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Optimization of Welding Parameters to Enhance Mechanical Properties of Az31b Magnesium Alloy Gta Welds

N. HarshaVardhana Prakash [1a*], B. Lakshmi Saranya[1b], D. Balaji Naik[2], G. Rambabu[1] , K. Srinivasa Rao[3]
[1a], [1]Department of Mechanical Engineering Andhra University, Visakhapatnam.*
[2]Department of Mechanical Engineering, Universal College of Engineering and Technology.
[1b,3]Department of Metallurgical Engineering, Andhra University, Visakhapatnam-530003.

Abstract:
In the current technological advancement, a light weight metal i.e. AZ31B magnesium – alloy is widely considered in various strategic sectors as this alloy has better welding quality and superior corrosion resistance. Magnesium alloy is one of the superior alloys for its better weight to strength ratio. To obtain optimum weld quality, selection of appropriate welding parameters plays vital role in enhancing weld quality and better mechanical properties. In present study, welding of AZ31B – magnesium –alloy is carried out by using GTAW (Gas tungsten arc welding). Effect of process parameters on weld joint for ultimate tensile strength, hardness characteristics are explained by statistical method. GATW is the fusion method which joins the metal in an inert atmosphere to produce quality weld joints with better properties. This welding technology is predominant in the manufacturing sector. The purpose of this study is to optimize welding parameters for better weld penetration and weld quality. Experimentation and analysis with appropriate range of welding process parameters were carried through analysis of variance (ANOVA). One of the influencing weld parameter is welding current. Developing suitable mathematical model is the prime objective of to obtain optimal process parameters to attain better mechanical properties. The derived mathematical model was harmonized with signal to noise ratio and desirability approach to achieve better ultimate tensile strength and hardness upon AZ31B alloy by GTAW.
Keywords: AZ31B Magnesium alloy, Gas tungsten arc welding, ANOVA, Taguchi design, Desirability approach

Introduction:
Lightweight metals are used in many applications for strategic sectors for better strength to weight ratio. Among the light weight metals, Magnesium alloys is the best suitable alloy for aerospace as well as structural applications [1-3]. It has better capabilities of good damping capacity along with high specific strength, castability, weldability and machinability [4].

Gas tungsten arc welding (GTAW) is generally opted for welding of magnesium alloys. It is having edge over other welding process for ease to operate, high efficiency, availability and easy automation [5].

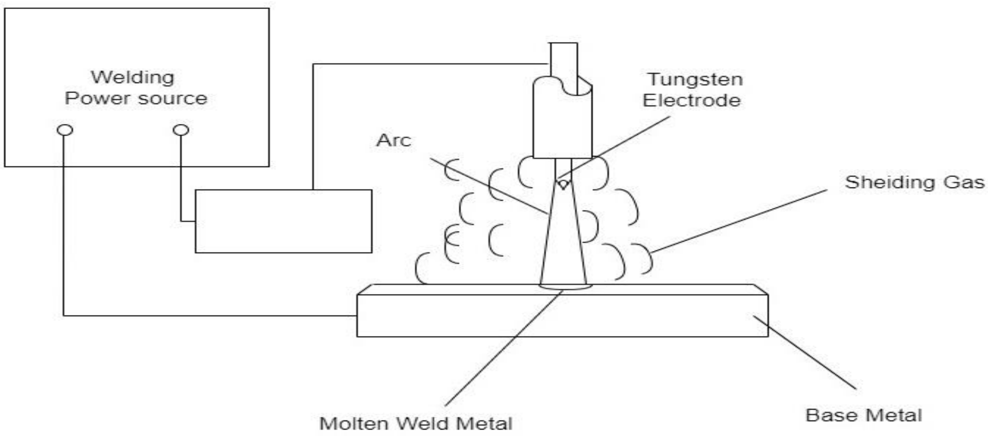

Fig 1. Schematic Diagram of GTAW Welding Process

Usually, GTAW is the multiple objective and factor in welding technology. GTAW is used for joining various other common metals eg, magnesium, steel and aluminum of thickness ranging from 1-6mm thick in 6G positions [6]. The weld joint obtained through this welding technology on magnesium alloys reasonably produce trivial penetration. Increase in heat input for the weld joint would result in grain coarsening, porosity and creates heat affected zone (HAZ). Consequently it effects on mechanical properties [7].

The weldability of Magnesium alloys primarily includes the influence of properties like thermal expansion coefficient, melting point and thermal conductivity, solidification temperature range, as well as elongation percentage [8]. Low yield strength of magnesium alloy results in reduced magnitude of residual stresses [9, 10]. The high expansion coefficient and high thermal conductivity leads to further expansion and contraction, which results in high residual stresses, increased distribution tendency and increased solidification cracking tendency. To overcome the issues related to high thermal conductivity, higher expansion coefficient and greater affinity to atmospheric gases, it becomes important to use special welding processes rather than the conventional process. Weld quality obtained is purely dependent on welding process parameters [11]. The manufacturer face a tough challenge in optimizing the welding process parameters to produce quality weld [12]. Selection, control and optimization of input process welding parameters is an area of obtaining a good quality weld. To obtain quality weld for above factors, suitable algorithms, generation of mathematical model, computational networks are widely taken into consideration to derive optimum welding parameters. Many fusion welding processes are used to join magnesium alloys such as GTAW however; it is extensively used in fabrication and development of magnesium alloy.

Sapkal and Teslang [13] used mathematical modeling and design of experiment (DOE) Taguchi method to optimize process welding parameters like current, voltage and welding speed. These control factors will impact in attaining maximum depth of penetration on mild steel.
Zhuang and Tong [14] adopted the revised Taguchi a method of evaluating the effectiveness of tungsten inert gas welding (TIG) process parameters on weld pool geometry. The combination of parameters like flow rate, gap of arc, welding speed, current and voltage are used to determine optimized conditions i.e. depth of penetration, UTS , Yield strength. However, the mechanical properties of weld joint are being affected by hardened sediments.

Malarvizhi and Balasubramanian [15] investigated the effects on tensile, fatigue and corrosion behavior of GTAW. It is therefore possible to monitor the input process parameters in welding, which gives leverage over mechanical properties, weld joint capacity and the external environment, improper selection of process parameters causes welding fusion zone (FZ) defects that can greatly impact the mechanical as well as corrosion properties of the weld. Several studies addressing the affect of process parameters on the mechanical behaviour of material after welding have been reported. Weld joints fabricated using the welding process is based on several input parameters and the combined effect of these significant parameters' can only be achieved through modeling. Therefore, in the present work statistical significance and optimization of process input weld parameters on both tensile and Hardness properties of AZ31B Mg alloy were carried out.

OBJECTIVE:

A thorough literature review was done from available data/literature in research articles from various journals and major objectives for the present research work were derived.

1. To find the optimum GTA welding parameters for the welding of AZ31B Magnesium alloys.
2. To obtain optimum weld penetration, quality and selection of appropriate welding parameters in enhancing weld quality and exhibition of better mechanical properties.
3. To optimize welding input parameters like current, voltage and welding speed in evaluating the influence of above-parameters on mechanical

properties such as hardness and tensile strength by deriving suitable mathematical modelling.

DESIGN OF EXPERIMENTS: Taguchi method

Optimal numbers of weld runs are carried by using Taguchi method. The weld parameters which are chosen to carry out experiment determines number of trials. The more the weld parameters the more are the weld trials which are to be carried out on the alloy. Subsequently to carry out experimentation, it consumes time to produce desired weld joint. To optimize the process of welding, substantial statistical method i.e Taguchi was selected to optimize the levels of welding parameters to carry out the experiment.

An orthogonal array is deduced from Taguchi method, which is applied to analyze the total parametric space to optimize number of experiments carried out on the weld. The total degrees of freedom need to be computed for selection of suitable orthogonal array to carry out experimental structure. Accordingly L27 orthogonal was chosen with three levels of welding parameters (voltage, current, and welding speed) in three columns and twenty seven rows as structured in below Table 1.

Table 1: L27 orthogonal array

Experiment No	Voltage	Current	Welding Speed
1	13	120	60
2	13	120	60
3	13	120	60
4	13	150	80
5	13	150	80
6	13	150	80
7	13	180	100
8	13	180	100
9	13	180	100
10	15	120	80
11	15	120	80
12	15	120	80
13	15	150	100
14	15	150	100
15	15	150	100
16	15	180	60
17	15	180	60
18	15	180	60
19	17	120	100
20	17	120	100
21	17	120	100
22	17	150	60
23	17	150	60
24	17	150	60
25	17	180	80
26	17	180	80
27	17	180	80

Experimentation:

In the present experimentation to study and analyze the process parameters 6 mm thick plates of AZ31B Magnesium alloy was used. The chemical composition of magnesium alloy was tabulated in Table 2.

Table 2: AZ31B alloy chemical composition

Element	Al	Zn	Mn	Cu	Si	Ni	Fe	Mg
% Weight Composition	2.904	0.996	0.324	0.049	0.032	0.002	0.004	95.689

to carry out experimentation on az31b mg alloy plates measuring 230mm x 300mm x 6mm were used to conduct gta welding. accordingly templates were prepared from the welded plates for further examination and analysis in the transverse direction. the microstructures of samples for various weld zones were analyzed using m/s leica make optical microscope. tensile samples were made in accordance with the astm b557m-15 specifications using a wire electro-discharge machine. a universal testing machine was used to measure each specimen's ultimate tensile strength. vickers micro-hardness tests (astm e384) were conducted across the weld using a 100-gram load, and the tensile tests were performed using m/s instron-8801 tensile testing machine.

Results And Discussions

selection of control parameters

table 3 depicts chosen and selected control parameters for investigation and analysis of the template for better mechanical properties. these welding parameters are configured to carry out investigation of optimal weld parameters. following are the vital weld parameters selected which influence on tensile strength and hardness. below three levels were selected to carry out analysis to derive optimal weld parameters.

Table 3: Setting levels for design parameters

Controlled factors	**Level 1**	**Level 2**	**Level 3**
Voltage (Volts)	13	15	17
Current (Amps)	120	150	180
Welding Speed	60	80	100

To carry out investigation and analysis three variables were selected at three levels. Further analysis was carried out by selecting suitable orthogonal array, full factorial experiment at least 3^3 =27 experiments were selected to carry out experimentation. The selected orthogonal array was tested on Taguchi methodology with a L27 (3^3) orthogonal array (27 tests, 3 variables, three levels). The design of experiment is illustrated in table 4

Table 4: Experimental Design

Exp No	**Voltage**	**Current**	**Welding Speed**	**Hardness (VHN)**	**Tensile Strength (MPa)**
1	13	120	60	43	160
2	13	120	60	44	165
3	13	120	60	43	163
4	13	150	80	45	160
5	13	150	80	46	158
6	13	150	80	46	162

Exp No	Voltage	Current	Welding Speed	Hardness (VHN)	Tensile Strength (MPa)
7	13	180	100	42	163
8	13	180	100	41	165
9	13	180	100	40	164
10	15	120	80	41	168
11	15	120	80	40	166
12	15	120	80	42	169
13	15	150	100	48	179
14	15	150	100	50	180
15	15	150	100	49	182
16	15	180	60	46	177
17	15	180	60	46	174
18	15	180	60	45	175
19	17	120	100	44	168
20	17	120	100	45	165
21	17	120	100	44	167
22	17	150	60	48	165
23	17	150	60	47	166
24	17	150	60	47	166
25	17	180	80	45	160
26	17	180	80	44	159
27	17	180	80	44	162

As per experimental design and number of iterations to carry out, twenty seven experiments were carried out by GTAW welding process. The results obtained were tabulated in table 4. Analysis of variance (ANOVA) of tensile strength and hardness are shown in table 5 and 6 accordingly.

Table 5: ANOVA of Tensile Strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Voltage (Volts)	2	773.63	386.82	116.30	0.000
Current (Amps)	2	42.74	21.37	6.43	0.007
Welding speed	2	276.07	138.037	41.50	0.000
Error	20	66.52	3.326	---	---
Lack of fit	2	19.85	9.926	3.83	0.041
Pure Error	18	46.67	2.593	---	---
Total	26	1158.96	---	---	---

From Table 5, the value of P for voltage, current and welding speed is less than or equal to 0.05. Therefore voltage, current and welding speed is the most influencing welding parameters to obtain desired tensile strength of the test specimen.

Table 6: ANOVA of VHN

Source	DF		Adj SS	Adj MS	F-Value	P-Value
Voltage (Volts)	2		22.74	11.37	5.46	0.013
Current (Amps)	2		101.41	50.70	24.36	0.000
Welding speed	2		14.52	7.26	3.49	0.05
Error	20		41.63	2.08	---	---
Lack of fit	2		31.63	15.81	28.47	0.000
Pure Error	18		10.00	0.55	---	---
Total	26		180.30	---	---	---

From Table 6, the value of P for voltage, current and welding speed is less than or equal to 0.05. Therefore voltage, current and welding speed are the most influencing parameters for hardness.

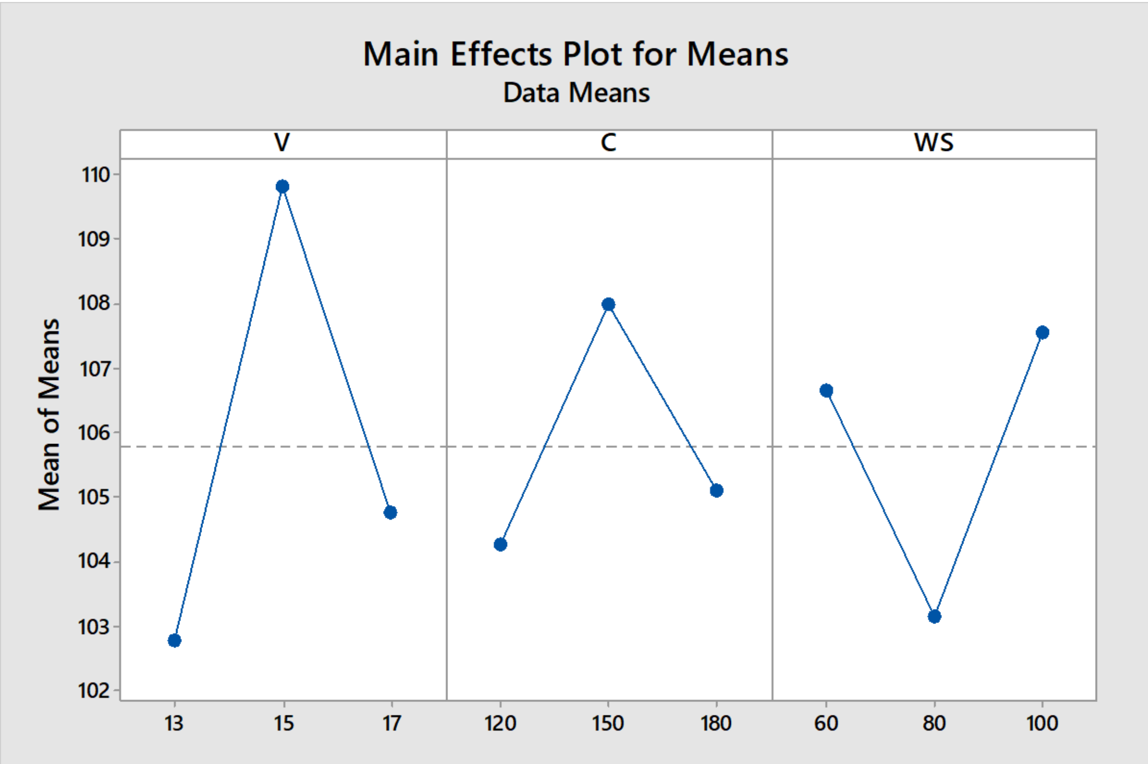

Fig 2: Main Effects Plot for Means

The main effects plot illustrated in Fig 2 shows that the optimum values of tensile strength and hardness are voltage: 15 V, current: 150 A and welding speed: 100.

Table 7: Optimum Parameters for all response variables

Exp No	Voltage	Current	Welding Speed	Hardness (VHN)	Tensile Strength (MPa)	SNRA1
1	13	120	60	43	160	-1.79943
2	13	120	60	44	165	-1.79943
3	13	120	60	43	163	-1.79943
4	13	150	80	45	160	-1.80288
5	13	150	80	46	158	-1.80288
6	13	150	80	46	162	-1.80288
7	13	180	100	42	163	-1.82207
8	13	180	100	41	165	-1.82207
9	13	180	100	40	164	-1.82207
10	15	120	80	41	168	-1.75025
11	15	120	80	40	166	-1.75025
12	15	120	80	42	169	-1.75025
13	15	150	100	48	179	-1.61519
14	15	150	100	50	180	-1.61519
15	15	150	100	49	182	-1.61519
16	15	180	60	46	177	-1.69428
17	15	180	60	46	174	-1.69428
18	15	180	60	45	175	-1.69428
19	17	120	100	44	168	-1.78106
20	17	120	100	45	165	-1.78106
21	17	120	100	44	167	-1.78106
22	17	150	60	48	165	-1.76230
23	17	150	60	47	166	-1.76230
24	17	150	60	47	166	-1.76230
25	17	180	80	45	160	-1.81218
26	17	180	80	44	159	-1.81218
27	17	180	80	44	162	-1.81218

In Table 7 various optimal welding parameters for tensile strength and hardness were shown. Experimentation and analysis was carried out to derive optimum weld parameters by applying signal-to-noise ratio. From above illustrated tabular values, it was evident that experiment 15 has reached the vital global solution for lager signal to noise ratio.

The weld samples were subjected to analysis to examine the microstructure. The investigation reveals heterogeneous microstructure features, including multiple twinned equivalent grains and the presence of secondary phase intermetallics, particularly β-Mg17Al12. As per the literature for reference, intermetallic compounds are more abundant in regions near grain boundaries. These intermetallic compounds play an important role in reducing mechanical properties, by imparting plastically sensitized areas at grain boundaries.

The heat-affected zone (HAZ), in contrast to the weld zone, showed a coarse grain structure and a low concentration of twins, which are comparatively less than base metal. The heat cycle that occurs during GTA welding usually dissolves the majority of the secondary phase in the weld pool zone. Figure 3 illustrates the better mechanical properties of the weld zone over the base metal can be attributed to the equi-axed grain structure with relative fine grain size and secondary phase. Precipitation hardening mechanism is one of the important phenomenon which influences the plastic deformation of weld joints. In general, precipitation hardening behavior determines the localized resistance to plastic deformation with presence of precipitates or secondary phase particles. These secondary phase particles obstructs the dislocation motion which in turn results the improved mechanical properties. Tensile and hardness values evidently shows the greater precipitation hardening behavior of weld zone. It contains relative more no. of secondary phase compared to HAZ. The use of a welding current of 150A has been found to be

With optimal welding parameters ultimate tensile strength (UTS) of 182MPa and hardness of 49HV were achieved, with a voltage of 15 V, current of 150 A, and welding speed of 100 mm/min. The better ultimate tensile strength

resulting inferior values can be attributed to the high heat input and increased residual stresses surpassing the critical threshold. On the other hand, welding conditions below the optimal range also exhibited lower mechanical properties,

likely due to improper metal transfer and insufficient heating.

CONFIRMATORY TEST:

With respect to optimum levels of selected welding parameters, the results were

8.

optimal for achieving efficient welds with improved characteristics. The effectual control of welding current is proven to be responsible for smooth transfer of metal in spray form without any splattering through the production of numerous melt droplets [16]. Welding currents over 150A have been associated with inferior properties, while a welding current of 180A has been observed to result in the formation of severe clustered porosity [17].

Fig 3: Microstructure of AZ31B GTAW weld a) BM, b) HAZ, c) WZ

(UTS a values concisely demonstrate th b e welds produced under the established process parameters had minimal porosity and free from weld defects. However, when the welding conditions exceeded the optimal values, the

Validation experiments were conducted to confirm the practical optimal machining factors (voltage 15V, current 150A, and welding speed: 100mm/min) for assessing

the tensile strength and hardness.

verified through control parameters in multi optimization technique. The confirmation test was conducted are shown in table

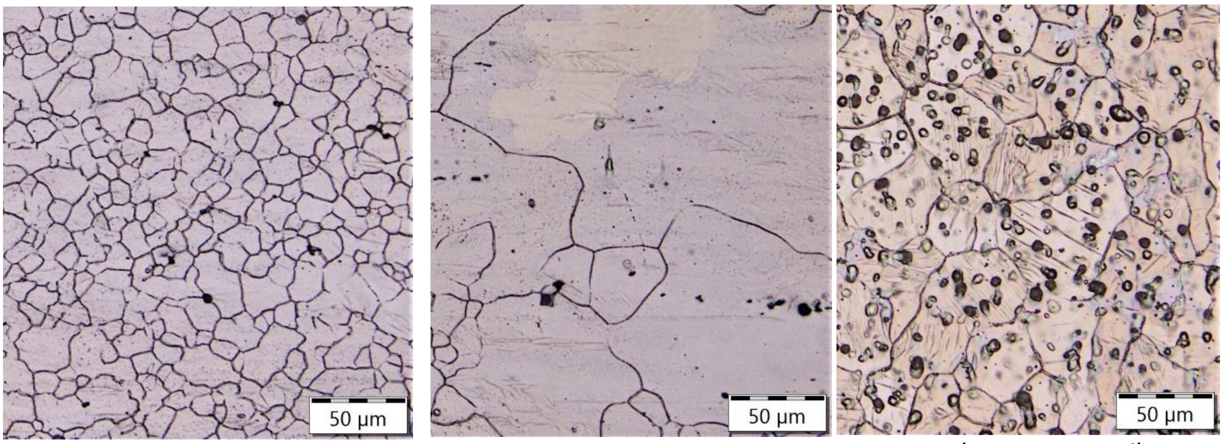

Table 8: Confirmatory test results

Exp. No	Voltage	Current	Welding Speed	Tensile strength	Hardness

1	15V	150A	100mm/min	182 MPa	49 VHN

Suggestions And Further Research:

- The material flow of AZ31B magnesium alloy is greatly influenced by the process parameters, and this has a substantial impact on the mechanical characteristics of the weldment. It is possible to alter the process parameters and conduct additional research using the same methodology.
- Experiments in a larger range of process parameters can be conducted to evolve an empirical relationship between the process parameter and the response.
- The same research can be done with various dissimilar materials.

Conclusions:

Experimentation and analysis was conducted on AZ31B Mg alloy to explore and to study the effects of GTAW process parameters on tensile strength and hardness by using Taguchi methodology optimization design strategy. The following conclusions are drawn here after the detailed study and analysis.

- The results indicated that the welding process variables, invariably affect on mechanical properties of weld joint.
- The micro structural analysis shown that the optimized welding parameters evidently produced welds with relatively minimum porosity, absence of defects, and a refined grain structure in the weld zone, thereby enhancing the efficiency of the weld.
- By using optimisation technique, analysis of variance (ANOVA), tensile strength and hardness of AZ31B material is 182 MPa and 49 VHN.
- The parameters optimization of AZ31B Mg alloy welds by using GTA-welding are established to150A for welding current, 100mm/min for welding speed, and voltage 15V: corresponding to above parameters optimal values for mechanical properties for tensile strength 182MPa and hardness 49HV.
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