Enhancing Weld Bead Characteristics in Shielded Metal Arc Welding Through the Application of External Magnetic Field

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***Abstract*— One method that is frequently used for joining metal parts is welding. The arc conducts current during welding operations. The magnetic field created in a work piece next to the welding torch may have an impact on it. Lack of fusion, porosity, and unevenly welded seams can be caused by arc instability, which can be brought on by magnetic disturbances around the welding arc. Simultaneously, there is a lot of spattering, which clearly leads to good quality and economy if avoided. Weldability and related qualities are greatly improved if the arc can be contained in the lowest feasible area. In order to improve arc stability and better weld beads, an attachment has been developed for this research to be able to weld in an external magnetic field. We also performed welding operations on mild steel plates both in and out of the presence of the external magnetic field. The two work parts are then subjected to a Rockwell Hardness Test. It has been noted that the work piece welded in an external magnetic field has an improved hardness number. This led us to the conclusion that using an external magnetic field in the Shielded Metal Arc Welding had benefits.**

***Index Terms*- Arc spatter, External magnetic field, Arc Instability, Weldability, Solenoid, Hardness.**

I. INTRODUCTION

Shielded metal arc welding (SMAW) is an arc welding (AW) process that uses a consumable electrode consisting of a filler metal rod coated with chemicals that provide flux and shielding. The welding stick (SMAW is sometimes called stick welding) is typically 225 to 450mm (9–18 in) long and 2.5 to 9.5mm (3/32–3/8 in) in diameter. The filler metal used in the rod must be compatible with the metal to be welded, the composition usually being very close to that of the base metal. The coating consists of powdered cellulose (i.e., cotton and wood powders) mixed with oxides, carbonates, and other ingredients, held together by a silicate binder. Metal powders are also sometimes included in the coating to increase the amount of filler metal and to add alloying elements. The heat of the welding process melts the coating to provide a protective atmosphere and slag for the welding operation. It also helps to stabilize the arc and regulate the rate at which the electrode melts.

A flux is used to prevent the formation of oxides and other unwanted contaminants, or to dissolve them and facilitate removal. During welding, the flux melts and becomes a liquid slag, covering the operation and protecting the molten weld metal. The slag hardens upon cooling and must be removed later by chipping or brushing. Flux is usually formulated to serve several additional functions, including (i) providing a protective atmosphere for welding, (ii) stabilizing the arc, and (iii) reducing spattering. Shielded metal arc welding is usually performed manually. It is preferred over oxyfuel welding for thicker sections above 5 mm (3/16 in) because of its higher power density. The equipment is portable and low cost, making SMAW highly versatile and probably the most widely used of the AW processes. Base metals include steels, stainless steels, cast irons, and certain nonferrous alloys. It is not used or seldom used for aluminum and its alloys, copper alloys, and titanium.

1.1 DEFECTS IN SMAW

During conventional SMAW, high magnetic field is setup in the plane of the parts being joined and circumferentially around the electrode and plate due to high currents. The field F1 is setup around the electrode, the field F2 around the plates being joined and the field F3 in the plates adjacent to the arc and in a direction similar to that field F1, since it is not possible to remove these fields from the welding operation. These fields produce defects like undercutting, incomplete penetration, lack of fusion and slag inclusion.

1.2 MAGNETIC FIELD

There is a strong connection between electricity and magnetism. With electricity, there are positive and negative charges. With magnetism, there are north and south poles. Similar to charges, like magnetic poles repel each other, while unlike poles attract. An important difference between electricity and magnetism is that in electricity it is possible to have individual positive and negative charges. In magnetism, north and south poles are always found in pairs. Single magnetic poles, known as magnetic monopoles, have been proposed theoretically, but a magnetic monopole has never been observed. Electric fields come from charges. So do magnetic fields, but from moving charges, or currents, which are simply a whole bunch of moving charges. In a permanent magnet, the magnetic field comes from the motion of the electrons inside the material, or, more precisely, from something called the electron spin. The electron spin is a bit like the Earth spinning on its axis.

The magnetic field is a vector, the same way the electric field is. The electric field at a particular point is in the direction of the force a positive charge would experience if it were placed at that point. The magnetic field at a point is in the direction of the force a north pole of a magnet would experience if it were placed there. In other words, the north pole of a compass point is in the direction of the magnetic field. The symbol for magnetic field is the letter B. The unit is the Tesla (T).

The simplest current we can come up with is a current flowing in a straight line, such as along a straight wire. The magnetic field from such current-carrying wire actually wraps around the wire in circular loops, decreasing in magnitude with increasing distance from the wire. To find the direction of the field, we can use your right hand. If we curl our fingers, and point our thumb in the direction of the current, our fingers will point in the direction of the field. The magnitude of the field at a distance r from a wire carrying a current I is given by equation 1.

Magnetic field from a long straight wire:

$$B= \frac{\mu_0 * I}{(2\Pi r)} \qquad \dots(1)$$

Where μ0 is the permeability of free space and its value is: 4Π * 10-7 T m/A

Currents running through wires of different shapes produce different magnetic fields. Consider a circular loop with a current travelling in a counter-clockwise direction around it (as viewed from the top). By pointing your thumb in the direction of the current, you should be able to tell that the magnetic field comes up through the loop, and then wraps around on the outside, going back down. The field at the centre of a circular loop of radius r carrying a current I is given by equation 2.

Magnetic field at the center of a wire loop

$$B= \frac{\mu_0 * I}{(2r)} \qquad \dots(2)$$

For N loops put together to form a flat coil, the field is just multiplied by N:

Magnetic field at the centre of a flat coil with N loops (equation 3)

$$B= \frac{\mu_0 * N * I}{(2r)} \qquad \dots(3)$$

If a number of current-carrying loops are stacked on top of each other to form a cylinder, or, equivalently, a single wire is wound into a tight spiral, the result is known as a solenoid. The field along the axis of the solenoid has a magnitude of (equation 4):

$$B = \mu 0 * n * I \qquad \dots(4)$$

Where n = N/L is the number of turns per unit length (or, in other words, the total number of turns over the total length).

An electric field E exerts a force on a charge q. A magnetic field B will also exert a force on a charge q, but only if the charge is moving (and not moving in a direction parallel to the field). The direction of the force exerted by a magnetic field on a moving charge is perpendicular to the field, and perpendicular to the velocity (i.e., perpendicular to the direction the charge is moving).

The equation 5 that gives the force on a charge moving at a velocity v in a magnetic field B is

$$F = qvB\sin\Theta \qquad \dots(5)$$

Where, Θ is the angle between the magnetic field and the velocity of the charge. This is a vector equation: F is a vector, v is a vector, and B is a vector. The only thing that is not a vector is q. Note that when v and B are parallel (or at 180°) to each other, the force is zero. The maximum force,

$F = qvB$, occurs when v and B are perpendicular to each other.

The direction of the force, which is perpendicular to both v and B, can be found using your right, hand, applying something known as the right-hand rule. One way to do the right-hand rule is to do this: point all four fingers on your right hand in the direction of v. Then curl your fingers so the tips point in the direction of B. If you hold out your thumb as if you're hitch-hiking, your thumb will point in the direction of the force. At least, your thumb points in the direction of the force as long as the charge is positive. A negative charge introduces a negative sign, which flips the direction of the force. So, for a negative charge your right hand lies to you, and the force on the negative charge will be opposite to the direction indicated by your right hand.

In this research work, an external magnetic field is applied using a solenoid setup along with additional arrangements for setup movement.

1.3 Effect of magnetic field in SMAW

In SMAW electromagnetic force, plasma stream force gravity and surface tension are the most important factors that affect metal transfer and spatter generation rate. It is conformed that metal transfer frequency was improved and spatter generation was diminished under the controls of external magnetic field. It was conformed that the external magnetic field could provide benefits in improving characteristics of arc plasma and liquid metal.

Application of external magnetic field has been reported in the literature to affect the characteristics of the welding arc and the weld properties. Magnetic field can be applied to the welding arc in three different modes. If magnetic field is in the direction of electrode travel, it is considered to be a longitudinal magnetic field. If the field is perpendicular to the direction of electrode travel and electrode axis, it is referred to as a transverse field. Factors which affect the arc behavior during the application of a magnetic field are as follows.

i. Distance between the electrodes
ii. Magnetic field intensity
iii. Arc current
iv. Weld material

II. LITERATURE REVIEW

Serdyuk, *et al.* (1963) reported the metal transfer when magnetic arc oscillation was applied to gas metal arc welding. Images of the metal transfer indicated the droplets were emitted from the electrode at the moment of maximum arc deflection and the path of the molten drop was the same as the direction of the arc deflection and the path of the molten drop was the same as the direction of the arc deflection and the path of the molten drop was the same as the time the drop was detached from the electrode.

Deminskii, *et al.* (1963) conducted experiments using GMAW process on an Aluminum-Magnesium alloy while a longitudinal magnetic field applied to the welding arc. The magnetic fields applied were alternating and of the order of 40 gauss. They reported the arc oscillated across the weld axis. They also applied an alternating, transverse magnetic field to the welding arc. It was reported this resulted in a change in the shape of the weld pool. Not only was the solidification affected but the mechanical properties were improved by the application of a magnetic field to the gas metal arc welding of aluminum and magnesium alloys.

Hicken *et al* (1972) reported that applying an optimum magnetic field to a welding arc on both nonmagnetic and magnetic materials increases welding speed several times, that produces undercut-free and non-porosity welds. Khan and Gupta (1978) notified that input parameters like welding current, welding speed; welding voltage and external magnetic field are highly influencing the quality of weld joints in SMAW. Karalis*et al* (1981) studied mechanical response of thin SMAW Arc Welded Structures when magnetic field is applied and proved that weldment properties are improved. Sharma (1995) developed an attachment for welding under variable external magnetic field and reported that by applying variable external magnetic field an attempt will be taken to improve the arc stability and weld beads. Robert (2004) studied the Engineering Principles of Welding processes and explained the physical, chemical and metallurgical properties of the weld beads.

Mahadi and Rasel (2011) developed a setup for improving weldability and associated properties by welding under variable external magnetic field and he reported that the welding arc affected by magnetic field produced in a work piece adjacent to it. Magnetic disturbance surrounding the welding arc may cause arc instability which is responsible for lack of fusion, porosity and unevenly welded joints. At the same time, there is considerable spattering which, if avoided, obviously results in good quality and economy. If the arc can be confined into the smallest possible region, it is of considerable help in improving weldability and associated properties. This attachment for welding under variable external magnetic fields has been developed as an attempt for improving arc stability and better weld beads apart from savings in electrode consumption. Singh and Gupta (2012) predicted Weld Bead Geometry and mechanical properties in SMAW under external magnetic field using Artificial Neutral Networks. And found that welding voltage, arc current, welding speed and external magnetic field have significant effects on the weld bead width.

From the above literature review the objectives set for the current research work are: (i) to study the effect of magnetic field on weld-quality and weld geometry when an external magnetic field is applied in SMAW, (ii) to design a setup to create an external magnetic field to perform SMAW, and (iii) to compare the properties of the weld beads in SMAW with the external magnetic field and without the external magnetic-field.

III. METHODS and MATERIALS

To achieve objectives set the steps involved are designing a setup to create an external magnetic field and perform the SMAW with the external magnetic field and without the external magnetic field and carrying out mechanical property test like hardness test on Rockwell hardness test equipment and do the comparative study.

3.1 DEVELOPMENT OF THE SETUP

The components used for the development of the setup are square Mild Steel bar with 19.05 mm thickness, 23 gauge copper wire, bar type Solenoid(1.298mH), four cylindrical shafts of diameter 18.5mm, four Bearings (ball type), Resistance pot(1kΩ, 3W), Autotransformer and Iron bar with circular cross-section.

Inductance of the solenoid calculated from known values like resistance, impedance and resultant resistances.

R = 0.289ohm , Z=0.4985

We know that $Z^2 = R^2+X_L^2$

$X_L = \sqrt{0.49850^2 - 0.2890^2}$ =0.40648

$X_L=2\pi fL$, Frequency = 49.85 Hz

$L = X_L/2\pi f = \frac{0.40648}{2\pi * 49.85}$ =1.298mH

Frequency used in the calculation of inductance is 49.8 HZ. Calculated the inductance value of the solenoid which is used in the setup is 1.298mH.

An attachment which will create external magnetic field is the one of the most important factor for this experiment. To fulfill the requirement, an attachment has been designed which is capable of moving throughout the weld run with the welding torch and produce variable external magnetic field. The external magnetic field is designed for 220 volts Alternating Current (AC). The current flowing through the coil can be varied by using a regulator. The attachment is made of 19.05 mm (¾ inch)square Mild Steel square bar, 23 gauge copper wire, a ferromagnetic core which will increase the magnitude of the magnetic flux density in the solenoid and a variable resistance. An arrangement has been made for moving the attachment by using four bearing wheels. A 19.05 mm (¾ inch) square Mild Steel square bar is used for the attachment which will create variable external magnetic field. The Mild Steel square bar is designed in such a shape (shown in Fig. 1) that it can produce sufficient magnetic field during welding process. This setup is created through different types of manufacturing processes such as welding of the mild steel square bars, turning operations on shafts of bearings, welding of bearings with the setup by stainless steel electrodes.

Figure 1: Developed Setup

The air gap is taken as small as possible to maximize the effect of the magnetic field. The attachment is constructed in a flexible desired shape so that the arc and temperature of the welding will not hamper the attachment. The back side of the attachment is integrated with a ferromagnetic core which will increase the magnitude of the magnetic flux density in the solenoid. The ferromagnetic core and mild steel bar combination should be so rigid that there will be no air gap between the ferromagnetic core and mild steel bar. Then the core is insulated by the heat resistant paper which will create insulation between the core and Solenoid. Insulated copper wire of 23 gauge is selected for the solenoid. After looping the 23 gauge copper wire around the core, the attachment is ready for creating external variable magnetic field. A variable resistance is placed in the system in order to get different strength of the magnetic field by varying the supply of current.

3.2 THE SMAW WITH AND WITHOUT APPLYING EXTERNAL MAGNETIC FIELD

The electromagnet attachment works on the principle of Electromagnetism. In this attachment, the magnetic poles of the electromagnet face each other. When there is a flow of current in the solenoid, a magnetizing effect is produced in the air gap (i.e. between the two poles of the electromagnet). To move the attachment four bearing wheels have been welded to the four corners of the mild steel bar attachment. An AC power source with variable resistance is used to provide different magnetizing currents to the electromagnet. This is accomplished by connecting the autotransformer, resistance pot, ammeter, and solenoid setup correctly. This design uses an autotransformer to supply the solenoid with the necessary input voltage, a resistance pot to adjust the resistance and supply the necessary current, and an ammeter to measure the current. The setup was manually moved along the weld run during the welding procedure. In Figure 2, a sample of Shielded Metal Arc Welding performed in presence of external magnetic field with the help of solenoid is shown.

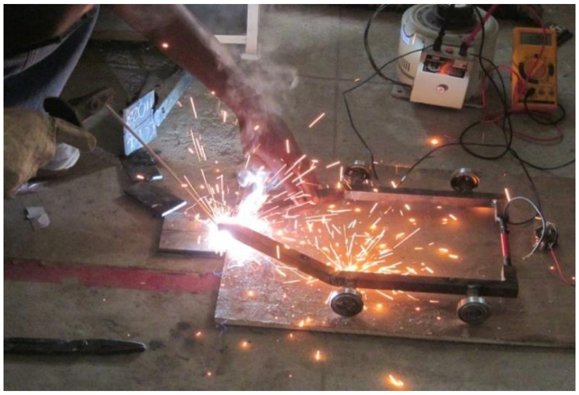

Figure 2: Welding operation in presence of external magnetic field

The conventional Shielded Metal Arc Welding process performed without applying external magnetic field is shown in Figure 3. .

Figure 3: Conventional SMAW

3.3 ROCKWELL HARDNESS TEST FOR BOTH THE CASES

The hardness of various materials is determined using the Rockwell Hardness Test. In this, the hardness values of the work pieces were measured both with and without the presence of a magnetic field (shown in Figure 4), and the results were recorded.

Figure 4: Performing Rockwell Hardness Test

IV. RESULTS AND ANALYSIS

The experiment uses an external magnetic field to execute the welding procedure, with an input voltage of 115V and an output current of 0.05A. The values of other parameters are shown in Table 4.1.

Table 4.1 Readings of the parameters during the experiment

Sample Number	Input Voltage(Volts)	t (plate thickness in mm)	Welding current (Amp)	Magnetizing Current (Amp)	Rockwell Hardness Number
1	-	5	115	-	57
2	5	5	115	0.05	65

From the above Table 4.1, Sample 1 indicates without External Magnetic Field and Sample 2 indicates with External Magnetic Field. From this table the hardness of the work piece is improved.

Figure 5: Absence of external magnetic field

Figure 6: Presence of external magnetic field

From the above figures, the weldment is smoother and no spatter in Figure 6 than the Figure 5 which is performed in the absence of external magnetic field. The results of the Hardness test conducted in the absence and presence of an external magnetic field are shown in Table 4.2 and Table 4.3, respectively.

Table 4.2 Hardness test readings without external magnetic field

P Position (on weld bead)	R Rockwell Hardness Number
E Base metal zone at end position	57
Heat affected zone	54
Weld bead	62

Table 4.3 Hardness test readings in presence of external magnetic field

Position(on weld bead)	Rockwell Hardness Number
Base metal zone at end position	58
Heat affected zone	67
Weld bead zone	68

This observation indicates that the application of an external magnetic field produces better hardness values, as well as no spattering loss and smoother weld beads. The work pieces are not smoother and get spatter along the molten pool when there is no external magnetic field.

V. DISCUSSIONS

Performing SMAW with external magnetic field resulted in increase in Rockwell hardness number than performing SMAW without the external magnetic field. This is due to the fact that, performing SMAW with external magnetic field decreases the pinch forces, which were caused by high currents. In general the pinch forces deflect the arc to the forward or backward instead of normal path. This causes edge distortion at the ends of weldment. This is also reduced by providing external magnetic field. Based on the present study the following conclusions are drawn
(i) hardness is improved in case of SMAW with external magnetic field, (ii) fusion of weld joint is improved, (iii) arc stability is improved, (iv) the desired position of the arc is maintained throughout the weld run in case of welding with external magnetic field and with minimum spatter, and (v) weld bead is smoother and edge distortion is reduced.

REFERENCES

[1] Serdyuk, D.B., and Kornienko, A.N., (1963), “The welding arc in an alternating transverse magnetic field”. *Automatic welding* (10):7–13.

[2] Deminskii, Y. A., and Dyatlov, V. I. (1963), “Magnetic control during gas shielded arc welding with a consumable electrode”. *Automatic Welding (4): 67–68.*

[3] Hicken, G. K., and Jackson, C. E. (1966), “The effect of applied magnetic fields on welding arcs”. *Welding Journal 45(11): 515-s to 524-s.*

[4] Khan M.I. (1979), “a study of Hard facing under magnetic field”, proc. ISME conf. New Delhi, paper E.P. 4.1 Dec., PP.174.-176.

[5] D. G. Karalis, V. J. Papazoglou, and D. I. Pantelis., (1981), “Mechanical Response of Thin SMAW Arc Welded Structures: Experimental and Numerical Investigation” . Theoretical and Applied Fracture Mechanics 51, pp 87-94, Elsevier.

[6] Khan M.I., (1992), “study of effect of superimposition of longitudinal magnetic field on arc characteristics, bead geometry, microstructure and mechanical properties”. Conf. on prod. Engg.Design and control, university of Alexandria, Egypt.

[7] Sharma, S., (1995), “Development of Attachment for Welding under Variable External Magnetic Field”, Journal of The Institution of Engineers (India), Volume 76, ISSN 0020-3408.

[8] Kang, Y.H. Na, S.J., (2002), “A study on the Modeling of magnetic Arc Deflection and Dynamic Analysis of Arc Sensor A feedback signal from a magnetic field introduced into the arc may lead to improved sensing of arc variables”. Welding Journal, Neywork, USA, ISSN 0043-2296, Vol 81, Part 1, pages 8-S-13-S.

[9] Robert, Wissler., (2004), “Engineering Principles of Welding- processes, physics, chemistry and metallurgy of welding journal”.

[10] R.P. Singh and R.C. Gupta Vol.8 number 1., (2012). “prediction of Weld Bead Geometry in SMAW under external magnetic field using Artificial Neutral Networks”, International Journal of Manufacturing Technology and Research.

[11] Groover M P., (2010), “Fundamentals of Modern Manufacturing Materials, Processes” and Systems 4thedn.

[12] M. S. U. R. Mahadi, N. A. and M. S. I. Rasel., (2011), “Improving weldability and associated

properties by welding under variable external magnetic field" *ICME 11-RT-033-welding Journal.*

[13] Ecer G.M., (1980), "Magnetic deflection of the pulsed current welding arc". *Welding journal* 59(6): 183-s to 191-s.

[14] Jayarajan T.N and Jackson, C.E., (1972), "Magnetic control of gas tungsten arc welding process". *Welding Journal* 51(8): 377-s to 385-s.

[15] Shetty Kang, Y. H. Na, S. J. (2002), "A study on the Modeling of Magnetic Arc Deflection and Dynamic Analysis of Arc Sensor A feedback signal from a magnetic field introduced into the arc may lead to improved sensing of arc variables". *Welding Journal, Neywork* , USA, ISSN 0043-2296,Vol 81: Part 1, pages 8-S-13-S.