	19.18584	31.71523	47.07021	18.81959	36.44641
24.	46.23649	9.948272	30.24657	45.6368	18.81959	36.70408
25.	46.50547	9.365059	31.30909	46.72759	19.59139	37.06260
26.	46.23419	8.235313	32.95092	46.07657	19.59139	36.97773
27.	46.67299	8.559771	34.81462	46.51142	15.76615	37.22631
Average	45.39517	15.63519	32.76573	45.33462	18.62935	36.63291
Max	46.80687	19.67550	35.52870	47.07021	19.81764	37.22631
Min	42.65064	8.235313	29.18584	42.23573	15.76615	36.1349

The responses table for the raw or mean and the S/N data for the five input parameters and the three levels at the weld zone of aluminium alloy 3003 (IS 737) as parent material and ER4043 as filler wire are used.

Table 4.65: The experimental values of mechanical properties for parent material

No. of experiments	Parent Material		
	Ultimate tensile strength (Mpa)	Impact strength (J/mm^2)	Hardness (HRB)
1.	234.5014	0.39064	73.5307
2.	229.0738	0.37725	68.4672
3.	231.9027	0.40819	69.8391
Average	**231.8259**	**0.39202**	**70.6123**

4.4.2 Comparisons of GMAW and GTAW with PM

Table 4.66: Ultimate tensile strength of parent material, GMAW and GTAW

Si. No.	Parent material and welding process	UTS
1.	PM	231.8259
2.	GMAW	187.1468
3.	GTAW	185.9891

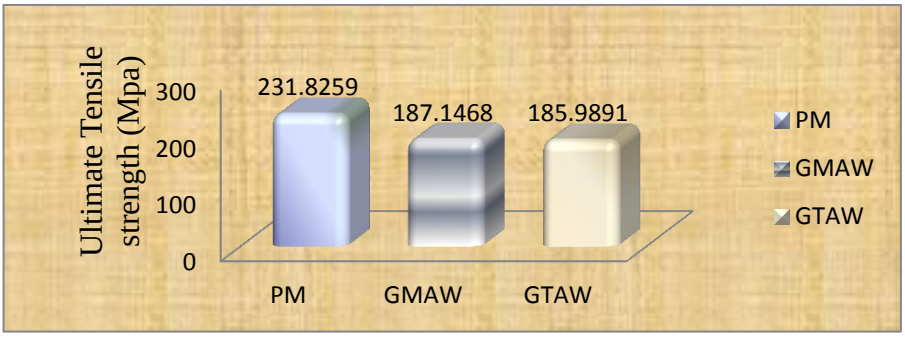


Fig. 4.37: The UTS of mean or raw data in parent material, GMAW and GTAW

Table 4.67: Impact strength of parent material, GMAW and GTAW

Si. No.	Parent material and welding process	Impact (J/mm^2)
1.	PM	0.39202
2.	GMAW	0.38746
3.	GTAW	0.16281

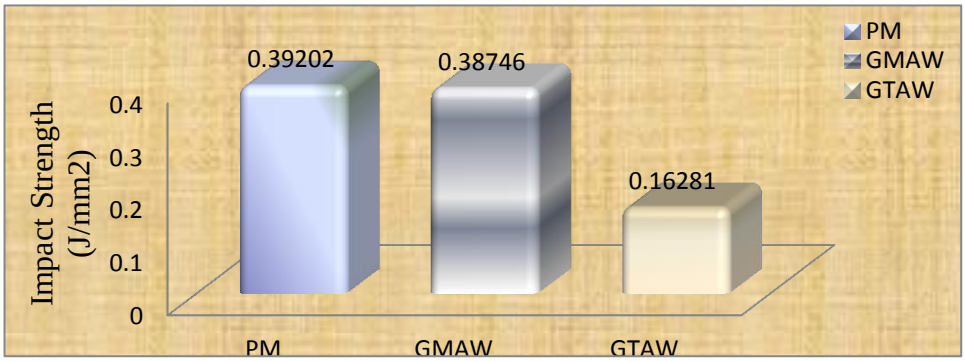


Fig. 4.38: The impact strength of parent materials, GMAW and GTAW

Table 4.68: Hardness of parent material, GMAW and GTAW

Si. No.	Parent material and welding process	Hardness (HRB)
1.	PM	**70.6123**
2.	GMAW	59.7633
3.	GTAW	72.6633

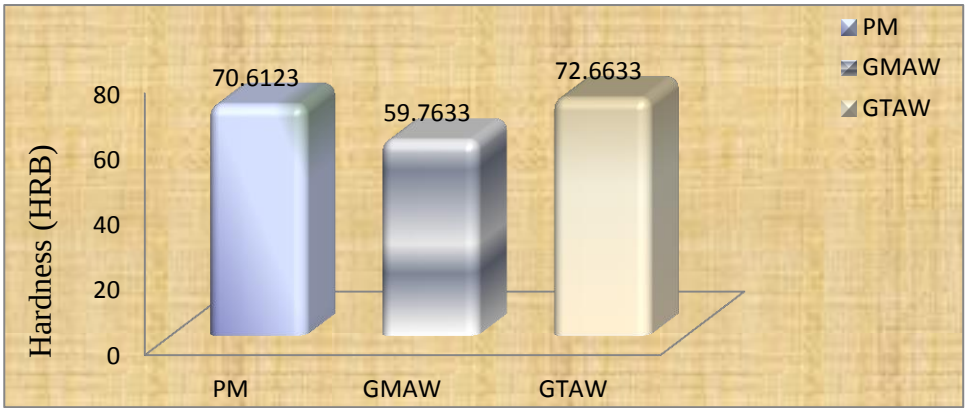


Fig. 4.39: The hardness of parent materials, GMAW and GTAW

The results of mechanical responses such as ultimate tensile strength, impact strength and hardness are shown in Figure 4.40, Figure 4.41 and Figure 4.42 respectively. It has been found that the ultimate tensile strength and impact strength of the gas metal arc welded aluminium 3003 – H2 is lower than the parent metal but are better than the gas tungsten arc welding methods. It has been found that the hardness of the GMAW is lower than the parent metal and GTAW. The joint efficiency is concept found in ASME code. It is a numerical value, which represents a percentage, expressed as the ratio of the strength of riveted, brazed and welded joint to the strength of the parent material. It is also a way to introduce safety factors in welding of shells for containment, and can be expressed as follows:

$$\text{Joint efficiency } (\boldsymbol{\eta}_{\mathbf{weld}}) = \frac{\text{Strength of welded joint}}{\text{Strength of parent material}} \times 100$$

The joint efficiency of the ultimate tensile strength is near about 82 % for the GMAW as compared to 80 % in the GTAW.

4.4.3 Parameter Optimization of Following Equation is Based upon Taguchi Design, used for Output Responses on the both Processes (Taken from APPENDIX-E)

$\eta_{\text{optimum}} = \bar{\mu}_T + (A_3 - \bar{\mu}_T) + (B_3 - \bar{\mu}_T) + (C_3 - \bar{\mu}_T) + (D_3 - \bar{\mu}_T) + (E_3 - \bar{\mu}_T)$.....(1)

$Y^2_{optimum} = 10^{\frac{\eta_{optimum}}{10}}$ (for properties, greater is better).....(2)

$Y^2_{optimum} = \frac{1}{10}^{\frac{\eta_{optimum}}{10}}$ (for properties, smaller-is-better)

Table 4.69: Parameters optimization based upon taguchi design used optimum values from S/N table (MINITAB-18) for output responses

Si. No.	Joining processes	Output responses	Optimum values for output responses ($Y_{optimum}$)
1	GMAW	Ultimate tensile strength	**230.94**
		Impact strength	**0.0784**
		Hardness	**55.85**
2	GTAW	Ultimate tensile strength	**226.98**
		Impact strength	**0.0983**
		Hardness	**72.11**

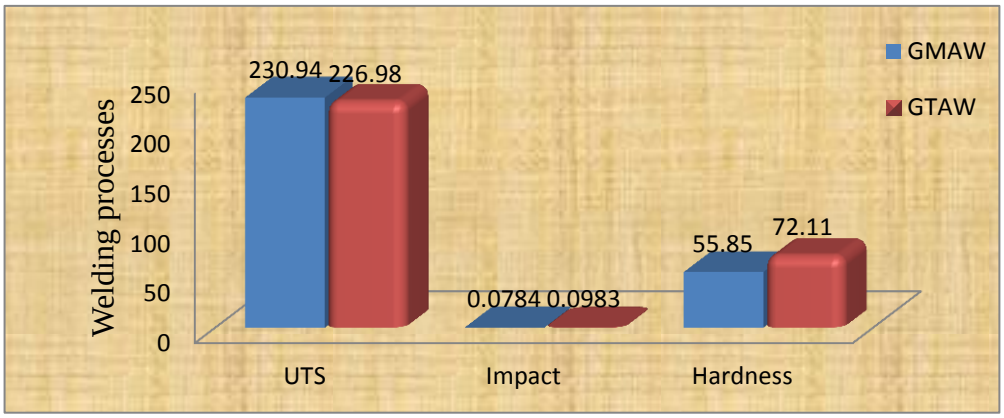


Fig 4.40: Parameters optimization based upon taguchi design used optimum values from S/N table (MINITAB-18) for output responses

4.5 SCANNING ELECTRON MICROSCOPY

According to SEM shows the microstructure of the parent material which has a uniform structure with uniformly distributed very fine strengthening precipitates and filler wire (Figure 4.41) having also near about as parent material (Figure 4.42 (a)). The Figure 4.46 shows at the weld zone of GMAW (B) and GTAW (C) at 1500X. The weld zone of GMAW joints contains equiaxed grains and it is due to the dynamic recraystallisation. At the weld zone of GTAW joint contains dendritic structure and it may be due to fast heating of parent material. Structure of parent material is due to the alloying elements such as silicon and manganese. These elements combine to form strengthening precipitates β”- Mn5Si6. These precipitates are stable at temperatures below 200^0C. In GTAW the strengthening precipitates are higher and lower than the parent material due to higher temperature.

In GMAW the temperatures are over 200-250^0C and β” is easily dissolved. In weld temperatures are higher therefore Mn2Si precipitates goes into the solution. During cooling, precipititation time is limited due to which only a small fraction of β` precipitates are formed.

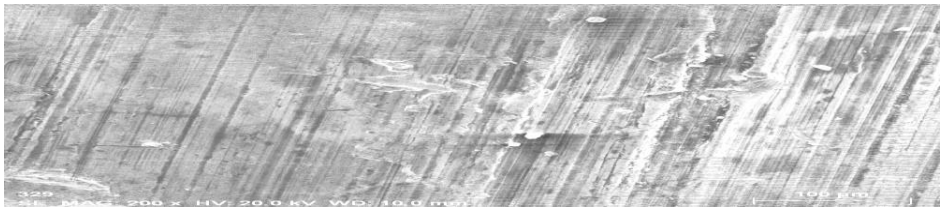
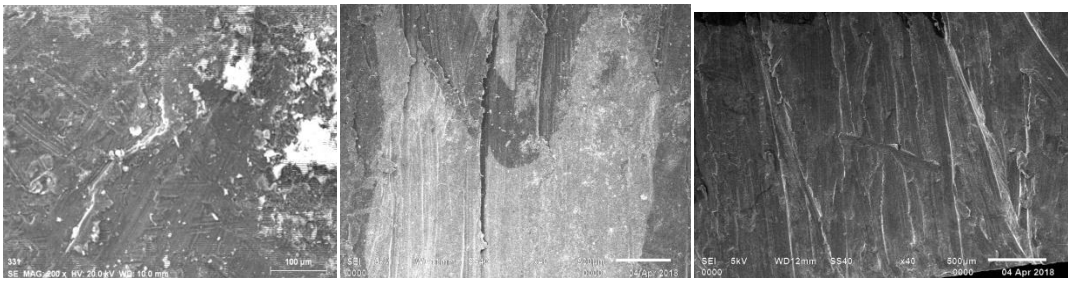


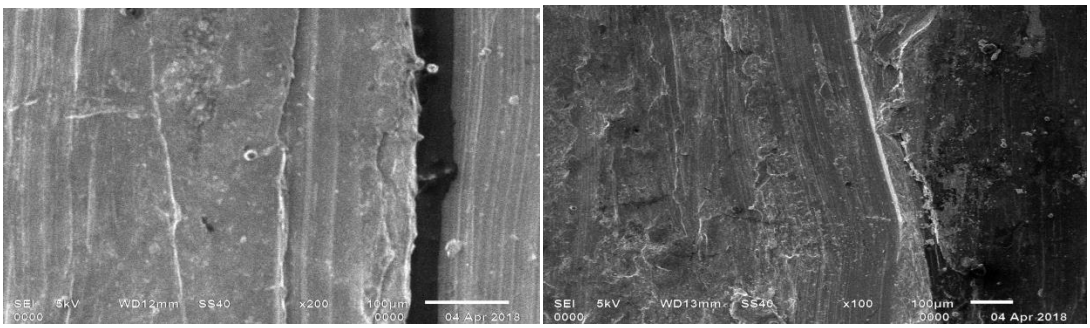
Fig. 4.41: SEM image of the filler wire (ER4043)



(A): PM (B): GMAW (C): GTAW

Fig. 4.42: SEM image of the parent material (AA3003)

The microstructure examinations as shown in Figure 4.42 (A) for parent material, GMAW (B) and GTAW (C) weldments demonstrate that all the techniques gave sound weld with no micro cracking or any weld defect. Also the results of the hardness measurements of the two weldments and parent material are show good strength compared with the parent material. The GMAW weld zone shows ferrite pearlite matrix with high percent of ferrite, the GTAW weld zone shows ferrite pearlite matrix with high percent of pearlite and the parent material shows equiaxed fine grains structure, they have micro hardness values (at the weld center) 44.3178Hv0.2, 67.9018 Hv0.2 and 71.9457Hv0.2 respectively.



(B): GMAW (C): GTAW

Fig. 4.43: SEM images at weld zone, GMAW (B) and GTAW (C)

The microstructure consists of austenite in grain size 5 to 6 in the matrix, No delta ferrite observed in GTAW. The microstructure consists of austenite in grain size 5 to 6 in the matrix, No IGC (Inter Granular Corrosion) observed in GMAW. In case of GMAW the microstructure is very fine and equiaxed, having uniformly distributed grains with strengthening precipitates as compared to GTAW welding processes in which dendritic grain structures is found.

4.6 CONFIRMATION EXPERIMENTS

The results obtained through optimization have to be validated. This was done through practical performance of the experiment in the same manner as the practical performed earlier as per DOE. The results showed that Taguchi was able to reach near the optimal solution, after satisfying the constraints. This was validated in present work practically, after performing a confirmatory experiment as per process parameters optimized by Taguchi method. The percentage error between the predicted value and the value obtained from the confirmation test is found to be mentioned in Table 4.70 and the percentage error is calculated by the following equation:

$$\text{\% age error} = \frac{\text{Confirmation test value} - \text{Predicted value}}{\text{Predicted value}} \times 100$$

Table 4.70: The confirmatory test results by using the optimum input parameters

Optimum parametric condition obtained by Taguchi design of experiment method									
Minimum values of responses obtained by the confirmatory test performed on GMAW									
Optimum inputs	Input	UTS	S/N ratio	Input	Impact	S/N ratio	Input	Hardness	S/N ratio
Welding current	200	215.5361	43.5782	200	0.33571	13.4281	200	44.6159	29.5719
Welding voltage	28			28			28		
Welding speed	80			65			65		
Gas flow rate	23			15			23		
Root gap	2.5			2.5			2.5		
% age error		2.51			1.47			1.71	
Minimum values of responses obtained by the confirmatory test performed on GTAW									
Welding current	240	212.183	44.2716	210	0.1283	16.92713	240	69.873	34.573
Welding voltage	30			22			30		
Welding speed	90			60			75		
Gas flow rate	20			12			12		
Root gap	1.5			1.0			2.0		
% age error		2.90			1.98			2.70	

The comparison of the predicted strength with actual strength using the optimal parameters is shown in Table 4.71. Good agreement between the predicted and actual penetration being observed.

Table 4.71: Results of conformation experiment

Output responses	Initial/Exp. process parameters (X)	Optimal process parameters		Improvement in output responses (Y-X)
		Predicted	Exp./Actual (Y)	
GMAW process				
Level	A3B2C2D2E2	A3B3C3D3E3	A3B3C3D3E3	
UTS (raw data)	218.949	221.1064	215.5361	3.412
S/N ratio	46.806	46.876	43.578	3.228
Level	A2B1C2D3E1	A3B3C2D1E3	A3B3C2D1E3	
Impact strength (raw data)	0.1038	0.3407	0.33571	0.231
S/N ratio	19.675	19.745	13.4281	6.253
Level	A3B1C3D2E1	A3B3C2B3E3	A3B3C2D3E3	
Hardness (raw data)	59.763	45.394	44.615	15.148
S/N ratio	35.528	35.598	29.571	5.957
GTAW				
Level	A3B2C1D3E2	A3B3C3D3E2	A3B3C3D3E2	
UTS (raw data)	225.689	218.523	212.183	13.506
S/N ratio	47.070	47.140	44.271	2.799
Level	A1B1C1D1E1	A1B1C1D1E1	A1B1C1D1E1	
Impact strength (raw data)	0.16281	0.1309	0.1283	0.035
S/N ratio	15.766	15.836	16.927	1.161
Level	A3B3C2D1E3	A3B3C2D1E3	A3B3C2D1E3	
Hardness (raw data)	72.663	71.775	69.873	2.790
S/N ratio	37.226	37.296	34.573	2.653

Summary and Conclusions

5.1 SUMMARY

The effect of various parameters on the quality of weld by gas metal arc welding (GMAW) and gas tungsten arc welding (GMAW) processes for weld of aluminium alloy, 3003-H2 are discussed in previous chapters. Optimal set of process parameters that yield optimum quality of GMAW and GTAW are obtained using Taguchi`s methodology. The parameters that were kept fixed during GMAW and GTAW for experimentation are:

Process parameters	GMAW and GTAW processes
Parent material	Aluminium alloy 3003-H2 (IS-737)
Filler material (wire)	ER4043 (Ø1.6)
Thickness of workpiece	5 mm
Shielding gas	Argon & Helium
Joint	Simple butt joint
Type of machine	Semi-automatic

The present research work is focused on comparative study of GMAW and GMAW processes parameters for joining the sample of aluminium alloys 3003-H2 as parent material and ER 4043 as filler material (wire).

Orthogonal array L_{27} was used to conduct the experiment based on the requirement of various levels and input parameters to evaluate the performance characteristics such as UTS, impact strength and hardness. The signal to noise (S/N) ratio and the analysis of variance (ANOVA) were employed to study and evaluate the material characteristics at weld zone for parent material. The optimum values were predicted using MINITAB-18 software, which were validated by conducting the confirmation experiments. Following conclusions are drawn for the range of processes parameters and output characteristics.

5.2 CONCLUSIONS

1. If the P-value is less than 0.05 then the corresponding variables are considered as statistically significant. For GMAW, it is found.
    - (i) Current, voltage and root gap are significant for UTS.
    - (ii) Current, voltage and gas flow rate are significant for impact strength.
    - (iii) Current, voltage and speed are significant for hardness.

2. If the P-value is less than 0.05 then the corresponding variables are considered as statistically significant. For GTAW, it is found:

    (i) Current, voltage, gas flow rate are significant for UTS.

    (ii) Current, voltage, welding speed are significant for impact strength.

    (iii) Current, voltage, gas flow rate and root gap are significant for hardness.

3. The percentage contribution of welding voltage for ultimate tensile strength during GMAW is 40.325% while for GTAW, it is around 38.084%. While the variable welding speed, gas flow rate and root gap have less contribution towards the total variation in ultimate tensile strength.

4. Similarly, the current (33.486%) and voltage (29.103%) have main effect for the variation of impact strength in GMAW process, while welding speed (30.985%), voltage (25.631%) and current (22.904%) have similar effect in GTAW process. All other parameters have less contribution for the variation of impact strength.

5. Variation in hardness is mainly affected by current (31.991%), welding speed (30.7255%) and voltage (17.102%) in GMAW process and current (37.157%), gas flow rate (30.144%) and voltage (13.263%) are the main responsible causes for variation in hardness in GTAW process. All other parameters have less contribution towards the total variation in hardness.

6. By use of ANOVA analysis the percentage contribution (PC) of GMAW for welding current is 37.887, welding voltage 40.325%, welding speed 4.269%, GFR 6.258% and root gap 9.935. similarly, percentage contribution of GTAW for welding current 37.537%, welding voltage 38.084%, welding speed 4.246%, GFR 6.648% and root gap 6.218. From ANOVA it is conclude that the welding voltage is most significant parameter for both GMAW and GTAW. Welding voltage is found to have effect on UTS, Increase in welding voltage, the value of UTS is increase in both welding. By use of Taguchi optimization method the optimal parameter is meeting at experiment L_{27} for both GMAW and GTAW are A3B3C3D3E3 and A3B3C3D3E2 respectively.

7. The highest PC of GMAW for welding current is 33.486% and welding voltage 29.103%, while PC of GTAW for welding speed is 30.985% and welding voltage 25.631%. From ANOVA it is conclude that the welding current and welding speed is most significant parameter for both GMAW and GTAW. Welding current is found to have effect on impact strength; decreasing in welding speed, the value of impact strength

is increase in both welding. By use of Taguchi optimization method the optimal parameter is meeting at experiment L_{27} for both GMAW and GTAW are A1B1C3D3E2 and A3B2C3D2E2 respectively.

8. The maximum values of PC of GMAW for welding current is 31.991% and PC of GTAW for welding current is 37.157. From ANOVA it is concluding that the welding current is most significant parameter for both GMAW and GTAW. Welding current is found to have effect on hardness; increase in welding current, the value of hardness is decrease in both welding. By use of Taguchi optimization method the optimal parameter is meeting at experiment L_{27} for both GMAW and GTAW are A3B3C2D3E3 and A3B3C2D1E3.

9. The mechanical property changes during both the welding processes have been compared with the parent material. The microstructure has also been examined. The ultimate tensile strength of GMAW is more than that of GTAW of AA3003-H2. The welded specimens have lower mechanical properties compared to the parent material.

10. The impact strength of parent material is larger than welded specimen of both welding processes. But impact strength of GMAW is higher than that of the GTAW joints.

11. It is found that hardness in weld zone is less than that of the parent material. The maximum hardness is found in GTAW and the minimum hardness is found in GMAW at weld zones.

12. In case of GMAW, the microstructure is very fine and equiaxed, having uniformly distributed grains with strengthening precipitates as compared to GTAW in which dendritic grain structures is found. Because of fine grain structure the GMAW joint possess good mechanical properties than that of the GTAW welding process.

13. On the basis of the above discussion it can be elaborate that the GMAW is the best suitable welding process to join aluminium alloy (AA3003-H2) as compared to GTAW process.

5.3 FUTURE SCOPE

Here we have found the optimum process parameters for tensile strength, impact strength and hardness, the data generated can be used for further study and new investigations. The science of manufacturing will be enriched by the knowledge contributed by the study howsoever the small it may be. There are various objects which can help to analyze the whole work with a new parameters and dimension. The following steps will lead for the further study of the process and further research work:

1. Further study for the transverse tensile properties of parent material can be analyzed by welding the parent material with two or more than two different or same filler metals.
2. Types of loading for compressive and tensile testing can be changed for the different four zones for further study.
3. Post heat treatment can be done in order to improve the properties of material further study.
4. The other techniques can be used like as Artificial Neural Network, Genetic Algorithm, so as to compare the results obtained from the Taguchi approach.

Above are some of the areas where this study can be extended for the further analysis of the whole work.

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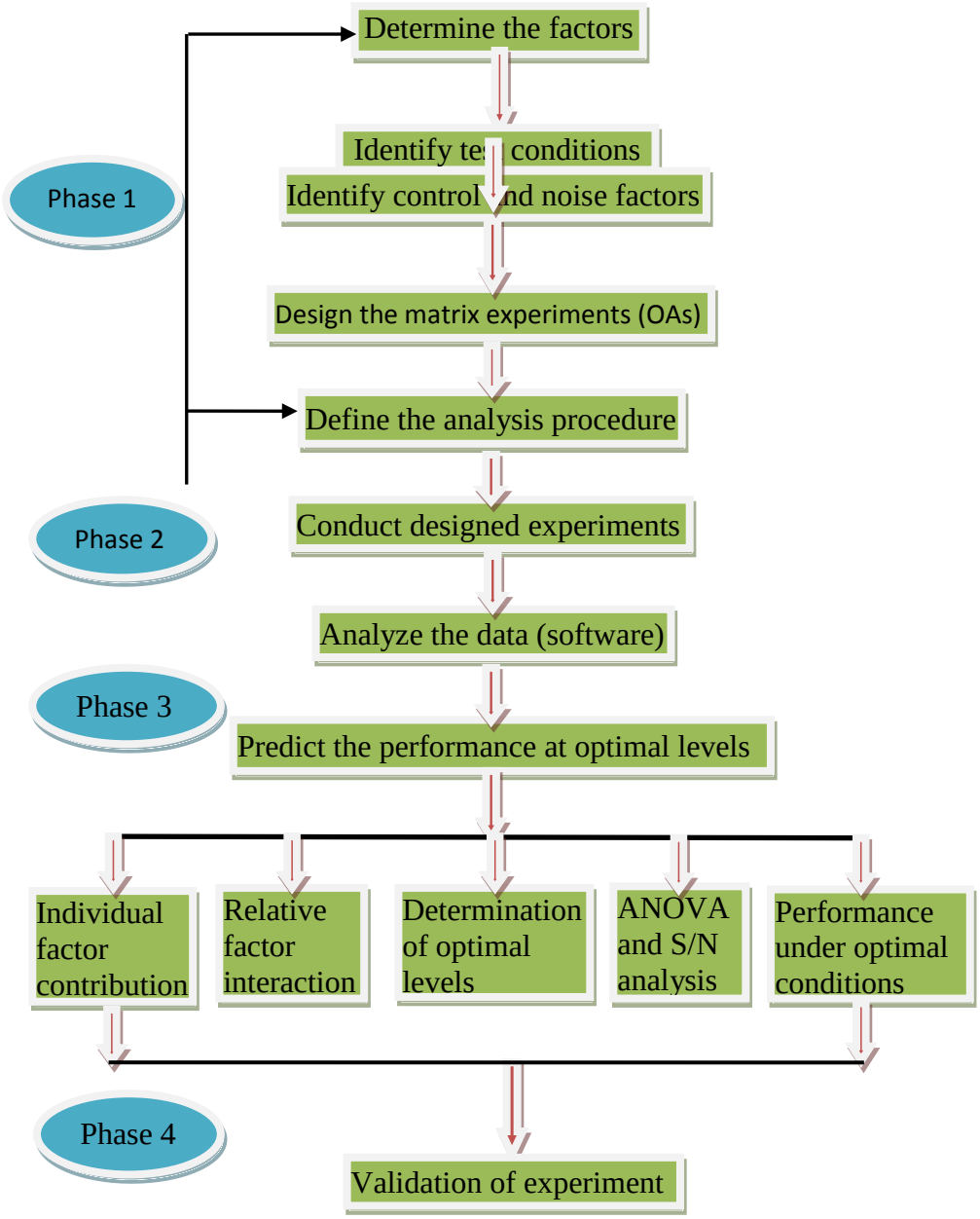
Appendices

APPENDIX-A

Flow chart of the taguchi approach



APPENDIX-B

F-Table 1: Critical values (alpha=.05 or 95% confidence level – 1st row)
(alpha=.01 or 99% confidence level – 2nd row)

df denominator	df numerator									
	1	2	3	4	5	6	7	8	9	10
2	18.51 98.50	19.00 99.00	19.16 99.16	19.25 99.25	19.30 99.30	19.33 99.33	19.35 99.36	19.37 99.38	19.38 99.39	19.40 99.40
3	10.13 34.12	9.55 30.82	9.28 29.46	9.12 28.71	9.01 28.24	8.94 27.91	8.89 27.67	8.85 27.49	8.81 27.34	8.79 27.23
4	7.71 21.20	6.94 18.00	6.59 16.69	6.39 15.98	6.26 15.52	6.16 15.21	6.09 14.98	6.04 14.80	6.00 14.66	5.96 14.55
5	6.61 16.26	5.79 13.27	5.41 12.06	5.19 11.39	5.05 10.97	4.95 10.67	4.88 10.46	4.82 10.29	4.77 10.16	4.74 10.05
6	5.99 13.75	5.14 10.92	4.76 9.78	4.53 9.15	4.39 8.75	4.28 8.47	4.21 8.26	4.15 8.10	4.10 7.98	4.06 7.87
7	5.59 12.25	4.74 9.55	4.35 8.45	4.12 7.85	3.97 7.46	3.87 7.19	3.79 6.99	3.73 6.84	3.68 6.72	3.64 6.62
8	5.32 11.26	4.46 8.65	4.07 7.59	3.84 7.01	3.69 6.63	3.58 6.37	3.50 6.18	3.44 6.03	3.39 5.91	3.35 5.81
9	5.12 10.56	4.26 8.02	3.86 6.99	3.63 6.42	3.48 6.06	3.37 5.80	3.29 5.61	3.23 5.47	3.18 5.35	3.14 5.26
10	4.96 10.04	4.10 7.56	3.71 6.55	3.48 5.99	3.33 5.64	3.22 5.39	3.14 5.20	3.07 5.06	3.02 4.94	2.98 4.85
df denominator	df numerator									
	1	2	3	4	5	6	7	8	9	10
11	4.84 9.65	3.98 7.21	3.59 6.22	3.36 5.67	3.20 5.32	3.09 5.07	3.01 4.89	2.95 4.74	2.90 4.63	2.85 4.54
12	4.75 9.33	3.89 6.93	3.49 5.95	3.26 5.41	3.11 5.06	3 4.82	2.91 4.64	2.85 4.50	2.80 4.39	2.75 4.30
13	4.67 9.07	3.81 6.70	3.41 5.74	3.18 5.21	3.03 4.86	2.92 4.62	2.83 4.44	2.77 4.30	2.71 4.19	2.67 4.10
14	4.60 8.86	3.74 6.51	3.34 5.56	3.11 5.04	2.96 4.69	2.85 4.46	2.76 4.28	2.70 4.14	2.65 4.03	2.60 3.94
15	4.54 8.68	3.68 6.36	3.29 5.42	3.06 4.89	2.90 4.56	2.79 4.32	2.71 4.14	2.64 4.00	2.59 3.89	2.54 3.80
16	4.49 8.53	3.63 6.23	3.24 5.29	3.01 4.77	2.85 4.44	2.74 4.20	2.66 4.03	2.59 3.89	2.54 3.78	2.49 3.69

APPENDIX-C

Experimentation and data collection

The experiment is performed against each of the trial conditions of the inner array. Each experiment at a trial condition is repeated simply (if outer array is not used) or according to the outer array (if used). Randomization should be carried for to reduce bias in the experiment.

Samples for welding as different root gap

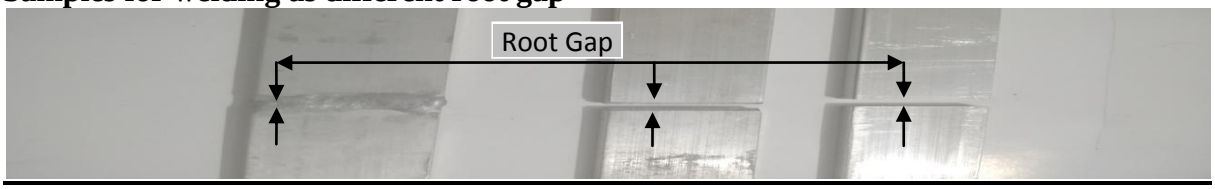


Fig.2: Aluminium alloy 3003 specimens

APENDIX-D

Strategy of the parameter design

Classification of the parameters and the selection of optimal levels:

ANOVA of raw or mean data and S/N ratio identifies the control factors, which affect the average response and the variation in the response respectively. The control factors are classified into four groups:

a) Parameters, which affect both average and variation
b) Parameters, which affect variation only
c) Parameters, which affect average only
d) Parameters, which affect nothing

The parameters design strategy is to select the suitable levels of (a) and (b) parameters to reduce variation and (c) parameters to adjust the average values to the target value. The number (d) parameters may be set at the most economical levels.

APENDIX-E

Prediction of mean

After determination of the optimum condition, the mean of the response (μ) at the optimum condition is predicted. This mean is estimated only from the significant parameters. The ANOVA identifies the significant parameters. Suppose, parameters A and B are significant and A2B2 (second level of both A and B) is the optimal treatment condition. Then, the mean at the optimal condition (optimal value of the response characteristic) is estimated (Ross, 1996) as:

(1) For ultimate tensile strength on GMAW process

$$\boldsymbol{\mu_T = \mu_{\bar{T}} + (A_3 - \mu_{\bar{T}}) + (B_3 - \mu_{\bar{T}}) + (C_3 - \mu_{\bar{T}}) + (D_3 - \mu_{\bar{T}}) + (E_3 - \mu_{\bar{T}})} \text{ .....(1)}$$

Where,

A_3, B_3 and E_3 are taken optimum values from Table 4.15 (mean), Table 4.16 (S/N ratio) for GMAW and Table 4.45 (mean), Table 4.46 (S/N ratio) due to the significant parameters, C_3 and D_3 are taken zero due to insignificant parameters

$\boldsymbol{\mu_{\bar{T}}}$ = Overall mean of the response = Calculation, overall mean of S/N ratio ($\boldsymbol{\mu_{\bar{T}}}$) was taken from Minitab software, $\boldsymbol{\mu_{\bar{T}}}$ = 187.1468

(μ_T)UTS = 202.3 + 200.5 + 192.6 – 2 x 187.1468 = 221.1064

A_3, B_3 and E_3 = optimum values of response at third levels of parameters A, B and E respectively. It may sometimes be possible that the predicated combination of parameter levels (optimal treatment condition) is identical to one of those in the experiment. If this situation exists, then the most direct way to estimate the mean for that treatment condition is to average out all the results for the trials which are set at those particular levels (Ross, 1996).

Similarly,

For Impact strength, $(\boldsymbol{\mu_T})_{\text{Impact}}$ = 0.34074

For Hardness $(\boldsymbol{\mu_T})_{\text{Hardness}}$ = 45.3944

(2) For ultimate tensile strength on GTAW process

$$\boldsymbol{(\mu_T)UTS = \mu_{\bar{T}} + (A_3 - \mu_{\bar{T}}) + (B_3 - \mu_{\bar{T}}) + (C_3 - \mu_{\bar{T}}) + (D_3 - \mu_{\bar{T}}) + (E_3 - \mu_{\bar{T}})} \text{...2}$$

μ_T = Consider only significant term = over all means of the response

$\boldsymbol{\mu_{\bar{T}}}$ **= 185.9891**

A3=200.4, B3=200.5, C3=187.4, D3=189.6 and E2=188.8

A, B & D are significant parameters ($P \leq 0.05$) and consider

C & E are insignificant and not consider

Putting all these values in equation (1), and we get

$(\boldsymbol{\mu_T})_{\text{UTS}}$**= 218.523**

Similarly,

For Impact strength, $(\boldsymbol{\mu_T})_{\text{Impact}}$ = 0.1309; For Hardness $(\boldsymbol{\mu_T})_{\text{Hardness}}$ = 71.77

APPENDIX-F

Table 2: Tensile strength (% P C) of raw and S/N data for GMAW and GTAW

Process parameters	Mean of GMAW	Mean of GTAW	S/N of GMAW	S/N of GTAW
Current	35.88	33.54	34.79	33.18
Voltage	37.33	34.08	36.68	33.08
Welding speed	0.27	0.24	0.64	0.74
Gas flow rate	2.27	18.67	3.04	19.49
Root gap	18.93	2.22	18.61	2.65

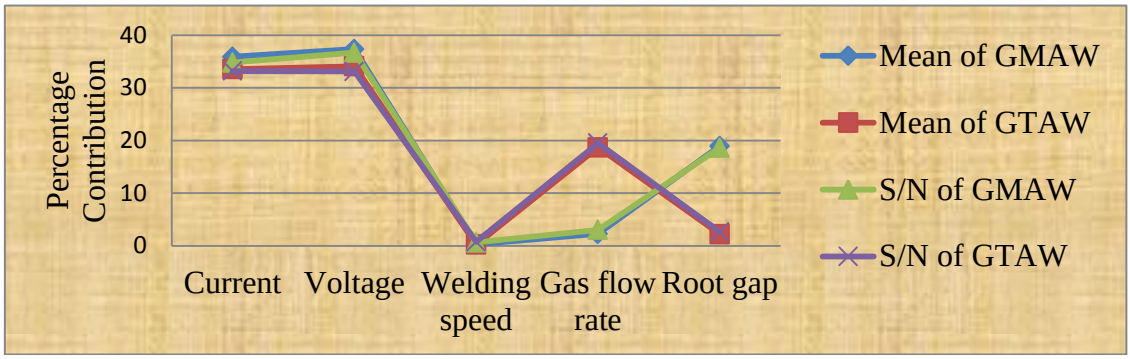


Fig.3: % P C of UTS (mean and S/N data) for both processes

Table 3: Impact strength (% P C) of raw and S/N data for GMAW and GTAW

Process parameters	Mean of GMAW	Mean of GTAW	S/N of GMAW	S/N of GTAW
Current	27.48	18.9	28.56	19.37
Voltage	23.09	21.63	19.89	24.08
Welding speed	4.07	25.98	2.33	28.25
Gas flow rate	18.69	4.38	18.89	2.91
Root gap	0.42	2.91	0.88	2.74

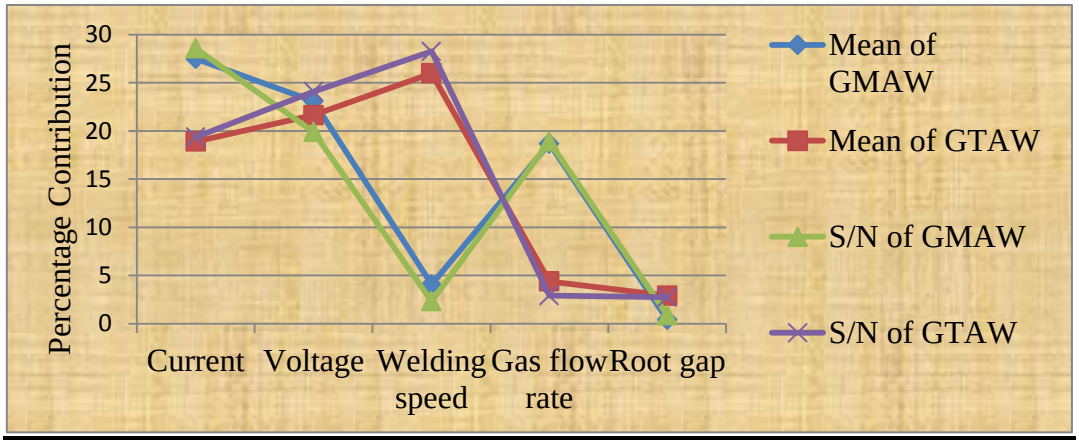


Fig. 4: % P C of impact strength (mean and S/N data) for both processes

Table 4: Hardness (% P C) of raw and S/N data for GMAW and GTAW

Process parameters	Mean of GMAW	Mean of GTAW	S/N of GMAW	S/N of GTAW
Current	23.99	34.56	24.25	34.72
Voltage	17.98	19.8	16.51	19.53
Welding speed	22.69	1.39	23.68	1.32
Gas flow rate	0.07	26.91	0.19	26.76
Root gap	0.13	14.38	0.13	16.34

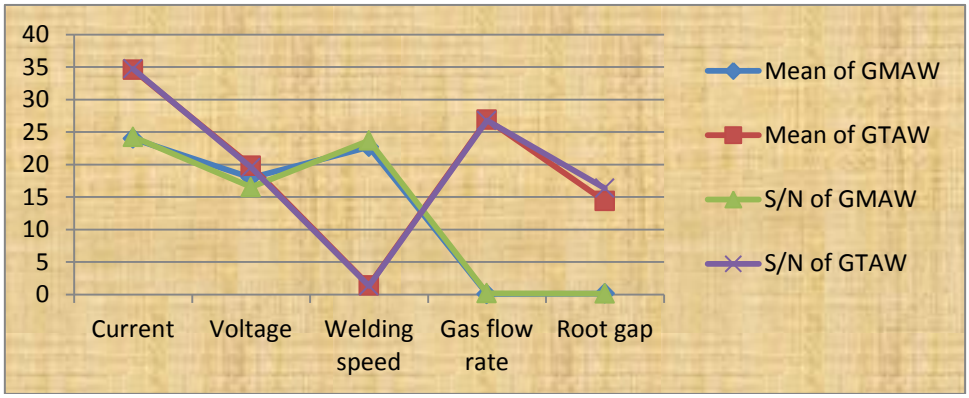


Figure 5: % P C of hardness (mean and S/N data) for both processes

LIST OF PUBLICATIONS

RESEARCH PUBLICATIONS
A. International Journals/International Research Paper
1. **Ram Gopal,** Dr. R. S. Jadoun, Dr. Rajiv Suman. "Parameters Optimization for Gas Metal Arc and Gas Tungsten Arc Welding of Aluminium Alloy 31000-H2 (IS 737) by Taguchi Design of Experiment Technique", International Journal of Scientific & engineering Research, Volume 7, Issue 12, December-2016 289 2. **Ram Gopal, Dr. R. S Jadoun** "A Review on Effects of GMAW and GTAW Mechanical Properties on Weld Zone of Aluminium Alloy by Taguchi Design of Experiment Technique", International journal for research in emerging science and technology, volume-4, issue-8, aug-2017 3. **Ram Gopal, R. S Jadoun. "**Comparative Study of Gas Metal Arc Welding (GMAW) and Gas Tungsten Arc Welding (GTAW) for Aluminium Alloy 3003-H2 Using Taguchi method", International Journal of Research and Scientific Innovation (IJRSI) | Volume V, Issue V, May 2018 | ISSN 2321–2705

VITA

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ABSTRACT

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Thesis Title : "Comparative Study of Gas Metal Arc Welding (GMAW) and Gas Tungsten Arc Welding (GTAW) for Aluminium Alloy 3003-H2 Using Taguchi Method"

Advisor : Dr. R. S. Jadoun

Gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW) processes are an efficient economical means of welding of ferrous and non-ferrous materials. GMAW and GTAW processes have a great potential for application in precision welding of aluminium alloy 3003-H2. The published literature reveals that no systematic effort has been made to study the GMAW and GTAW processes in a comprehensive manner by considering all performance characteristics to predict the quality of weld.

Realizing the potential and importance of the GMAW and GTAW processes for precision welding of aluminium alloy, the present work aims at investigating the effect of various processes parameters on the quality of weld in aluminium alloy. Experiments were carried out in a phased manner and the work was divided into three parts i.e. using GMAW, using GTAW and comparison of GMAW & GTAW.

Comparative study of gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW) for ultimate tensile strength, impact strength and hardness have been performed by Taguchi method. The control parameters viz. welding current, welding voltage, welding speed, gas flow rate and root gap were chosen as welding input parameters. The materials used for this purpose were aluminium alloys of grades 3003-H2 as parent material and ER4043 as filler material (wire) having dimensions (100x40x5 mm). Helium and argon were used as a shielding gas. Filler wire 4043 of diameter 1.6 mm was used. An orthogonal array, L_{27} was used to conduct the experiments. Signal to noise (S/N) ratio and analysis of variance (ANOVA) were employed to study the welding characteristics.

Optimization of parameters was done by Taguchi method using statistical software MINITAB-18. Confirmation tests were carried out to validate the experimental results. Welding voltage for UTS, welding current for impact and welding current for hardness of GMAW were found to be most significant factors. Similarly, welding voltage for UTS, welding speed for impact strength and welding current for hardness of GTAW were found to be most significant factors.

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Advisor

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सारांश

नाम : राम गोपाल **परिचयाँक** : 39340

सत्र और प्रवेश वर्ष: प्रथम, 2013-14 **उपाधि** : पी॰एच॰डी॰

मेजर : उत्पादन अभियांत्रिकी **विभाग** : औद्योगिक उत्पादन अभियांत्रिकी

माइनर : यांत्रिक अभियांत्रिकी

शोध शीर्षक : "गैस धातु आर्क वेल्डिंग (जीएमएडब्ल्यू) और गैस टंगस्टन आर्क वेल्डिंग (जीटीएडब्लू) का टैगुची विधि के उपयोग द्वारा एल्यूमीनियम मिश्र धातु 3003-एच2 का तुलनात्मक अध्ययन"

सलाहकार : डॉ॰ आर॰ एस॰जादौन

गैस धातु आर्क वेल्डिंग (जीएमएडब्लू) और गैस टंगस्टन आर्क वेल्डिंग (जीटीएडब्ल्यू) प्रक्रिया फेरस और गैर-लौह सामग्री के वेल्डिंग का एक प्रभावी आर्थिक साधन हैं। जीएमएडब्ल्यू और जीटीएडब्ल्यू प्रक्रियाओं में एल्यूमीनियम मिश्र धातु 3003-एच 2 की सटीक वेल्डिंग में प्रयोग के लिए एक बड़ी संभावना है। प्रकाशित साहित्य से पता चलता है कि वेल्ड की गुणवत्ता की भविष्यवाणी करने के लिए सभी प्रदर्शन विशेषताओं पर विचार करके जीएमएडब्ल्यू और जीटीएडब्ल्यू प्रक्रियाओं का व्यापक तरीके से अध्ययन करने के लिए कोई व्यवस्थित प्रयास नहीं किया गया है।

एल्यूमीनियम मिश्र धातु के परिशुद्धता वेल्डिंग के लिए जीएमएडब्ल्यू और जीटीएडब्ल्यू प्रक्रियाओं की संभावित और महत्व को समझते हुए, वर्तमान कार्य का लक्ष्य एल्यूमीनियम मिश्र धातु में वेल्ड की गुणवत्ता पर विभिन्न प्रक्रिया मानकों के प्रभाव की जांच करना है। प्रयोग चरणबद्ध तरीके से किए गए थे और जीटीएडब्ल्यू की तुलना में जीएमएडब्लू का उपयोग करके काम तीन भागों में विभाजित किया गया था।

गैस धातु आर्क वेल्डिंग (जीएमएडब्लू) और गैस टंगस्टन आर्क वेल्डिंग (जीटीएडब्ल्यू) के तुलनात्मक अध्ययन के लिए अंतिम तन्य शक्ति, प्रभाव शक्ति और कठोरता के लिए टैगुची विधि द्वारा किया गया है। नियंत्रण पैरामीटर जैसे। वेल्डिंग धारा, वेल्डिंग वोल्टेज, वेल्डिंग की गति, गैस प्रवाह दर और रूट अंतर वेल्डिंग इनपुट पैरामीटर के रूप में चुने गए थे। इस उद्देश्य के लिए उपयोग की जाने वाली सामग्री ग्रेड 3003-एच 2 के एल्यूमीनियम मिश्र धातु मूल सामग्री और ईआर 4043 के रूप में पूरक सामग्री (तार) आयाम (100x40x5 मिमी) के रूप में थी। हीलियम और आर्गन को ढालने वाली गैस के रूप में इस्तेमाल किया गया था। व्यास 1.6 मिमी व्यास तार ईआर 4043 का उपयोग किया गया था। एक ऑर्थोगोनल सरणी, एल 27 प्रयोगों का संचालन करने के लिए प्रयोग किया जाता था। वेल्डिंग विशेषताओं का अध्ययन करने के सिग्नल टू नोइस (एस / एन) अनुपात और भिन्नता (एनोवा) का विश्लेषण किया गया था।

सांख्यिकीय सॉफ़्टवेयर MINITAB-18 का उपयोग करके टैगुची विधि द्वारा पैरामीटर का अनुकूलन किया गया था। प्रयोगात्मक परिणामों को प्रमाणित करने के लिए पुष्टिकरण परीक्षण किए गए थे। यूटीएस के लिए वेल्डिंग वोल्टेज, प्रभाव के लिए वेल्डिंग धारा और जीएमएडब्ल्यू की कठोरता के लिए वेल्डिंग धारा सबसे महत्वपूर्ण कारक पाए गए थे। इसी प्रकार, अल्टिमेट टैन्साइल स्ट्रेन्थ (यूटीएस) के लिए वेल्डिंग वोल्टेज, जीटीएडब्ल्यू की कठोरता के लिए प्रभाव शक्ति और वेल्डिंग वर्तमान के लिए वेल्डिंग गति सबसे महत्वपूर्ण कारक पाए गए।

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