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Parametric analysis of MIG welding

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Abstract

Aluminium is one of the most commonly used materials in aerospace and automotive industries for structural purpose. For making a structure of aluminum and its alloy, a welding process plays very important role. Various researchers are working on alternate welding processes to join the low melting alloy materials. Among them, one of arc welding process called Metal Inert Gas (MIG) is used to joining low melting alloy materials. Design of Experiments (DOE) concept is applied to study the MIG welding process with respect to input parameters. They are voltage and current. The output parameters such as hardness, bead width and the temperature are analysed. Experiments are carried out to measure the temperature of welding by using the K-type thermocouple. In order to measure welding bead width USB port microscope is used, which is most important parameters to decide the strength of welding.

However, penetration of heat flux increases with increasing of voltage and current values. As well as it is found that hardness and temperature of welding plate are increased with increase values of voltage and current. As these values increase at a constant weld speed, a width of the weld is increased due to proper melt of the filler wire. By using DOE concepts an empirical relationship has been developed to predict the harness, strength of the welded joints. Simulation model has been developed to predict the temperature distribution of welded zone.

Keywords: *MIG welding machine, Design of Experiment, Aluminium alloy, Hardness*

1. Introduction

In the area of structure design strength of the material with respect to weight is the most important property for any material. In this field, lightweight material like aluminium and magnesium play the most role [1]. In the structure application welding involves for joining the component, selection of the welding process for aluminium is very difficult task [2]. Since 1970 MIG (Metal Inert Gas) welding is commonly used for welding the liquefied natural gas (LNG) cylinder because it has high deposition rate at high welding current, because puckered bead is formed which is unavoidable at high current with thin wire. By use of MIG welding process, high deposition rate and efficiency found in the welding process [3-5]. In present days MIG (Metal Inert Gas) welding is commonly used for welding the aluminium alloys.

There are numerous input parameters which are control during any welding process such as welding current, voltage, weld speed, gas flow rate wire feed etc. In this study welding current and voltage select as an input parameter. Current is very important parameter for deciding the quality of the welded product. Penetration of the weld bead mainly affected by the supplied voltage and current. It is very important factor for deciding the tensile strength of the welded product [11, 12].

2. Methodology

Based on the literature review, still there is a scope to strengthen the MIG (Metal Inert Gas) welding process for light weight material having low melting point. To achieve good quality of MIG welding process, it is necessary to require various type of measuring device to measure the quality in terms of output parameters of the welded specimen. Various measuring devices and instruments are used in this thesis work such as Universal Testing Machine (UTM), Brinell hardness testing rig, USB port microscope, K type thermocouple and NIELVIS DAQ card. The main purpose of this research work is to acquire the highest mechanical strength of the working material during the welding process. Brinell hardness testing rig is used to create the indentation on the welded specimen and diameter of indentation is measured by the USB port microscope. Thermocouple is used to measure the temperature variation on the plate surface during the welding process. The motivation of this research work is to achieve the highest strength of the welded specimen by controlling the various input parameter which can be controlled during specimen welding. Therefore, an attempt has been made to improve the strength of the welded plate by controlling various welding input parameters on MIG (Metal Inert Gas) welding process.

3. Experiment setup and condition

In the MIG (Metal Inert Gas) welding process the vertical milling machine is used for holding the welding torch. The torch is mounted on the tool post by use of the appropriate fixture. With the help of suitable jig and fixture, the plate is astride on the table of the milling machine after the proper fixing of the plate thermocouples place or pinned on the surface of the plate which is connected to the DAQ card. The size of the plate is 2.5 mm thick and 17 cm long, and 22 cm wide.

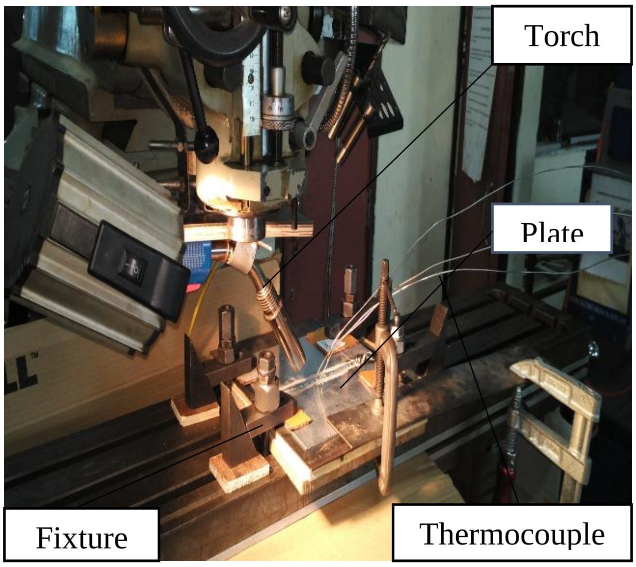

Figure 1.1 Experimental Setup

The material of the welded sheet is Aluminium alloy 1100. The chemical configuration is 99.73% pure aluminium remain part is silicon, iron, tungsten, copper, magnesium and manganese. As shown in the Figure 1.1.

4. Development of Mathematical Model

In this work current and voltage are used as an input parameters which vary up to three level and applied the full factorial design. From the formula $N=L^m$ (where N equal to a number of an experiment, L indicates the level of the input parameter and m indicate the number of input factor), total number of experiment after the calculation are nine as shown in the Table 1.1. Total response of the depending output parameter is measured for various MIG (Metal Inert Gas) welding condition. After define, the confidence level 95% significant model has been developed. The coefficient of the temperature, hardness, bead width and strength is represented by the Equation (1, 2, 3, 4 and 5) [6].

The f value is most important factor for define the model is significant or insignificant. If F value is more than the calculated value, it is confirmed that model is significant. If the value of p in term of the regression model is less than (0.005), it implies that obtained model is statically significant [10]. The value of the R square in the regression analysis is (97.5% for the tensile strength and 95.34% for the hardness) is achieved which signify that model is good for fitness.

Table 1.1 Experimental Data

VOLTAGE (A)	CURRENT (A)	TEMP (^0C)	HARDNESS (BHN)	WIDTH UPPER (mm)	WIDTH LOWER (mm)	TENSILE STRENGTH (MPa)
20	105	538	111.096	9.550	6.350	96.7
21	105	544	114.218	9.102	6.983	73.0
21	95	529	76.990	7.198	4.241	108.1
20	95	502	56.393	6.261	1.556	87.0
20	100	530	84.202	7.802	5.175	112.6
19	105	529	82.929	8.350	4.704	105.0
19	95	499	50.938	6.261	1.078	65.0
21	100	536	86.640	8.350	6.318	104.3
19	100	520	67.651	6.971	3.033	103.6

$$Temperature = -2379.89 - 28.166V + 59.03333I + 2.833V^2 - 0.2071I^2 - 0.075VI \quad 1$$

$$Hardness = -624.074 + 146.636V - 21.8775I - 4.00248V^2 - 0.104I^2 + 0.26184VI \quad 2$$

$$Widthupper = -80.1204 + 8.11578V - 0.2096I - 0.1669V^2 - 0.027586I^2 - 0.0442VI \quad 3$$

$$Widthlower = -412.814 + 4.57794V + 6.77409I + 0.0325V^2 - 0.027586I^2 - 0.0442VI \quad 4$$

$$Tensilestrength = -181.38 + 668.2V + 230.52I - 0.7V^2 - 0.775I^2 - 3.76VI \quad 5$$

5. Result and discussion

5.1. Effect of the voltage and current on the Tensile strength

Basically, tensile strength is the most important property of the any welded specimen. It is seen that if any input parameter (current and voltage) increases, the tensile strength also increases up to a certain limit and after that, it will decrease. If the current value is low, it will produce incomplete penetration. As the current value increases the proper penetration is achieved and finally tensile strength increases. With further increase in the value of current, droplet transfer mode is changed and massive burning of the plate takes place and finally tensile strength decreases as shown in the Figure 1.2. Voltage is the significant input parameter for deciding the tensile strength of the welded plate. As the value of voltage is small short circuiting transmission takes place, molten material close to the weld pool breakdowns and decrease the weld stability and quality of the weld. From another point of view, as the voltage is two high bigger droplets are formed and it will produce porosity and lastly tensile strength decreases. The maximum value of tensile strength with respect to voltage is 100.04 MPa as shown in the Figure 1.3.

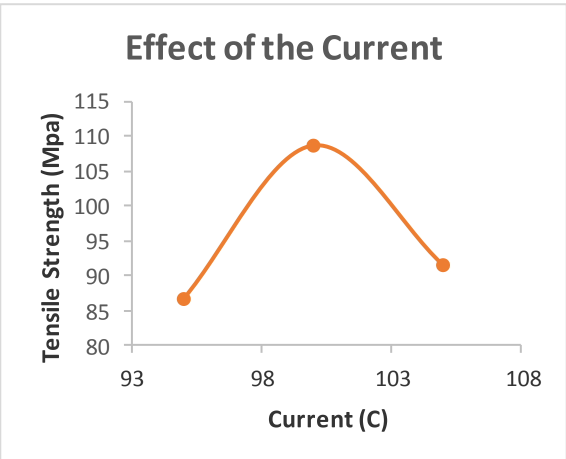

Figure 1.2 effect of current on tensile strength

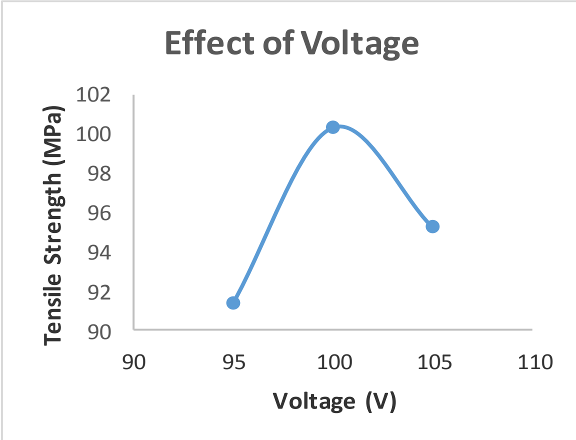

Figure 1.3 Effect of Voltage on tensile strength

5.2 Effect of the voltage and current on the Temperature

From the experimental analysis, it is clear that as the value of current and voltage increases the temperature at each point on the plate surface increases. As the current and voltage increases, the heat generation rises because power (heat) is the function of voltage and current. Due to this reason, the value of the temperature is increased on the surface of the plate. It is clear in the Table 1.2.

Table no 1.2 Effect of voltage and current on temperature

S.No	Voltage (V)	Current (A)	Temperature (°C)
1	19	95	499
2	20	100	530
3	21	105	544

5.3 Effect of voltage and current on weld width

Many mechanical properties of the welded specimen depend on the shape of the bead. These mechanical properties are tensile strength and impact strength etc.

Table no 1.3 Effect of voltage and current on bead width

S.No	Voltage (V)	Current (A)	Bead width (mm)
1	19	95	6.247
2	20	100	7.794
3	21	105	9.1252

.It is confirmed that as the value of the voltage and current increases the penetration as well as the width of the bead increases progressively. If the value of current and voltage increases the fusion of the filler wire will increase and it will increase the bead penetration as well as width. Table 1.3 clear the variation in the bead with respect to voltage and current variation.

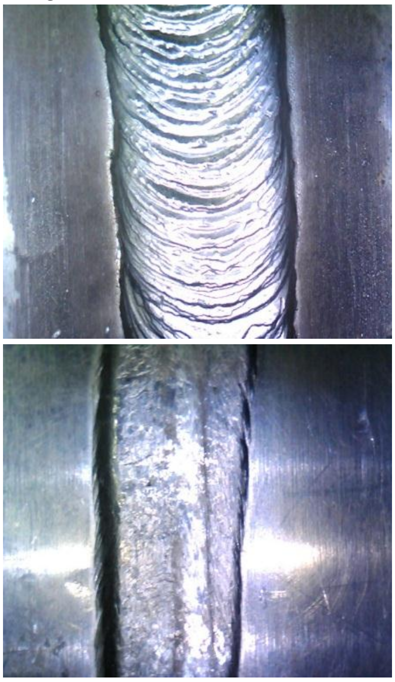

Figure 1.4 Effect of voltage and current on weld bead at (21V and 105A)

5.4 effect of voltage and current on hardness

Hardness is also one of the important mechanical property. After the welding, hardness value is calculated for each specimen at various points that is shown in the Table 1.4. It is clear that as the value of the voltage and current increases, it will increase the hardness of the welded plate. If voltage and current increase, more heat is generated. As the heat rises, size of the grain increases and hence, gap between grain boundaries decreases. It will result in an increase in the hardness of the welded plate near the weld bead.

Table no 1.4 Effect of voltage and current on hardness

S.No	Voltage (V)	Current (C)	Hardness (BHN)
1	19	95	51.0984
2	20	100	84.0838
3	21	105	114.574

6. Simulation of Temperature

In order to validate the temperature result finite element analysis (ANSYS APDL 12.1) is used to analysis the welding temperature on the plate surface. For the simulation purpose the material properties like thermal conductivity, specific heat and density is taken as standard value of the aluminium alloy [8]. It is only metal whose conductivity increases as the temperature increases as shown in the Table 1.5. The temperature at the bead stays more than the melting point of the work material. The results indicate that the developed model is able to predict the temperature with reasonable accuracy. Governing equation for heat transfer is [9].

$$kx\frac{\partial^2 t}{\partial x^2} + ky\frac{\partial^2 t}{\partial y^2} + kz\frac{\partial^2 t}{\partial z^2} + q = \rho c\left[\frac{\partial t}{\partial \tau} - v\frac{\partial t}{\partial x}\right]$$

$$k_n - q + h(T - T_o) + \sigma\varepsilon\left(T^4 - {T_o}^4\right) = 0$$

Where k= Thermal conductivity (W/m.K)

c= Specific heat (J/Kg.K)

t= Temperature (^{o}C)

v= Weld speed (m/sec)

h= Convective heat transfer coefficient (W/m^{2}K)

σ= Stefan Boltzmann constant

ε= Emissivity

Table 1.5 Mechanical properties of aluminium alloy

Temperature (^{0}C)	Density (g/cm^3)	Conductivity (W/cm.^{0}C)	Specific heat (J/g ^{0}C)
-20	2.7	1.6	0.9
80	2.67	1.7	0.97
180	2.623	1.9	1
280	2.613	2.05	1.09
380	2.612	2.2	1.15
480	2.611	2.35	1.2
580	2.61	2.5	1.3

From the analysis, it is clear that the error between the experimental and the simulated data is within the acceptable limit at (20 volt, 100 ampere and 25 cm/min weld speed) the temperature at 10 mm distance is 551 degree Celsius which is 2.79 percent more than the experimental data i.e. 536 degree Celsius The maximum temperature at 10 mm distance is 526 degree Celsius (as shown in Figure 1.5) and the experimental value of this is 499 degree Celsius which is 27 degree more than the experimental at (19V, 95A and 25cm/min). Lastly as the heat increases that is at 21 volt, 105 ampere and 25 cm/min weld speed, and the value of temperature is 569 degree Celsius which is 4.59 percentage more than the experimental value (544 degree Celsius).

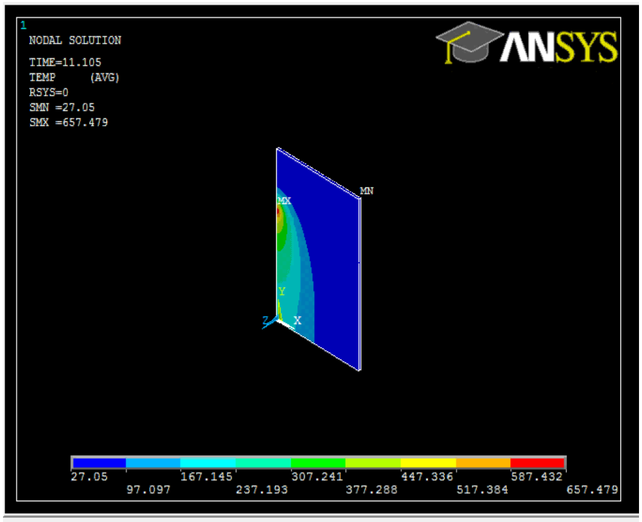

Figure 1.5 Temperature variation at 19V, 95A and 25cm/min

Conclusions

1. The maximum temperature on the plate surface is 544.35 ^{0}C at (21 volt, 105 ampere and 25 cm/min) voltage, current and weld speed. The maximum variation of the temperature with respect to unit change in voltage and current is 5 to 7 ^{0}C.
2. The maximum tensile strength of the welded plate in 117.3 MPa, at 20V voltage and 100A current. It is confirm as the current and voltage increase after the optimum value tensile strength decrease.
3. Maximum hardness of the plate is found at 20V voltage and 100A current, that is 84.03 BHN.
4. As the value of the current and voltage increase the width of the welded bead increase. The maximum value of the welded bead is 9.125 mm at 21V and 100A.
5. From the simulation analysis it is obtained that there is not much error between the experimental and simulation temperature, maximum error is 6% between experimental and simulation results.

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