Experimental Investigation And Optimization of GTAW Parameters Used For Joining Aluminium GM41

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Abstract- *Gas Tungsten Arc Welding (GTAW) is one of the most widely used welding process in a fabrication or manufacturing industry. The welding parameters play an important in affecting the cost and quality of weld in a process. In this work, an automated GTAW technique is adopted for joining the Aluminium Alloy GM41 plate/ work piece(s) of dimension 120mm X 50mm X 3mm through their butt. Further in this work, the experimental investigation of the effects of chosen welding parameters i.e. welding current (I), welding speed (S) and shielding gas flow rate (F) on the tensile strength of the welded joint has been done. For further investigation and to find the optimal set of parameters, the taguchi (TAGUCHI) approach has been adopted. L9 Orthogonal array has been implemented to conduct the investigation with the set of above mentioned parameters. Further with the help of statistical software tool MINITAB 19 and using this optimization model, the Mean Response and Signal-to-Noise ratio (S/N ratio) values has been found and their graphical mean plot representation is given for the optimal set of process parameters. Finally the regression analysis along with the ANOVA has been carried out at considered operating levels to predict the optimal solution, and the factorial plot at optimal set of process parameter has been represented, which results in the better understanding of the influence or effect of welding parameters on the tensile strength of a weld joint.*

Keywords- GTAW, Aluminium GM41, Welding Parameters, Welding current (I), Welding speed (S), Shielding gas flow rate (F), Ultimate tensile test, TAGUCHI, L9 Orthogonal Array, MINITAB 19, Mean Response, S/N ratio, Regression analysis, ANOVA, Factorial plot, Optimal process parameters

I. INTRODUCTION

Welding is a permanent joining process used to join different materials like metals, alloys or plastics, together at their contacting surfaces by application of heat and or pressure. During welding, the work-pieces to be joined are melted at the interface and after solidification a permanent joint can be achieved. Sometimes a filler material is added to form a weld pool of molten material which after solidification gives a strong bond between the materials. Weld ability of a material depends on different factors like the metallurgical changes that occur during welding, changes in hardness in weld zone due to rapid solidification, extent of oxidation due to reaction of materials with atmospheric oxygen and tendency of crack formation in the joint position

A. Basic mechanism of GTAW (TIG) welding

TIG welding 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 (rectifier), 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 vapours [1]. 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 20,000ºC and this heat can be focused to melt and join two different part of material. The weld pool can be used to join the base metal with or without filler material. Schematic diagram of TIG welding and mechanism of TIG welding are shown in Fig. 1 & Fig. 2 respectively.

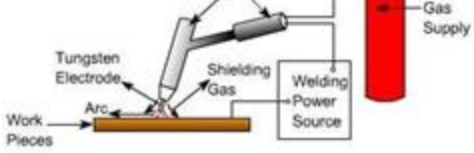
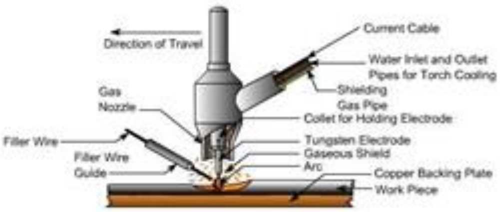


Fig 1: Schematic Diagram of TIG Welding System. [18]



Fi g. 2: Principle of TIG Welding. [18]

Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length. The current carrying capacity of each size of electrode depends on whether it is connected to negative or positive terminal of DC power source.

The power source required to maintain the TIG arc has a drooping or constant current characteristic which provides an essentially constant current output when the arc length is varied over several millimeters. Hence, the natural variations in the arc length which occur in manual welding have little effect on welding current. The capacity to limit the current to the set value is equally crucial when the electrode is short circuited to the work piece, otherwise excessively high current will flow, damaging the electrode. Open circuit voltage of power source ranges from 60 to 80 V.

II. LITERATURE REVIEW

Gas Tungsten Arc Welding is one of the most widely used processes in 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 and thereby the construction and manufacturing costs of steel structures and mechanical devices. Therefore, these parameters affecting the arc and welding should be estimated and their changing conditions during process must be known before in order to obtain optimum results; in fact a per-fect arc can be achieved when all the parameters are in conformity. These are combined in two groups as first order adjustable and second order adjustable parameters defined before welding process. 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. **Norman et. al [1]** investigated the microstructures of autogenous TIG welded Al-Mg-Cu- Mn alloy for a wide range of welding conditions. Welding was done with current in the range 100-190 A and welding speed 420-1500 mm/min. The fine microstructure was observed at the center of the weld which was form due to higher cooling rate at the weld center compared to the fusion boundary. It was observed that as the welding speed increases, the cooling rate at the center of the weld also increases, producing smaller size dendrite structure. **Urena et. al [2]** investigated the influence of the interfacial reaction between the Al alloy (2014) matrix and SiC particle reinforcement on the fracture behavior in TIG welded Al matrix composites. TIG welding was carried out on 4 mm thick AA2014/SiC/Xp sheets using current setting in the range of 37-155 A and voltage of 14-16.7 V. From experimental results it was found that, the failure occurred in the weld metal with a tensile strength lower than 50% of the parent material. Fracture of the welded joint was controlled by interface deboning through the interface reaction Layer. Probability of interfacial failure increases in the weld zone due to formation of Aluminium-carbide which lowers the matrix/reinforcement interface strength. **Lothongkum et. al [3]** investigated the TIG welding of 3 mm thick AISI 316L stainless steel plate at different welding position. Pure argon gas and mixture of argon with nitrogen (1-4 vol. %) were used as shielding gas with a flow rate of 8 l/min during top and back sides of welds. Effects of welding speeds and nitrogen contents in argon shielding gas on pulse currents were study to achieve an acceptable weld bead profile with complete penetration. It was found that increasing nitrogen contents in argon gas decreases the pulse currents and increasing welding speed will increase the pulse current. **Ahmet durgutlu et.al [4]** investigated the effect of hydrogen in argon as shielding gas for TIG welding of 316L austenitic stainless steel. They used current 115 A, welding speed 100 mm/min and gas flow rate 10 l/min for welding of 4 mm thick plate. For all shielding media, hardness of weld metal is lower than that of HAZ and base metal. Penetration depth, weld bead width and mean grain size in the weld metal increases with increasing hydrogen content. The highest tensile strength was obtained for the sample welded under shielding gas of 1.5%H_2–Ar. **Sivaprasad et.al [5]** performed TIG welding of 2.5 mm thick Nickel based 718 alloy using welding current in the range of 44-115 A, voltage 13-15 V and welding speed 67 mm/min. the influence of magnetic arc oscillation on the fatigue behaviour of the TIG weldments in two different post-weld heat treatment conditions were studied. **Wang Rui et. al [6]** investigated the effect of process parameters i.e. plate thickness, welding heat input on distortion of Al alloy 5A12 during TIG welding. For welding they used current (60-100) A, welding speed (800-1400) mm/min and thickness of w/p (2.5-6) mm. The results show that the plate thickness and welding heat input have great effect on the dynamic process and residual distortion of out-of-plane. **Wang Xi-he et. al [7]** performed TIG welding of SiCp /6061 Al composites without and with Al-Si filler using He-Ar mixed as shielding gas. For the welding authors uses gas flow rate 6.9 l/min, welding speed 1800 mm/min, current-60 A. The results show that addition of 50 vol.% helium in shielding gas improves the arc stability, and quality of welding improves when the Al–Si filler is added. The microstructure of the welded joint shows non-uniformity with SiC particles distributing in the weld centre. **Ahmed Khalid Hussain et. al [8]** investigated the effect of welding speed on tensile strength of the welded joint by TIG welding process of AA6351 Aluminium alloy of 4 mm thickness. The strength of the welded joint was tested by a universal tensile testing machine. Welding was done on specimens of single v butt joint with welding speed of 1800 - 7200 mm/min. From the experimental results it was revealed that strength of the weld zone is less than base metal and tensile strength increases with reduction of welding speed. **Wang et. al [9]** studied the influences of process parameters of TIG arc welding on the microstructure, tensile property and fracture of welded joints of Ni-base super-alloy. For welding plate width of 1.2-1.5 mm, welding current in the range of 55-90 A, with variable welding speed in the range 2100-2900 mm/min was used. From experimental result it was observed that, the heat input increases with increase of welding current and decrease of welding speed. **Dongjie Li et.al [10]** proposed a double-shielded TIG method to improve weld penetration and compared with the traditional TIG welding method under different welding parameters i.e. welding speed, arc length and current. They used gas flow rate 10 l/min, welding speed (90-300) mm/min, current (100-200) A and thickness of w/p 10 mm. The results show that the changes in the welding parameters directly impact the oxygen concentration in the weld pool and the temperature distribution on the pool surface. **Raveendra et. al [11]** done experiment to see the effect of pulsed current on the characteristics of weldments by GTAW. To weld 3 mm thick 304 stainless steel welding current 80-83 A and arc travel speed 700-1230 mm/min. More hardness found in the HAZ zone of all the weldments may be due to grain refinement. Higher tensile strength found in the non-pulsed current weldments. It was observed that UTS and YS value of non-pulsed current were more than the parent metal and pulsed current weldments. **A.Sivasankaran [12]**, in his works, he worked on the improvement of ultimate tensile strength of Aluminium 8011 weld specimen made of tungsten inert gas welding. He planned the experiments which was based on Taguchi method using L16 orthogonal array, test has been conducted at different levels of welding parameters like pulse current, peak current, pulse frequency and pulse duty cycle. Signal-to-noise ratio (S/N ratio), analysis of variance (ANOVA) and graphical mean effect plots for S/N ratio are employed to investigate the optimal level of process parameters and influence of welding parameters on weld strength. Finally the confirmatory test has been carried out at optimal operating level to compare the predicated value of ultimate tensile strength with the experimental value. **Surjeet Singh et. al [13]** in his study, he investigated the effects of various welding parameters in Tungsten Inert Gas welding (TIG) of AA 6082 on tensile strength. The process parameters considered are current, filler material and shielding gas flow rate. Current is varied from 80 Amp to 120 Amp with increment of 20 Amp. A double side V butt weld joint is made with two different filler material AA 4043 and AA 4047. Argon is used as shielding gas with varied flow rate from 8 lpm to 12 lpm. The results show an average increase of 4.5% in tensile strength when current increases from 80 Amp to 120 Amp. Better results are observed with AA 4043 as compared to AA 4047. **Shanavas S and Edwin Raja Dhas J [14],** they worked on the influence of Tungsten Inert Gas (TIG) welding parameters on the quality of weld on AA 5052 H32 aluminium alloy plates were analyzed and the mechanical characterization of the joint so produced was compared with Friction stir (FS) welded joint. The selected input variable parameters are welding current and inert gas flow rate. Other parameters such as welding speed and arc voltage were kept constant throughout the study, based on the response from several trial runs conducted. The quality of the weld is measured in terms of ultimate tensile strength. A double side V-butt joints were fabricated by double pass on one side to ensure maximum strength of TIG welded joints. Macro and microstructural examination were conducted for both welding process. **Jayashree P K et. al [15]**, has focused to determine the favourable welding conditions for Tungsten Inert Gas (TIG) welding of 6061Al alloy based on Taguchi’s design of experiments. Hence the concentration is on experimentally identifying the effect of the different welding parameters on hardness and weld bead geometry at weld zone under different welding condition obtained by L9 Orthogonal array using Taguchi’s design of experiments. **Mr. S. Sethuraman et. al [16],** his work aims to optimize process parameters for gas tungsten arc welding (GTAW) of Aluminium alloy AA6063 using Argon as inert gas. The Taguchi method is used to obtain the Optimization parameters of Tungsten Inert Gas welding on 6063 Aluminum Alloy. Taguchi method is by ANOVA and Regression analysis is used to determine the effect of the individual parameters and a appropriate combination was found out. We have used Non-destructive testing to find out weld defects for different levels of input parameters. The optimal parameters of TIG welding process is resolute and the experimental results demonstrate the proposed approach**. O.S. Ogbonna et. al [17],** gave a well-documented review of the various investigations by researchers on MIG and TIG welding of alloys used in the automobile in this work.

III. OBJECTIVE & METHODOLOGY

A. OBJECTIVE

The Objective of this work is as follows:

1. As per the literature survey, we came to a conclusion that the welding of Aluminium is a big challenge with conventional arc welding process.
2. As far as TIG welding is concerned, its strength plays an important role in the success of joint for longer life span. So, for which an experimental analysis is to be done by considering the best possible process parameters for it.
3. Optimum Welding process parameters are needed to be proposed by applying a suitable optimization methodology, which results in the manufacture of goods/particulars efficiently & effectively with less cost & high strength.
4. An optimal study of the results is to be done, so that the best possible outcome can be proposed for the future work.

B. METHODOLOGY

1. Introduction to Design of Experiments (DOE)

Within the theory of optimization, an experiment is a series of tests in which the input variables are changed according to a given rule in order to identify the reasons for the changes in the output response. According to Montgomery "Experiments are performed in almost any field of enquiry and are used to study the performance of processes and systems. The process is a combination of machines, methods, people and other resources that transforms some input into an output that has one or more observable responses. Some of the process variables are controllable, whereas other variables are uncontrollable, although they may be controllable for the purpose of a test. The objectives of the experiment include: determining which variables are most influential on the response, determining where to set the influential controllable variables so that the response is almost always near the desired optimal value, so that the variability in the response is small, so that the effect of uncontrollable variables are minimized."

Thus, the purpose of experiments is essentially optimization and RDA. DOE, or experimental design, is the name given to the techniques used for guiding the choice of the experiments to be performed in an efficient way.

Usually, data subject to experimental error (noise) are involved, and the results can be significantly affected by noise. Thus, it is better to analyse the data with appropriate statistical methods. The basic principles of statistical methods in experimental design are replication, randomization, and blocking. Replication is the repetition of the experiment in order to obtain a more precise result (sample mean value) and to estimate the experimental error (sample standard deviation). Randomization refers to the random order in which the runs of the experiment are to be performed. In this way, the conditions in one run neither depend on the conditions of the previous run nor predict the conditions in the subsequent runs. Blocking aims at isolating a known systematic bias effect and prevent it from obscuring the main effects. This is achieved by arranging the experiments in groups that are similar to one another. In this way, the sources of variability are reduced and the precision is improved.

Attention to the statistical issue is generally unnecessary when using numerical simulations in place of experiments, unless it is intended as a way of assessing the influence the noise factors will have in operation, as it is done in MORDO analysis.

Due to the close link between statistics and DOE, it is quite common to find in literature terms like statistical experimental design, or statistical DOE. However, since the aim of this chapter is to present some DOE techniques as a mean for collecting data to be used in RSM, we will not enter too deeply in the statistics which lies underneath the topic, since this would require a huge amount of work to be discussed.

Statistical experimental design, together with the basic ideas underlying DOE, was born in the 1920s from the work of Sir Ronald Aylmer Fisher. Fisher was the statistician who created the foundations for modern statistical science. The second era for statistical experimental design began in 1951 with the work of Box and Wilson who applied the idea to industrial experiments and developed the RSM. The work of Genichi Taguchi in the 1980s, despite having been very controversial, had a significant impact in making statistical experimental design popular and stressed the importance it can have in terms of quality improvement.

2. Terminology in DOE

In order to perform a DOE it is necessary to define the problem and choose the variables, which are called factors or parameters by the experimental designer. A design space, or region of interest, must be defined, that is, a range of variability must be set for each variable. The number of values the variables can assume in DOE is restricted and generally small. Therefore, we can deal either with qualitative discrete variables, or quantitative discrete variables. Quantitative continuous variables are discretized within their range. At first there is no knowledge on the solution space, and it may happen that the region of interest excludes the optimum design. If this is compatible with design requirements, the region of interest can be adjusted later on, as soon as the wrongness of the choice is perceived. The DOE technique and the number of levels are to be selected according to the number of experiments which can be afforded. By the term levels we mean the number of different values a variable can assume according to its discretization. The number of levels usually is the same for all variables, however some DOE techniques allow the differentiation of the number of levels for each variable. In experimental design, the objective function and the set of the experiments to be performed are called response variable and sample space respectively.

3. DOE Techniques

In this section some DOE techniques are presented and discussed. The list of the techniques considered is far from being complete since the aim of the section is just to introduce the reader into the topic showing the main techniques which are used in practice.

1. Randomized Complete Block Design (RCBD)
2. Latin Square
3. Full Factorial
4. Fractional Factorial
5. Central Composite
6. Box-Behnken
7. Plackett-Burman
8. Taguchi
9. Random
10. Halton, Faure and Sobol sequences
11. Latin Hypercube
12. Optimal Design

From the study of above mentioned DOE techniques, I came to a conclusion of using Taguchi techniques as an optimizing technique for justifying this experiment for precisely and accurately.

1) Philosophy of the Taguchi method

1. Quality of product depends on the process by which it has been produced. One can improves the quality by optimising the parameter affects the process.
2. Best quality can be achieved by decreasing uncontrollable environmental factor which leads to deviation from a target.
3. The cost of value ought to be measured as an element of deviation from the standard and the losses should be measured system wide.

2) Strategy and Procedures of Taguchi parameters outline

Step-1: Selection of the quality attributes

There are three different quality characteristics in the methodology of Taguchi, such as **smaller-the-better, larger the- better, and nominal-the-best**. So, as per our need we consider, Larger the better. And the goal of this research is to find out the effect of parameters and achieve maximum tensile strength of the weld joint.

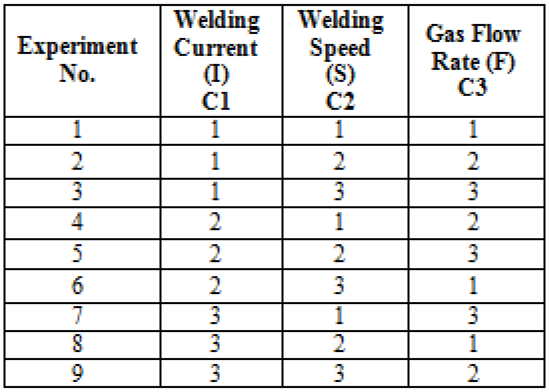
Step–2: Choice of noise factors and control factors or process parameters

In this, the considered controllable factors or process parameters are welding current (I), welding speed (S), and gas flow rate (F) which were selected because these are the factors that affect the breaking load or tensile strength of the weld joint. Since these factors are controllable so they are considered as the controllable factors in the study. Uncontrollable factor may be the ambiance temperature, Humidity and Environment.

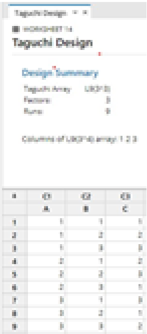
Step–3: Choice of Orthogonal Array

Standard Orthogonal Arrays (OA) in the Taguchi parameter design are of 9 basic types. Selection of arrays depends on the degree of freedom of selected parameter. An L9 Orthogonal Array is selected with the help of the statistical software tool MINITAB 19, for the selected set of process parameters in this work. The layout of this L9 OA is as mentioned in Table 1 below:

Table 1 Selected L9 Orthogonal Array



Experiment No.	Welding Current (I) C1	Welding Speed (S) C2	Gas Flow Rate (F) C3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2



Taguchi Design

Design Summary

Taguchi Array L9(3^3)

Factors: 3

Runs: 9

Columns of L9(3^4) array: 1 2 3

#	C1 A	C2 B	C3 C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

MINITAB Window

Step–4: Leading the experiments

Table 1 illustrates the experimental settings in the study for maximum tensile strength. The parameters used in this experiment are welding current (I) with three level, welding speed (S) with three level and the gas flow rate (F) with three level. All nine analysis have been conducted on statistical tool MINITAB, results of which have been observed.

Step–5: Anticipating the Optimum Performance

Utilizing the previously mentioned data, one could anticipate the optimum combination of welding current, welding speed and inert gas flow rate for maximum tensile strength during rigorous testing. With this prediction, one could conclude that which combination will creates the better result. A confirmation of the experimental design was necessary in order to validate the optimum variables combination.

Step-6: Building the design by utilizing a confirmation experiment

The confirmation experiment help to verify our prediction particularly when small fractional factorial experiments are utilized. Confirmation experiment in this study is to fulfill the purpose of validating the optimum process parameters for high strength of weld joint.

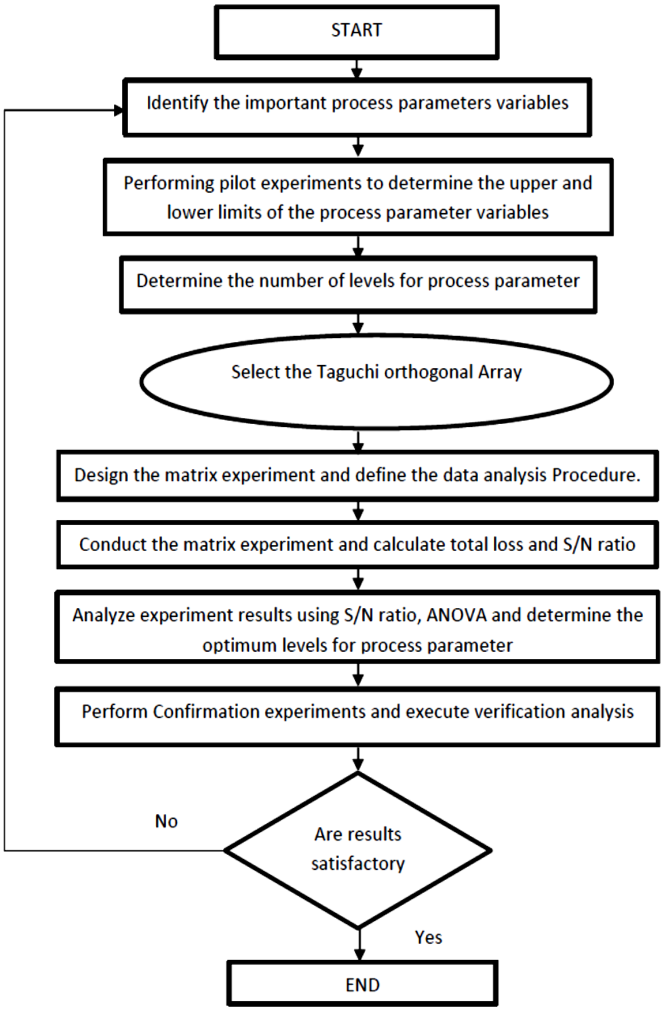


Fig.3: Flow Chart of the Procedure of Taguchi Method

IV. EXPERIMENTAL SETUP

1. Adopted Automated GTAW System

For proper welding and control on welding parameters mainly on welding speed an automated welding setup has been adopted. The automated welding setup with its main components is shown in Fig. 4 below:

Fig. 4: Experimental set-up for TIG welding

The welding setup consists mainly of following parts:

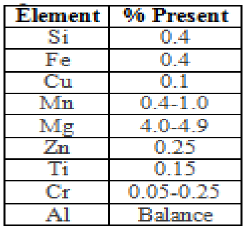
1. Speed control unit (movable tractor)
2. Rail track
3. TIG Welding torch
4. TIG welding machine
5. Gas cylinder
6. Work holding table
7. Welding Torch

2. Material Selection

The first step towards the experiment is the finalization of the material of the workpiece to be used is as **Aluminium Alloy GM41. Properties of Aluminium Alloy GM41 [19]**

a) Chemical Composition of Aluminium Alloy GM41

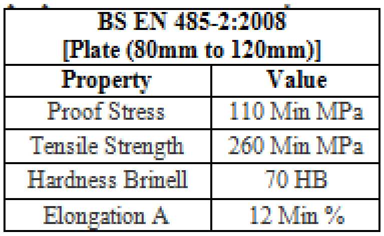
Table 2 Chemical composition for aluminium alloy GM41



Element	% Present
Si	0.4
Fe	0.4
Cu	0.1
Mn	0.4-1.0
Mg	4.0-4.9
Zn	0.25
Ti	0.15
Cr	0.05-0.25
Al	Balance

b) Mechanical Properties of Aluminium Alloy GM41

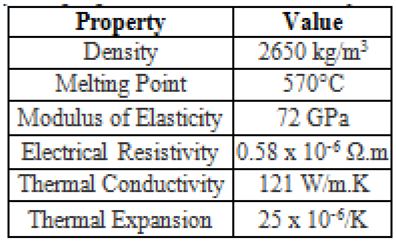
Table 3 Mechanical properties for aluminium alloy GM41 Soft O/H111



BS EN 485-2:2008 [Plate (80mm to 120mm)]	
Property	**Value**
Proof Stress	110 Min MPa
Tensile Strength	260 Min MPa
Hardness Brinell	70 HB
Elongation A	12 Min %

c) Physical Properties of Aluminium Alloy GM41

Table 4 Physical properties for aluminium alloy GM41



Property	Value
Density	2650 kg/m^3
Melting Point	570°C
Modulus of Elasticity	72 GPa
Electrical Resistivity	0.58×10^{-6} Ω.m
Thermal Conductivity	121 W/m.K
Thermal Expansion	25×10^{-6}/K

3. Applications of Aluminium Alloy GM41

Aluminium GM41 is used in:

1. Shipbuilding
2. Rail cars
3. Vehicle bodies
4. Tip truck bodies
5. Mine skips and cages
6. Pressure vessels

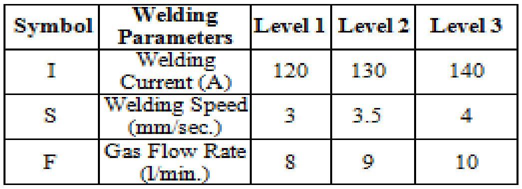
4. Experimental procedure

Commercial Aluminium plate of thickness 3 mm was selected as work piece material for the present experiment. Al plate was cut with dimension of 120 mm x 50 mm with the help of band-saw and grinding done at the edge to smooth the surface to be joined. After that surfaces are polished with emery paper to remove any kind of external material.

After sample preparation, Aluminium plates are fixed in the working table with flexible clamp side by side and welding done so that a butt join can be formed. TIG welding with Alternate Current (AC) was used in experiments as it concentrates the heat in the welding area. Zirconated tungsten electrodes of diameter 3.4 mm was taken as electrode for this experiment. The end of the electrode was prepared by reducing the tip diameter to 2/3 of the original diameter by grinding and then striking an arc on a scrap material piece. This creates a ball on the end of the electrode. Generally an electrode that is too small for the welding current will form an excessively large ball, whereas too large an electrode will not form a satisfactory ball at all.

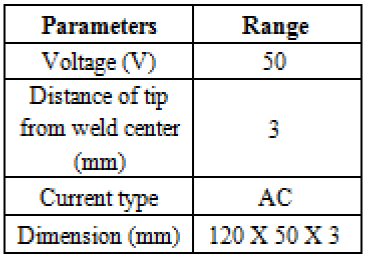
For the first phase of experiment welding parameters selected are shown in table 5. Before performing the actual experiment a number of trial experiments have been performed to get the appropriate parameter range where welding could be possible and no observable defects like undercutting and porosity occurred. The other parameters and workpiece dimension is shown in table 6 and arrangement plan of process parameter for the experiment is given in table 7 below:

Table 5 Selected Welding process parameters for the experiment.



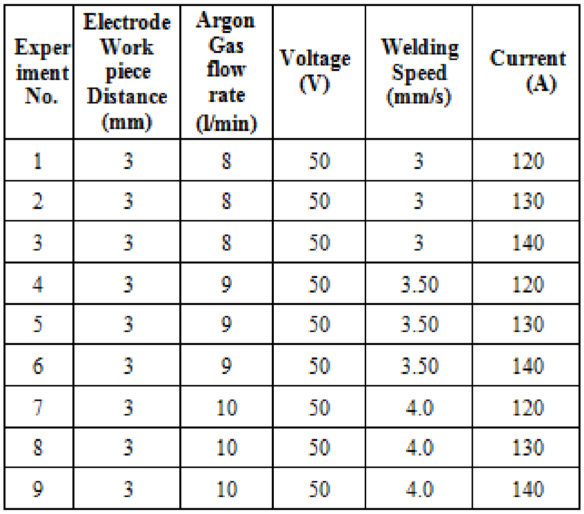
Symbol	Welding Parameters	Level 1	Level 2	Level 3
I	Welding Current (A)	120	130	140
S	Welding Speed (mm/sec.)	3	3.5	4
F	Gas Flow Rate (l/min.)	8	9	10

Table 6 Other parameters and dimension of the workpiece for the experiment.



Parameters	Range
Voltage (V)	50
Distance of tip from weld center (mm)	3
Current type	AC
Dimension (mm)	120 X 50 X 3

Table 7 Arrangement Plan of Process Parameters for the experiment



Experiment No.	Electrode Work piece Distance (mm)	Argon Gas flow rate (l/min)	Voltage (V)	Welding Speed (mm/s)	Current (A)
1	3	8	50	3	120
2	3	8	50	3	130
3	3	8	50	3	140
4	3	9	50	3.50	120
5	3	9	50	3.50	130
6	3	9	50	3.50	140
7	3	10	50	4.0	120
8	3	10	50	4.0	130
9	3	10	50	4.0	140

Fig. 5: Welded specimen 1-3 performed with the welding speed of 3 mm/sec. and welding current 120, 130 and 140 A and gas flow rate of 8 l/min., Welded specimen 4-6 performed with welding speed of 3.5 mm/sec. and welding current 120, 130 and 140 A and gas flow rate of 9 l/min. and Welded specimen 7-9 performed with welding speed 4 mm/sec. and welding current 120, 130 and 140 with gas flow rate of 10 l/min. respectively.

After performing the welding, welded specimens were cut with dimension of 100 mm x 25 mm for tensile test, which were further cut in to I shape. Tensile test was performed with universal tensile testing machine (Instron-600) with maximum load capacity of 600 KN.

Fig. 6: Tensile test specimen

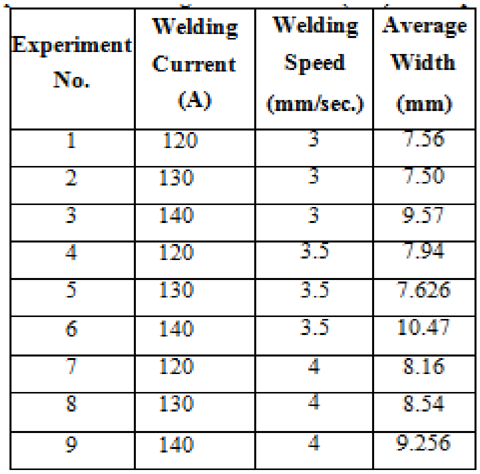
Fig. 7: Performing test on UTM

V. RESULTS & DISCUSSION

1. Welding Width

Welding width for all the samples were measured and calculated average welding width as shown in table 8. Average value of welding width then plotted against the applied welding current for different welding speed as shown in Fig. 8. From the plot it is clearly seen that welding width increases almost linearly with increase of welding current.

Table 8 Experimental Readings of Weld width (mm) of samples.



Experiment No.	Welding Current (A)	Welding Speed (mm/sec.)	Average Width (mm)
1	120	3	7.56
2	130	3	7.50
3	140	3	9.57
4	120	3.5	7.94
5	130	3.5	7.626
6	140	3.5	10.47
7	120	4	8.16
8	130	4	8.54
9	140	4	9.256

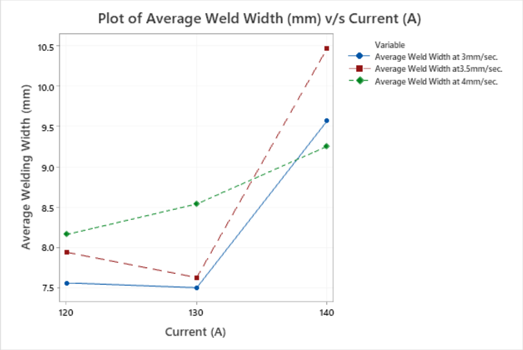


Fig. 8: Graphical plot of average welding width of the samples at variable welding current.

2. Surface Roughness

Surface roughness of the weld zone for all the samples were measured and average surface roughness value was calculated from three reading which is tabulated in Table 9. Roughness value found in the range of 1.1 to 3.5 micron, is quite low for a welded specimen. Therefore it can be say that using an automated system good quality of welding is possible which may not require any further finishing operation. These roughness values are again plotted against applied current in Fig. 9. But no specific effect of applied current on the surface roughness value has been observed.

Table 9 Experimental Readings of Surface roughness value of samples

Experiment No.	Welding Current (A)	Welding Speed (mm/ sec.)	Average Roughness (µm)
1	120	3	1.383
2	130	3	1.150
3	140	3	2.222
4	120	3.5	1.492
5	130	3.5	1.160
6	140	3.5	2.274
7	120	4	3.574
8	130	4	3.57
9	140	4	1.252

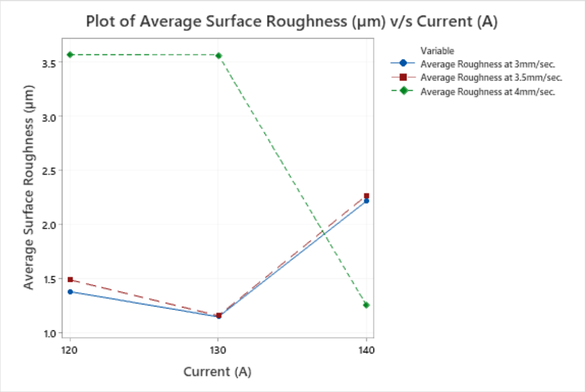


Fig. 9: Graphical plot of average surface roughness of the samples at different welding current.

3. Tensile test

Tensile test of the welded joint was performed with universal tensile testing machine (Instron) with maximum load capacity 600 KN. Load give with a speed of 1 mm/min.
Table 10 shows the tensile strength value for all the welded joints produced at variable welding speed and current setting. These values are much lower than the tensile strength of the Aluminium alloy GM41. Actual Tensile strength of the Aluminium found 260 MPa from the material properties of Aluminium GM41.

On comparing the received tensile strength from the test, the fig. 10 it is clearly seen that for all current setting condition tensile strength values of the welded joint performed with welding speed 3.5 mm/s are more satisfying than the tensile stress values of the welded joint performed with other welding speeds.

Table 10 Maximum applied load (N) with corresponding tensile strength (MPa) of samples.

Sample No.	Welding Current (A)	Welding Speed (mm/sec.)	Gas Flow Rate (l/min.)	Load Applied (N)	Tensile strength (MPa)
1	120	3	8	1415.63	20.59
2	130	3	9	1716.36	23.49
3	140	3	10	1984.58	26.20
4	120	3.5	8	2888.43	37.64
5	130	3.5	9	2322.59	31.65
6	140	3.5	10	2957.51	39.15
7	120	4	8	3319.39	45.82
8	130	4	9	2278.42	30.82
9	140	4	10	1389.81	19.87

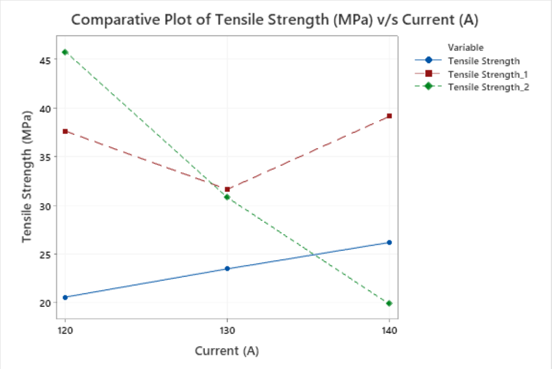


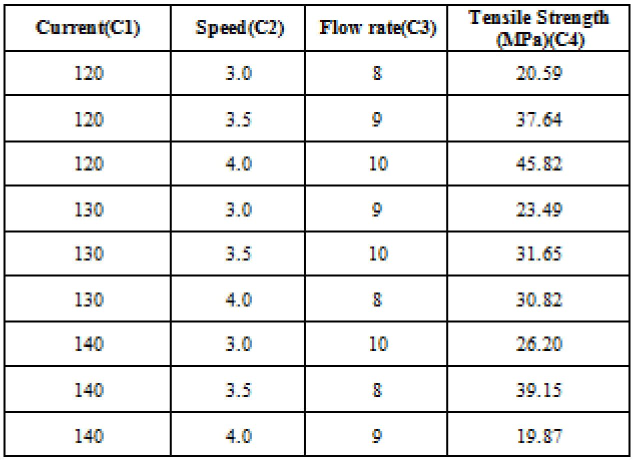
Fig. 10: Comparative plot Tensile strength of the welded joint against applied current at variable welding speed.

4. Application of D. O. E

Taguchi's Approach

The Taguchi method is an efficient optimization technique to work on a given set parameters and predict the optimal solution to the problem stated. So, for getting the required solution in this work, first we have to select the three process parameters like welding current (I), welding speed (S) and Gas flow rate (F) against the tensile strength of the weld joint and arrange them in the desired Orthogonal array. We have considered L_9 Orthogonal array due to three process parameters. Below tabulated (Table 11) is the process parameters in L_9 array, after which, with the help of statistical analysis software MINITAB 19, the analysis has been carried out for finding optimal set of parameters. The Response Mean and Signal-to-noise (S/N) ratio table and supporting graphical plot are discussed below:

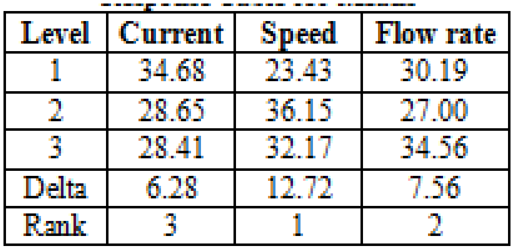
Table 11 Considered Process Parameters arranged in L_9 orthogonal array for solving.



Current(C1)	Speed(C2)	Flow rate(C3)	Tensile Strength (MPa)(C4)
120	3.0	8	20.59
120	3.5	9	37.64
120	4.0	10	45.82
130	3.0	9	23.49
130	3.5	10	31.65
130	4.0	8	30.82
140	3.0	10	26.20
140	3.5	8	39.15
140	4.0	9	19.87

a) Mean of Response

Table 12 Response Table for Means



Level	Current	Speed	Flow rate
1	34.68	23.43	30.19
2	28.65	36.15	27.00
3	28.41	32.17	34.56
Delta	6.28	12.72	7.56
Rank	3	1	2

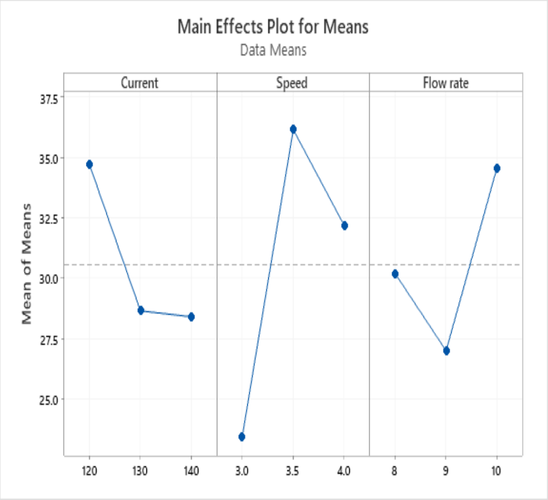
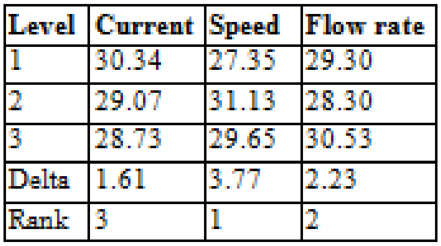


Fig. 11: Main effects plot for Means of Means

b) Signal-to-Noise Ratios for response.

Table 13 Response Table for Signal-to-Noise Ratios Larger is better



Level	Current	Speed	Flow rate
1	30.34	27.35	29.30
2	29.07	31.13	28.30
3	28.73	29.65	30.53
Delta	1.61	3.77	2.23
Rank	3	1	2

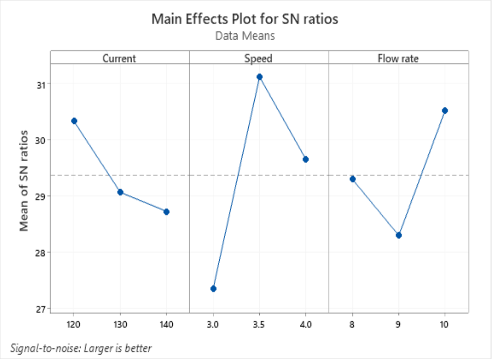


fig. 12: main effects plot for mean of s/n ratios

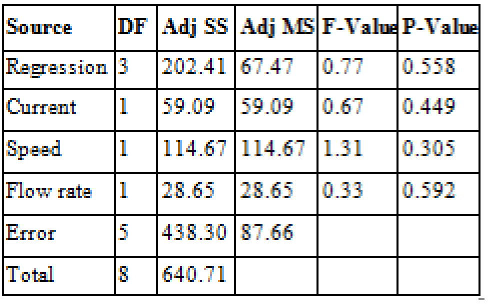
c). Regression Analysis

Regression Equation for the optimal set of parameters

Tensile Strength (MPa) = 21.1 - 0.314 Current + 8.74 Speed + 2.19 Flow rate

d). Analysis of Variance (ANOVA)

Table 14 Table of results through ANOVA



Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	202.41	67.47	0.77	0.558
Current	1	59.09	59.09	0.67	0.449
Speed	1	114.67	114.67	1.31	0.305
Flow rate	1	28.65	28.65	0.33	0.592
Error	5	438.30	87.66		
Total	8	640.71			

e). Factorial Plots for Tensile Strength (MPa)

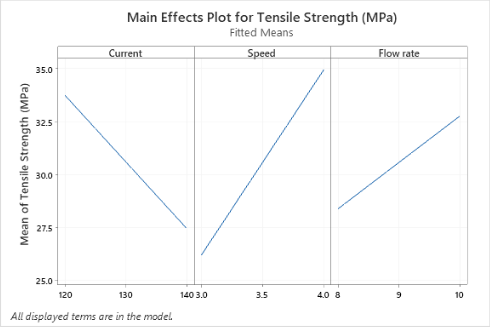


Fig. 13: Mean effects plot for tensile strength against different process factors.

On analysing all the mean effects plot mentioned above, a pair of optimal set of process parameters for getting high tensile strength has been predicted and verified through regression analysis. The predicted set of parameters are Welding Current = 130 A, Welding speed 3.5 mm/ sec. and the shielding gas flow rate = 9 l/min for better welding strength while using TIG for aluminium GM41.

VI. CONCLUSION

The experimental study conducted on the influence of process parameters as welding current, welding speed and gas flow rate and its optimization while TIG welding of GM41 aluminium alloy using Taguchi's L9 orthogonal array draws the following conclusions:

1. With the automated welding system uniform welding of Aluminium plate can be possible.
2. Welding strength or tensile strength of the weld joint depends on the welding parameters like welding current, welding speed and shielding gas flow rate.
3. The outcome of welding current is having uppermost physical and also statistical influence on hardness and tensile strength of the weld. So we can say, higher the current, more will be the strength.
4. The influence of welding speed noticed to have minimal physical and statistical influence on hardness, width and tensile strength of the weld. So we can say, lower the welding speed, more will be the strength.
5. The influence of gas flow rate is having least physical along with statistical influence on hardness and tensile strength of the weld.

The main effects, SN, Contour, Surface plot shows that selection of welding parameters such as 130 A current, speed of 3.5mm/sec. and gas flow rate of 9L/min, results in the best combination to get the maximum tensile strength. Maximum weld width is obtained with140A current, speed of 3.5mm/sec., and surface roughness is obtained with a welding current of 140A, welding speed of 4mm/sec. during welding of GM41 aluminum alloy.

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