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Effects of Electromagnetic Field Intensity on Gas Metal Welding Arc in Stainless Steel Cladding Overlays

J S Gill, A.S.Shahi

Abstract. **The present paper reports the results of the experimental investigations carried out by using a newly designed and developed Electromagnetic steering set up used along with the conventional GMAW process for single layer stainless steel claddings. The main objective behind this work was to control the arc heat using such an arrangement that could reduce the arc stiffness/force in such a manner that the heat impingement into the base metal could be reduced and good quality weld claddings with minimum dilution could be achieved. In GMA welding with inert gas shielding, the self-induced electromagnetic force projects metal axially towards the work piece. The new arrangement in the present case named as GMAW-EM makes use of an electromagnetic set up that surrounds the welding arc with a yoke. An electromagnetic magnetic field around the welding arc is superimposed by an auxiliary power source such that the welding arc could be deflected in a such a manner that a relatively broader area over the work piece surface is covered by the welding arc, which further provided greater metal surfacing rate per unit area with comparatively lower base metal dilution as compared to the conventional GMAW process.**

Key words arc stiffness, auxiliary magnetic field, base metal dilution, electromagnetic force

I. INTRODUCTION

Surface engineering offers global companies the possibility to improve the engineering performance of components through a range of technologies. Various welding processes are being employed into the weld surfacing; the usage of them being dependent upon the economy, the surfacing process to be used, material to be deposited and the quality of work. Gas metal arc welding (GMAW) is the arc welding process which produces the coalescence of metals by heating them with an arc between a continuously fed electrode and the work with weld being shielded by the gas externally. The GMAW process is suitable for weld surfacing due to its higher electrode efficiencies, all positional capabilities, low heat input, neat and clean welds. low cost per length of weld metal deposited when compared to other arc welding processes. GMAW process for weld surfacing has not been explored to its potential due to the higher penetration achieved due to the spray metal transfer mode when inert gas is used as the shielding medium thus giving higher values of dilution. The GMAW-EM set up used in the present study is shown in the Figure 1 given below.

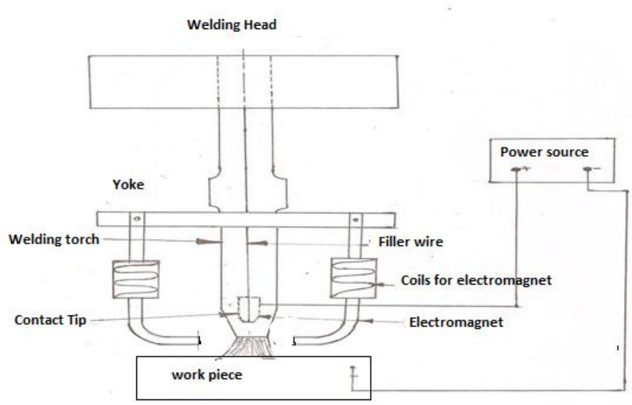

Figure 1 Schematic sketch of GMAW-EM set up

With the fundamental fact that the welding arc is sensitive to external magnetic fields which leads to a condition called 'arc blow' where the arc gets deflected from its intended path, which not only hinders the smooth metal deposition, but also results in a considerable spatter. This inherent nature of the arc leaves a very tight tolerance for any cladding operation i.e. achieving favourable conditions where the arc must be deflected and at the same time metal deposition must be smoother and spatter free. As reported in literature few researchers have attempted to use an auxiliary magnetic field for electromagnetically steering of the arc and have found satisfactory results. The arc can be deflected in any direction under the influence of applied external magnetic field. The amount and the direction of arc deflection are dependent upon the intensity and the direction of magnetic field applied. Oscillating the arc sideways with respect to the direction of welding has been found to be effective for cladding purposes, because it gave wider clad beads with uniformly shallow penetration

J S Gill, A.S.Shahi is with **Department of Mechanical Engineering, SLIET, Longowal, Punjab, India, jsgillsliet@gmail.com, ashahisliet@yahoo.co.in**

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levels, higher melt off rate and higher height of reinforcement.

II. EXPERIMENTATION

Feasibility studies through screening experiments were carried out by using the Electromagnetic steering set up used with the conventional GMAW process for single layer 'Bead on plate experimentation of stainless steel claddings. The main motive behind this work was to control the arc heat by deflecting the arc so as to reduce the arc stiffness/force such that good quality and consistent weld claddings with minimum dilution could be achieved. The outcome of these preliminary investigations was found to be encouraging in terms of achieving higher productivity of the conventional GMAW process when EM set up as shown in Figure 1 was used for the same set of input welding conditions.

The experimental details and the findings obtained are briefly summarized as below: -

Wire feed rate = 5 m/min, Arc voltage = 24.8 V, Welding speed = 22 cm/min, Nozzle-to-plate distance = 15 mm, Electrode to work angle = 90º, Gas flow rate (Industrially pure argon) = 18L/min, Welding position= Flat, Level of automation = Fully automatic, Auxiliary magnetic field intensity used at the axis of the arc = 150 Gauss (corresponding to a voltage of 16V supplied to the electromagnet using DC power source), Base material and thickness used = Low carbon structural steel AISI 1020 thickness =,12 mm, Filler wire used = Austenitic stainless steel solid wire (E309L of 1.2 mm diameter)

For revealing the weld profiles, the specimens were cut from the centre of the plates (since equilibrium conditions are achieved here) and prepared using standard metallographic procedures of grinding, polishing, lapping and etching. The weld bead comparison is shown in Figure 2 given below of (1) GMAW-EM and (2) conventional GMAW techniques.

Figure 2 Bead on plate comparisons between (1) GMAW-EM and (2) conventional GMAW processes

As seen from Figure 2 (1and 2), distinct differences were observed i.e. GMAW-EM bead has more width and reinforcement with significantly low penetration, and consequently negligible dilution (although for ensuring bond integrity with the base metal there has to be a minimum dilution of around 5 %)

Table 2: Bead geometry comparisons (GMAW v/s GMAW-EM)

Bead geometry parameters	**Weld bead -1 (GMAW-EM)**	**Weld bead- 2 (GMAW)**
Bead width (mm)	13.70	8.80
Bead height (mm)	5.82	4.60
Penetration depth (mm)	Negligible	2.00

Further these welding conditions were used to fabricate the clad overlays with SS filler wires E316L for clad overlays and E309L for buttering layers. Figure 3 shows the fabricated clad overlay by GMAW-EM setup

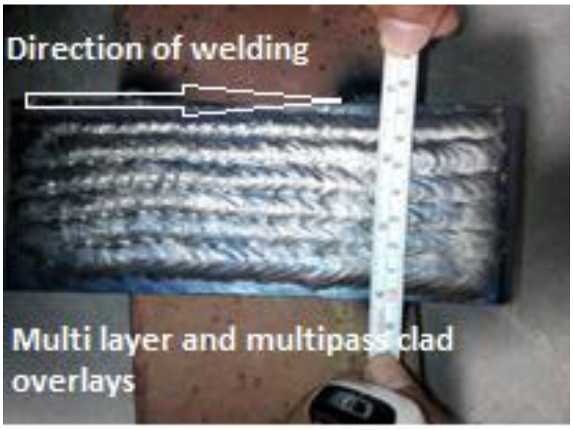

Figure 3 Multi-layer and multi-pass clad overlays

The metallographic examination and corrosion rate was examined from the samples cut from these specimens, the results of which are discussed ahead.

III. RESULTS AND DISCUSSION

The welding arc responded instantly to the externally applied magnetic field. The arc deflected at right angle to the axis of the weld bead when the electromagnetic field was applied in the longitudinal direction. A subsequent increase in the width of the weld bead about 33 % increase as compared to conventional GMAW process was obtained under these conditions.

Besides this, since the volume of the metal melted remains the same for each parametric combination (which is decided by the wire feed rate) decrease in weld penetration results in increased reinforcement of the weld bead. These are the conditions which are most favourable for any cladding operation i.e. less penetration depth and consequently low dilution, accompanied by wide and peaked weld beads.

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Since the weld metal ferrite content can influence a wide range of properties which include corrosion resistance and resistance to hot cracking or micro fissuring. Small amount of BCC ferrite commonly known as delta ferrite, in the austenite which is predominantly FCC structure is observed in the austenitic stainless steels. The amount of delta ferrite present in the claddings was measured across different locations of the clad to check the tendency of microfissuring/solidification cracking. Ferrite measurements were carried out in accordance to the standard test procedures for steel casting austenitic alloy, estimating ferrite content (ASTM A800 M-14). Delta ferrite measurements were found to be lying within the range of 5.5% to 8% which is assumed to be beneficial for the austenitic stainless steels to resist the tendency of hot cracking.

To study the microstructure of the specimens of a suitable size 25× 25 square mm were fabricated using a wire cut EDM machine with a thickness of 4 mm from the weld pads or fully cladded plates as shown in Figure 4. Standard polishing methods were adopted for general microstructure observations as per ASTM E 407-07 (ASTM, 2007). The specimens were polished on a twin disc polishing machine with emery papers of grit size starting from 60, 100, 200, 400, 600, 800, 1000, 1200 and 1400 followed by velvet cloth polishing with diamond paste. Figure 5 shows a comparative look of the microstructures obtained of clad overlays by conventional GMAW process and by using GMAW-EM set up.

The boiling nitric acid or Huey's test was used for testing the susceptibility of stainless steel cladding towards inter-granular corrosion attack and to calculate the corrosion rate in terms of material loss per unit time, which was conducted as per ASTM A-262-Practice-C. The entire lateral surfaces of the prepared test specimens were finely grounded and polished to facilitate better surface exposure to the corrosive test solution. A 65 % by weight nitric acid solution was prepared by adding distilled water to concentrated nitric acid (HNO_3) of reagent grade with specific gravity 1.42 at the rate of 108 ml of distilled water per litre of concentrated nitric acid. The specimens were polished with 120 grit abrasive paper and weighed initially. The specimens were placed in a glass cradle and kept inside the round bottom boiling flask fitted with condenser to dissipate the heat developed during boiling of the acid. The corrosion rate was calculated by the following formula recommended for stainless steels according to ASTM A262 G1:

$$\text{Corrosion rate (mm/month)} = (278 \times W)/(A \times t \times d)$$

Where, 't' is the time of exposure in hours, *'A'* is the total surface area in cm^2; *'W'* is the weight loss in grams and *'d'* is the density, where for chromium–nickel–molybdenum stainless steels it is taken as 8 g/cm^3. Average corrosion rate was found to be 0.062 inch per month and 0.047 inch per month for the specimens by GMAW and GMAW-EM techniques which show a significant improvement in the corrosion rate by the specimens fabricated by GMAW-EM process.

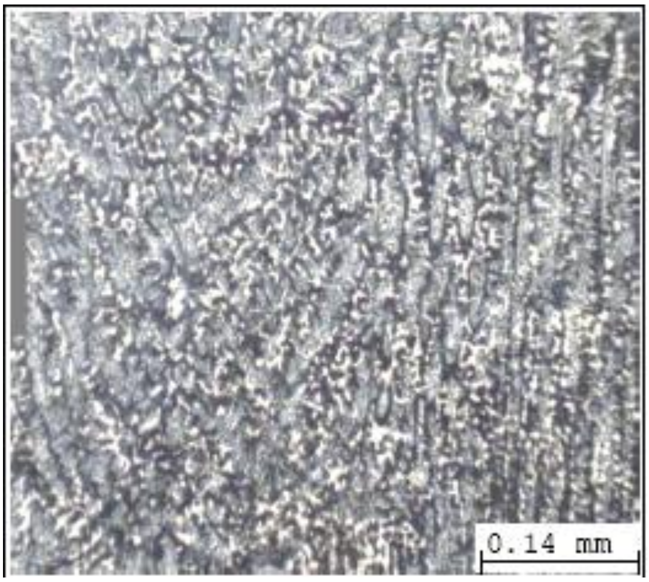

Figure 5 (A) Photomicrograph showing the ferrite morphology in stainless steel weld metal with conventional GMAW process

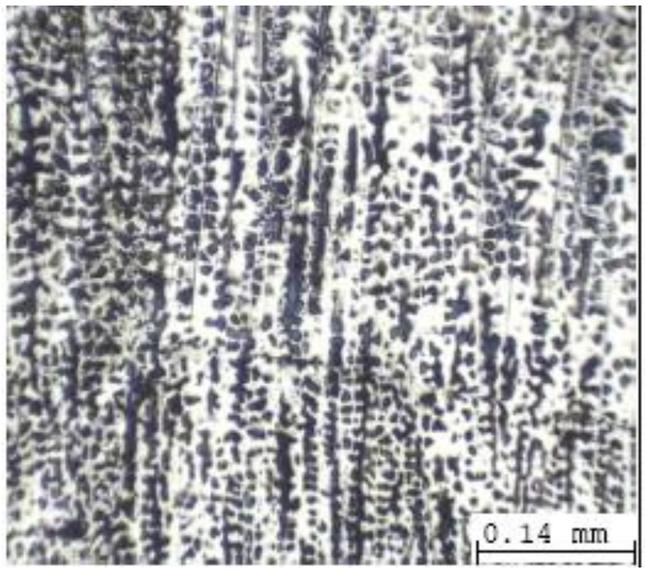

Figure 5 (B) Photomicrograph showing more distinct ferrite morphology in stainless steel weld metal in austenitic matrix of stainless steel weld metal produced with GMAW-EM set up

IV. CONCLUSIONS

The following conclusions can be drawn from the study:

1. The arc of the GMAW process could be controlled by controlling the direction and magnetic field intensity for controlling dilution to a minimum value for stainless steel claddings.
2. The GMAW-EM process resulted in weld beads with significantly higher width, larger reinforcement and low depth of penetrations compared to the conventional GMAW weld beads.
3. EM-GMAW weld beads had narrower HAZ besides weld metal grains possessing planar growth.
4. The EM-GMAW process showed the capability of enhancing the productivity of the conventional GMA process for stainless steel cladding, both in terms of economy as well as quality as resulted from the corrosion rate measurements.

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