Effects of External Magnetic Field on Mechanical properties of a welded M.S metal through Metal Shield Arc Welding

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Abstract— The aim of this study is to show the characteristic changes obtained by the deflection of welding arc in the presence of external magnetic field. The magnetic field has been applied from various orientations upon the weld bead. The welding process which has been considered under study is shielded metal arc welding on Mild steel plate. The objective of this paper is to study the effect of magnetic field on the weld quality and geometry when the field is applied longitudinal to the electrode travel i.e. the field lines are perpendicular to the electrode travel. However there is lack of information for optimum parameters, very little work has been reported in this direction. A magnetic field externally applied to the welding arc, deflects the arc by electromagnetic force in the plane normal to the field lines. The magnetic field exerts force on the electrons and ions within the arc, which causes the arc to be deflected away from the normal arc path. The welding arc can be deflected forward, backward, or sideways with respect to electrode and welding direction depending upon the direction of an external magnetic field. In this paper various mechanical properties tests such as tensile strength, hardness, impact test etc. are conducted to see the effect of external magnetic field on it. It is observed that weld pool penetration reduces while the weld bead width increases thereby affecting the parameters of the process. The results and conclusions are discussed as per the observations while the tensile strength and hardness of parent materials are observed as well.

Keywords— Arc Instability, Magnetic Effects, Metal shield arc Welding, Weld Beads.

I. INTRODUCTION

Welding is a process in which materials of the same fundamental type or class are brought together and caused to join (and become one) through the formation of primary chemical bonds under the combined action of heat and pressure. The definition found in ISO standard is “Welding is an operation in which continuity is obtained between parts for assembly, by various means”. Hence, the welding is the fusion of two or more pieces of metal together by using the heat produced from an electric arc welding machine. Arc welding dates back to the late 1800’s, when a man was welding with a bare metal rod on iron, the sparks from the welding caught a stack of newspapers on fire near him and while welding, he noticed that his welds started looking a lot better. The reason for this was the smoke took the oxygen out of its welding environment and decreased porosity. The arc is struck between the electrode and the metal. It then heats the metal to a melting point. The electrode is then removed, breaking the arc between the electrode and the metal. This allows the molten metal to “freeze” or solidify. The arc is like a flame of intense heat that is generated as the electrical current passes through a highly resistant air gap. During welding, magnetic field is set up in the plane of the parts being joined and circumferentially around the electrode and the plate as shown in Fig 1. The field, F1, is set up around the electrode; the field F2, around the plate plates being joined and the field, F3, in the plates adjacent to the arc and in a direction similar to that of field F1. Since it is not possible to remove these fields from welding operation, it is necessary to use external control as a means to overcome these magnetic effects [1]. A magnetic field externally applied to the welding arc deflects the arc by electromagnetic force (Lorentz force) in the plane normal to the field lines. The magnetic field exerts force on the electrons and ions within the arc, which causes the arc to be deflected away from the normal arc path. The welding arc can be deflected forward, backward, or sideways with respect to electrode and welding direction depending upon the direction of an external magnetic field. In this paper various mechanical properties tests such as tensile strength, hardness, impact test etc. are conducted to see the effect of external magnetic field on it. It is observed that weld pool penetration reduces while the weld bead width increases thereby affecting the parameters of the process. The results and conclusions are discussed as per the observations while the tensile strength and hardness of parent materials are observed as well.
dependent upon the flux density of the applied magnetic field, the arc current, arc length, and so on [4,6,7].

2. Application of magnetic field

2.1 Longitudinal magnetic field:
A magnetic force acts on the arc, in this system when the angle between the direction of the electron stream and magnetic lines of force are not zero. As the arc has a conical shape and the current carrying electrons also moves along the surface of the arc, their motions can be resolved in two components, one along the axis of the arc and other perpendicular to it. The component along the arc does not contribute to the magnetic movement. The component perpendicular to arc exerts a force on the arc causing the arc to rotate clockwise or anticlockwise depending upon the direction of the magnetic field and polarity used.

2.2 Transverse magnetic field:
According to the Flemings left hand rule the arc in the influence of transverse magnetic field will be deflected forward or backward depending upon the direction of magnetic field lines force and the polarity of welding system. Work of earlier investigation can be analyzed keeping this in mind. Kovalev showed that the transverse magnetic field can be used as automatically regulating the depth of penetration. Hicken and Jackson found beneficial effects of constant transverse magnetic field when the arc was deflected forward with respect to the electrode travel speed. It was possible to increase the welding speed four times and steel obtains the welds free from undercuts. Weld width was found to reduce with increase in magnetic field. Sheinkin found the application of transverse magnetic field to increase the productivity of the submerged arc welding process used for making butt joints between prepared edges.

3. Experimental procedure

3.1 Preparation of Specimens:
The mild steel pieces of the dimension 200 mm X 20 mm X 6 mm are used as a work-piece for the welding. Each metal piece first cleaned for dust and rust. Before the actual welding process the space between the specimens is fixed with a support. The space between the specimens for the butt welding is depends upon the thickness of the work-piece. For a 6 mm thickness there is no requirement of making groove, so a 3 mm gap is maintained during the whole process of welding. The quality and geometry of weld is much depends on correct and same gap throughout length of the specimen.
3.2 Welding In Magnetic Field (M):

The magnetic field is applied as per the set-up and then the arc welding machine and electrodes are fixed at their respective places. Multi-meter, clamp-meter and gauss-meter are placed and connected to take the readings. As per the semi-automation to the process feed rod is connected with the work-piece motion. The weld-pieces obtained after the process is shown in fig. different welding parameters readings associated with the process are tabulated and it is shown in the table no.1.

![Figure-5 Image for cleaning of Specimen](image)

![Figure-6 Image shows welding of specimen with magnetic field magnetic field](image)

<table>
<thead>
<tr>
<th>WORKPIECE NO.</th>
<th>CURRENT (A)</th>
<th>VOLTAGE (V)</th>
<th>MAGNETIC-FIELD INTENSITY (GAUSS)</th>
<th>WELDING SPEED (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1.</td>
<td>90</td>
<td>25</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>M2.</td>
<td>90</td>
<td>25</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>M3.</td>
<td>90</td>
<td>25</td>
<td>70</td>
<td>60</td>
</tr>
</tbody>
</table>

Table-1 Shows operating parameters for welding (with magnetic field)

3.3 Welding Without Magnetic Field (WM):

The similar setting as with magnetic welding is used in without magnetic field process of welding. Only change is that the magnetic field arrangement is removed. The range of current and voltage are remained similar to the magnetic field welding. The weld-pieces obtained after the process is shown in fig. different welding parameters readings associated with the process are tabulated and it is shown in the table no.2.

![Figure-7 Image for welding of specimen without magnetic field](image)

Table-2 Shows operating parameters for welding (without magnetic field)

<table>
<thead>
<tr>
<th>WORKPIECE NO.</th>
<th>CURRENT (A)</th>
<th>VOLTAGE (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM1, WM2, WM3</td>
<td>90</td>
<td>25</td>
</tr>
</tbody>
</table>

3.4 Grouping and cutting of weld-pieces:

Each weld-piece (with and without magnetic field) cut into three pieces and grouped according to the range of current and voltage and provided a specific code. Now, the total no. of weld-pieces is 9 and their corresponding parametric readings are tabulated as below. Each weld specimen has a code which shows its specifications. The letter shows the weld-piece is from the category of magnetic field or without magnetic field. The letter M shows magnetic field and WM shows without magnetic field. The number provided to the code shows its range of current and voltage. The number 1, 2, 3 shows the range of current 110-120 Ampere and voltage 23-26 volts.

Weld-pieces with magnetic field:

Table-3 Shows experimental value for current, voltage, magnetic field intensity and welding speed at various stage of experiment.

![Figure-8 Image shows welding of specimen without magnetic field](image)
3.5 Hardness test:

Vickers hardness test

The Vickers hardness is as an alternative to the Brinell method to measure the hardness of materials. The Vickers test is often easier to use than other hardness tests since the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. It is ability to resist plastic deformation from a standard source. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH). The hardness number can be converted into units of pascals, but should not be confused with a pressure, which also has units of pascals. The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force, and is therefore not a pressure.

3.6 Tensile strength test:

This test is used to measure the tensile strength of a welded joint. The tensile strength, which is defined as stress in kgf per square meter. It is calculated by dividing the breaking load of the test piece by the original cross section area of the specimen. The test result which is conducted on universal testing machine (UTM) is given in the table. The width thickness of the test specimen are measured before testing, and the area in square inches is calculated by multiplying these before testing, and the area in square inches is calculated by multiplying these two figures.

The shearing strength of the weld in pounds per linear inch is determined by dividing the maximum load by the length of fillet weld that ruptured. The shearing strength in pounds per square inch is obtained by dividing the shearing strength in pounds per linear inch by the average throat dimension of the weld in inches. The test specimens are made wider than required and machined down to size.
3.7 Impact Test:

The two kinds of specimens used for impact testing are known as Charpy and Izod. Both test pieces are broken in an impact testing machine. The only difference is in the manner that they are anchored. The Charpy piece is supported horizontally between two anvils and the pendulum strikes opposite the notch. The Izod piece is supported as a vertical cantilever beam and is struck on the free end projecting over the holding vise. A Charpy test measures the weld's ability to withstand an impact force.

![Charpy test specimen](image1.png)

**Fig. 11 - Image for UTM Used for tensile test**

4. Results and discussion

4.1 Effect of external magnetic field on Hardness

The determination of the Rockwell hardness of a material involves the application of a minor load followed by a major load, and then noting the depth of penetration from a dial, on which a harder material gives a higher number. The test result of the hardness test was conducted on both types of weld-pieces (with magnetic field and without magnetic field) are shown in the table-5 below. From experimental data the hardness increases within the magnetic field. When magnetic field applied on vertical the hardness of metal is gradually increases up to 262.11

**Table 5 - Shows Experimental values for Hardness carried out at various conditions**

<table>
<thead>
<tr>
<th>WORK-PIECE NO.</th>
<th>PARENT METAL (HV)</th>
<th>WELD METAL (HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MILD STEEL (WITHOUT MAGNETIC FIELD)</td>
<td>154.754</td>
<td>194.0125</td>
</tr>
<tr>
<td>WITH MAGNETIC FIELD (HORIZONTAL)</td>
<td>154.754</td>
<td>176.68</td>
</tr>
<tr>
<td>WITH MAGNETIC FIELD (VERTICAL)</td>
<td>154.754</td>
<td>262.11</td>
</tr>
</tbody>
</table>

![Hardness test specimens](image2.png)

**Fig 12 - Image for Weld specimen for Charpy test**

4.2 Effect of external magnetic field on tensile strength

In the presence of external magnetic field welding is performed. After that tensile test is carried out by UTM. Three specimens M1, M2, & M3 are taken for tensile test. It was observed that tensile strength of weld joints is much more improved. Detail observation data are shown in the test report-1, 2 & 3.

![Tensile test setup](image3.png)

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![Test Report Tensile](image4.png)

**Fig. 13 - Test Report Tensile**

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4.3 Effect of external magnetic field on impact test

The toughness values of the weld-pieces are tabulated below. Weld-pieces are placed at the impact testing machine as simply supported

Table-6 Shows Experimental values for Toughness (J) carried out at various conditions

<table>
<thead>
<tr>
<th>WORK-PIECE NO.</th>
<th>TOUGHNESS (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITHOUT MAGNETIC FIELD</td>
<td>20.5</td>
</tr>
<tr>
<td>WITH MAGNETIC FIELD (VERTICAL)</td>
<td>36.0</td>
</tr>
<tr>
<td>WITH MAGNETIC FIELD (HORIZONTAL)</td>
<td>12.5</td>
</tr>
</tbody>
</table>

4.4 Comparison of all the mechanical properties with and without application of external magnetic field

The effect of magnetic field on the tensile strength is increased. The change in the properties is calculated in terms of percentage and there is an increase of 6.6% on an average. This shows that a magnetic field applied longitudinal to weld bead, deflected the arc such that the tensile properties of the weld-pieces increases

Table-7 Shows Percentage change in value for without magnetic field and Magnetic field vertical for various mechanical properties

<table>
<thead>
<tr>
<th>PROPERTIES</th>
<th>WITHOUT MAGNETIC FIELD</th>
<th>MAGNETIC FIELD (VERTICAL)</th>
<th>CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TENSILE STRENGTH</td>
<td>399</td>
<td>442</td>
<td>9.72% INCREASE</td>
</tr>
<tr>
<td>HARDNESS</td>
<td>194.012</td>
<td>262.11</td>
<td>25.98% INCREASE</td>
</tr>
<tr>
<td>TOUGHNESS</td>
<td>20.5</td>
<td>36.0</td>
<td>43.05% INCREASE</td>
</tr>
</tbody>
</table>

Table-8 Shows Percentage change in value for without magnetic field and Magnetic field Horizontal for various mechanical properties

<table>
<thead>
<tr>
<th>PROPERTIES</th>
<th>WITHOUT MAGNETIC FIELD</th>
<th>MAGNETIC FIELD (HORIZONTAL)</th>
<th>CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TENSILE STRENGTH</td>
<td>399</td>
<td>357</td>
<td>10.52% DECREASE</td>
</tr>
</tbody>
</table>
HARDNESS  
<table>
<thead>
<tr>
<th>194.012</th>
<th>176.68</th>
<th>8.93% DECREASES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOUGHNESS</td>
<td>20.5</td>
<td>12.5</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

On the basis of different experiments welding process and effect of magnetic field in the longitudinal direction the following conclusions are derived:

- Effect of magnetic field applied longitudinal to welding direction affects the bead width of joint and decreases it.
- Undercuts, spatter etc. welding defects are reduced.
- The tensile strength of the weld joint is on improvement side due the refinement of grains.
- Hardness of the weld Increases as compared with the weld-pieces which are welded without magnetic field.
- Reinforcement height of weld reduces as the weld bead width is increasing.
- Toughness of the weld metal increases.
- When solenoid is introduce in the transverse direction then the mechanical properties such as Hardness, Toughness and Tensile strength are decreases.
- If travel speed is increased, tensile strength of weld generally increases.
- If magnetic field is increased, tensile strength of weld generally increases.

Hence, we can say that the use of external magnetic field longitudinal to the welding direction is helping in improvement of weld quality and weld geometry. It can also affect the weld quality.

6. REFERENCES

[15] Principles of Magnetism and Stray Currents in Rotating Machinery
By Paul J. Nippes, P.E., President of Magnetic Products and Services, Inc.