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Optimization of Process Parameters of MIG Welding to Improve Tensile Strength of Fe-415 Mild Steel

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Abstract: Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, is a welding process in which an electric arc forms between a consumable wire electrode and the work piece metal(s), which heats the work piece metal(s), causing them to melt and join. In present work experiments are conducted to investigate the Ultimate Tensile Strength of MIG welded joint. Work piece material considered is FE-415 Steel. Experiments are planned as per Taguchi's L9 orthogonal array. Welding current, voltage and gas flow rate are the selected process parameters. MIG welding is carried out at various levels of the process parameters as per Taguchi's L9 orthogonal array. After completion of welding, tensile test is carried out to check the ultimate tensile strength (UTS) of specimen. Single response optimization has been carried out. Further, the results are verified through confirmatory experiment. Based on the observations and analyses it is concluded that gas flow rate is the most significant process parameter followed by voltage and welding current. As the welding current and gas flow rate increases, the tensile strength of welded joint is also increases. On the other hand, with increase in voltage, the tensile strength decreases first and then increases again.
Keywords: GMAW, MIG, MAG, FE-415, UTS

I. INTRODUCTION

Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, is a welding process in which an electric arc forms between a consumable wire electrode and the work piece metal(s), which heats the work piece metal(s), causing them to melt and join. Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air. The process can be semi-automatic or automatic. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations. Originally developed for welding Aluminum and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it provided faster welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common. Further developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process. Today, GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation. Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility. A related process, flux cored arc welding, often does not use a shielding gas, but instead employs an electrode wire that is hollow and filled with flux.

II. PARAMETERS OF MIG WELDING

1) *Welding Current:* Welding usually requires high current (over 80 amperes) and it can need above 12,000 amperes in spot welding. Low current can also be used; welding two razor blades together at 5 amps with gas tungsten arc welding is a good example. Welding machines are usually classified as constant current (CC) or constant voltage (CV); a constant current machine varies its output voltage to maintain a steady current while a constant voltage machine will fluctuate its output current to maintain a set voltage. Shielded metal arc welding and gas tungsten arc welding will use a constant current source and gas metal arc welding and flux-cored arc welding typically use constant voltage sources but constant current is also possible with a voltage sensing wire feeder.

2) *Arc Voltage:* An arc voltage discharge is an electrical breakdown of a gas that produces an ongoing electrical discharge. The current through a normally nonconductive medium such as air produces plasma; the plasma may produce visible light. An arc discharge is characterized by a lower voltage than a glow discharge, and it relies on thermionic emission of electrons from the electrodes supporting the arc
3) *Gas Flow Rate:* Carbon Dioxide is most used in MIG welding .Argon also be used and some application mixer of C02 and Ar also used .Gas flow rate influence the welding speed and improves process tolerance . Volume flow rate is more important than pressure when generally we talks about Gas Flow Rate .MIG welding shielding gas flow is set and measure as Litre Per minute. Its varies depending upon the application ,stick out distance & type of welding (Robot, Semi-Automatic & Manual).Normally 12 LPM to 20 LPM gas flow rate is preferred in all MIG Welding operations. If we use less than recommended it will lead to welding defects such as porosity, in stable arc etc.

III. ARC INITIATION

There are two most commonly used methods to initiate an electric arc in welding processes namely touch start and field start. The former is used in the case of all common welding processes while the later one is preferred in case of automatic welding operations and in the processes where electrode has tendency to form inclusions in the weld metal.

1) *Torch Start:* In this method the electrode is brought in contact with the work piece and then pulled apart to create a very small gap. Touching of the electrode to the work piece causes short-circuiting; so resulting flow of heavy current leads to heating, partial melting and even slight evaporation of the metal at the electrode tip. These entire things happen in a very short time usually a few seconds. Heating of electrode produces few free electrons due to the thermal ionization. Dissociation of metal vapour also produces charged particles. Pulling up the electrode apart from the work piece, flow of current starts through these charged particles and for movement of these charged particles arc is developed. To use the heat of electric arc for welding purpose it is necessary that after the ignition of the arc it must be maintained and stabilized.
2) *Field Start:* In this method, high electric field (107V) is applied between electrode and work piece so that electrons are released from cathode by field emission. Development of high strength field leads to ejection of electron from cathode spot. Once the free electrons are available in the arc gap, normal potential difference between electrode and work piece ensures flow of charged particles to maintain a welding arc.

IV. STRUCTURE OF THE ARC

The welding arc consists of a mechanism for emitting electrons from the cathode which after passing through ionized hot gas merge into anode. The arc voltage is divided into three parts, i.e. cathode drop, arc column and anode drop. So arc voltage is sum of cathode drop, arc column and anode drop.

$$V = V_C+V_P+V_A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, V_C = cathode drop
V_P = column drop
V_A = anode drop

1) *Cathode Drop:* It is that part of the negative electrode where the electrons are emitted. The cathode spot, in TIG welding, forms at the tip of a sharply pointed tungsten or thoriated tungsten rod used with argon shielding. It has a current density of the order of 10^2 A/mm^2. In a low carbon coated steel electrode the cathode spot appears to envelop the entire molten tip of the electrode. Electron emission from the cathode can be by anyone of the several mechanisms such as thermionic emission, auto-electronic emission, photo-electric emission and secondary emission.
2) *Arc Column:* It is the bright visible portion of the arc. The temperature of the arc column depends upon the gases present in it and the amount of welding current flowing in the circuit. The column temperature varies from 6000^{0}C for iron vapours to about 20000^{0}C for argon shielded tungsten arc. The flow of current in the arc column results in the development of electromagnetic forces. These constricting forces are balanced by a static pressure at the pressure gradient established in the gaseous conductor with zero pressure at the outer periphery.
3) *Anode Drop:* In the anode region the electrons lose their heat of condensation. The voltage drop in the anode drop zone is of the order of 10^{-2} to 10^{-1} mm. When the rod electrode acts as the anode, it occupies the lower hemi-sphere of the molten droplet at the tip of the electrode. The total heat input at the anode is due to the condensation of the electrons as well as conduction and convection due to the plasma jet. In DC arc with non-consumable electrode, the anode heat is greater than the heat liberated at the cathode.

V. ARC FORCES AND THEIR SIGNIFICANCE ON WELDING

All the forces acting in the arc zone are called arc forces. In respect with welding, influence of these forces on resisting and facilitating the detachment of molten metal drop hanging at the electrode tip is important. These forces affect the mode of metal transfer. Metal transfer is of great importance because flight duration of molten metal drop in arc region affects the quality of weld metal and element transfer efficiency. These forces are:

1) *Gravity Force:* This is due to gravitational force acting on molten drop hanging at the tipof the electrode. Gravitational force depends on the volume of the drop and density of the metal.

   Gravitational Force (Fg) = ρVg …………………………………. (2)

   Where ρ is density of the metal, V is the volume of drop, g is gravitational constant.

2) *Surface Tension Force:* This force is due to surface tension of the liquid metal hanging attip of the electrode. Magnitude of the surface tension force is influenced by the size of the droplet, electrode diameter and surface tension coefficient. This force tends to resist the detachment of the molten metal drop from the electrode tip and usually acts against gravitational force.

   Surface Tension Force (Fs) = $(2\sigma\pi Re)/4R$ ……………………………. (3)

   Where σ is surface tension coefficient, R is drop radius; R_e is radius of electrode tip.

3) *Force Due to Impact of Charge Carriers:* As per polarity, charged particles (ions and electrons) move towards anode and cathode and impact with each other. This impact generates force at the tip of the electrode and tends to hinder the detachment.

   Force due to Impact of Charge Particals (Fm) = $m(dV/dt)$ ………………. (4)

   Where, m is mass of charge particles, V is velocity and t is time.

4) *Force Due to Electromagnetic Field:* Flow of current through the arc gap develops the electromagnetic field. Interaction of this electromagnetic field with that of charged carriers produces a force. This force reduces the cross section for molten metal drop near the tip of the electrode.

   Electromagnetic Force (Fe) = $(\mu I^2)/8\pi$

Where μ is magnetic permeability of metal, I is the welding current flowing through the gap.

VI. WORK PIECE MATERIAL

Fe-415 Mild steel is steel in which the main interstitial alloying constituent is carbon in the range of 0.20–0.35%.it is also called low carbon or plain carbon steel.

The American Iron and Steel Institute (AISI) defines lowcarbon steel as the following: Steel is considered to be low carbon steel when minimum content is specified or required for chromium, cobalt, molybdenum, nickel, niobium, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 percent; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.6.Fe-415 contain low carbon that make it malleable and ductile, but it is cheap and easy to form; surface hardness can be increase through carburizing.

The density of Fe-415 is approximately 7.85g/cm3 Young's modulus is 200GPa. Its melting point is 1400*C. Its Yield Stress (N/mm2)-415,Ultimate Tensile Strength 485 (N/mm2).For this purpose, Fe-415 Mild Steel cut into required dimension 100*50*5(thickness)mm has been used for butt welding.

VII. EXPERIMENTAL PLAN

Taguchi's idea of orthogonal array, as discussed in the previous chapter, has been adopted for planning the experiments of welding of Fe-415 MILD Steel. L9 orthogonal array has been selected considering three factors and three levels of each factor. The input parameters considered in the study are: current, gas flow rate and voltage. Nine butt welded samples have been made using different levels of current, gas flow rate and arc gap.

The responses measured are ultimate tensile strength. Table 1 shows the factors and their levels, as used in experimental runs. The welding conditions which have been kept nearly constant in all the nine experiments.

Table 1 Experimental Layout

Sr. No.	Current (Amp)	Voltage (Volt)	Gas Flow Rate (LPM)
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

VIII. CONDUCT OF EXPERIMENT

The experimental layout is based on Taguchi's L9 orthogonal array. Nine number s of experiments are performed according to the design layout by using three levels of each process parameters. The welded pieces are shown in fig. 1. The observed values of ultimate tensile strength are tabulated in table 2.

Fig. 1 Welded Work Pieces

Table 2 Observation Table

Sr. No.	Current (Amp)	Voltage (Volt)	Gas Flow Rate (LPM)	UTS
1	200	22	12	7.5
2	200	24	15	7.9
3	200	26	18	18.1
4	220	22	15	6.2
5	220	24	18	13.9
6	220	26	12	16.2
7	240	22	18	27.8
8	240	24	12	7.8
9	240	26	15	18.2

IX. RESULTS AND DISCUSSION

From the obtained results, it is observed that gas flow rate is the most significant parameter followed by voltage and current. From graphs, ultimate tensile strength is directly proportional to the current and gas flow rate while voltage puts inverse effect on tensile strength of welded joint.

TABLE 3 Response Table for S/N Ratio

Level	Current	Voltage	Gas Flow Rate
1	20.20	20.74	19.84
2	20.97	19.55	49.67
3	23.97	24.85	25.63
Delta	3.77	5.30	5.96
Rank	3	2	1

TABLE 4 Response Table for Means

Level	Current	Voltage	Gas Flow Rate
1	11.167	13.833	10.500
2	12.100	9.867	10.767
3	17.933	17.500	19.933
Delta	6.767	7.633	9.433
Rank	3	2	1

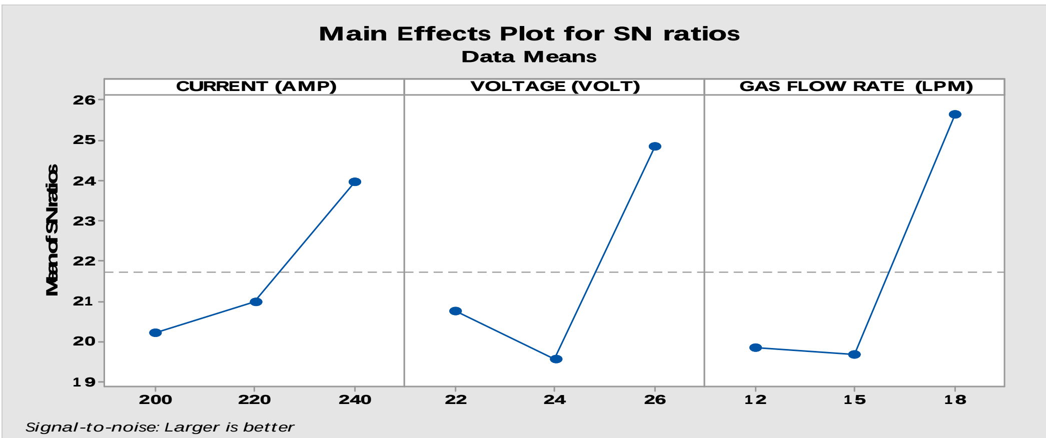

Fig. 2 Main Effect Plot for S/N Ratio

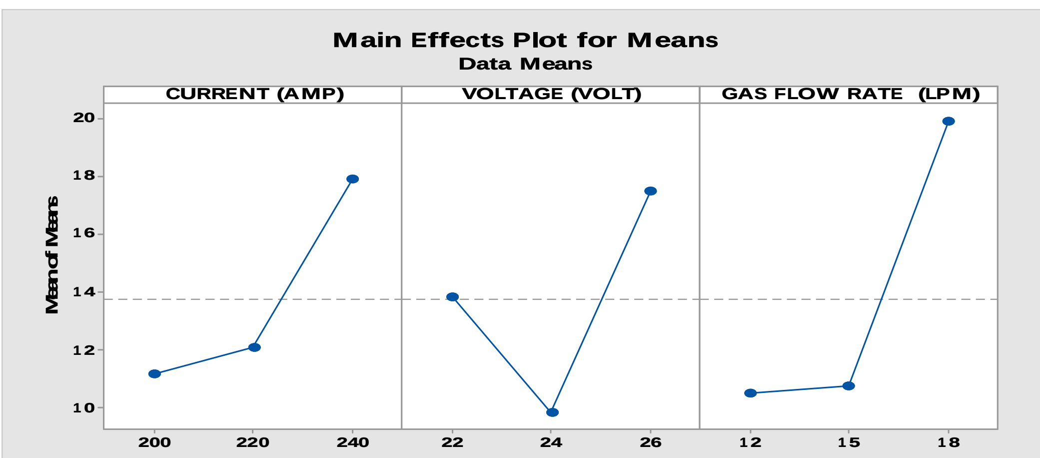

Fig. 3 Main Effect Plot for Means

X. CONCLUSIONS

The following conclusions are derived from the current study.

a) Optimum process variables for Ultimate Tensile Strength are **A3 B3 C3**i.e. Welding Current (A3) 240 Ampere, Voltage (B3) 26 Volt &Gas flow rate (C3) 18 L.P.M.

b) S/N ratio for Ultimate Tensile Strength increases with increase in welding Current and Gas flow rate.

c) From the analysis of Rank Response table it is clear flow rate is the most significant factor effecting Ultimate Tensile Strength and Welding Current is the least significant factor.

d) There has been improvement in Ultimate Tensile Strength from initial setting to optimal process parameter by 20.75KN.

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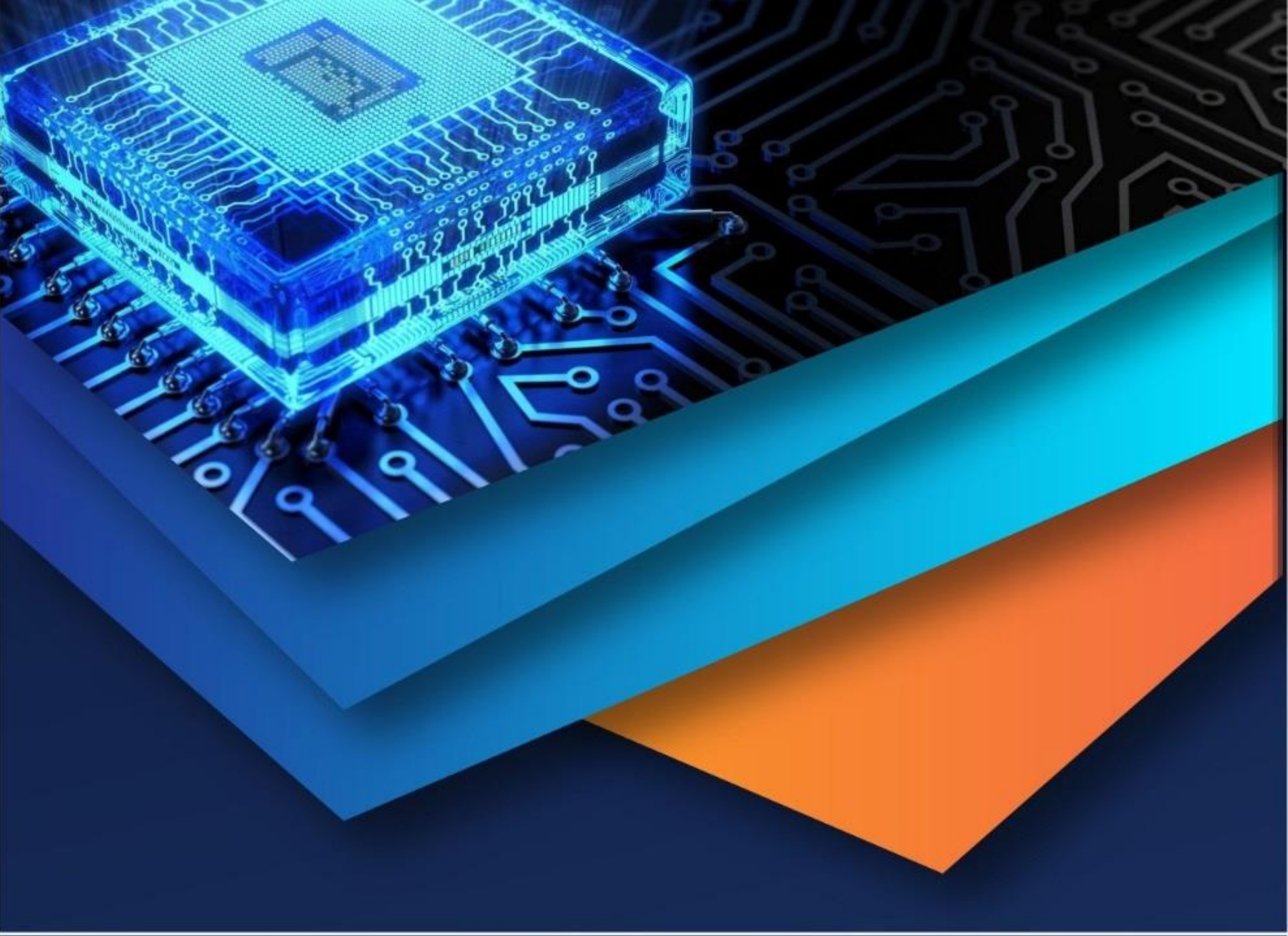

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