ABSTRACT

The effects of longitudinal weld pool oscillation on tensile properties of IS 2062-2006 mild steel welds were investigated. Mild steel workpieces were welded at different frequencies and amplitudes of longitudinal oscillation. Frequencies and amplitudes of oscillations were varied in the range of 0 to 400 Hz and 0 to 30µm, respectively. Test specimens were tested and yield strength, ultimate tensile strength, percentage elongation, impact strength and hardness were determined. Metallographic examination of the test specimens was carried out. Yield strength, ultimate tensile strength, percentage elongation improves significantly in oscillatory (longitudinal) prepared welds in comparison to stationary welded test specimens. The maximum increase in tensile properties (yield strength-21.37%, U.T.S.-20.87% ) in oscillatory prepared welds is at 400Hz -5µm and the minimum increase is at 100Hz - 5µm condition. The increase in values of tensile properties under longitudinal oscillation is attributed to grain refinement, dendrite fragmentation and grain detachment mechanisms.

Key Words: Longitudinal Weld Pool Oscillation(LWPO), Mild steel, Tensile properties, Grain size, Dendrites

1. INTRODUCTION

Steel constitute the most widely used category of metallic material, primarily because they can be manufactured relatively inexpensively in large quantities to very precise specifications. They also provide a wide range of mechanical properties, from moderate yield strength levels (200 to 300 MPa) with excellent ductility to yield strengths exceeding 1400 MPa with fracture toughness levels as high as 110 MPa [1]. The composition of filler wire and shielding gas in GMA welding of mild steel determines the inclusion characteristics, microstructure and mechanical properties. Altering the composition of the metal powders in the core, metal cored wires are designed to meet a huge variety of applications[2]. The metal cored wire normally used in the process is being replaced by flux-cored
wire or solid wire due to higher deposition rate and better wetting [3,4]. Venkataraman et al. [5] obtained grain refining in the electroslag welds of steels by electrode vibration and enhanced electromagnetic stirring of the weld pool and improved their toughness and resistance to centerline cracking. Dendrite fragmentation was considered as the mechanism for grain refining. Naoki et al. [6] stated that the grain size is strongly affected by the mechanical vibration. By applying vibration, the grain size, especially the granular structure in the inner area becomes small. Weiter Wu [7] experimentally confirmed that with welding, when vibration is applied during the weld process, solidification of the weld pool is affected. As the weld pool solidifies, dendrites can be broken up before they grow to become too large. This finer microstructure provides better mechanical properties and eliminate hot cracking sensitivity of the weld. Govindarao et al. [8] have used vibration techniques for improving mechanical properties of steels. During the welding of metals along with mechanical vibrations, uniform and finer grain structures can be produced. This increases the toughness and hardness of the metals. Jaskirat Singh et al. [9] studied the effect of mechanical vibration and given that that the weld joints fabricated with vibratory condition were found to possess relatively high yield strength (YS) and high ultimate tensile strength (UTS), without any appreciable loss in the ductility. Metallographic studies show that the weld metals under vibratory condition possessed relatively finer microstructure and hence high micro hardness, owing to dendrite fragmentation.

2. EXPERIMENTAL PROGRAMME

The plates of IS2062-2006 steel were machined on a shaper and an FN 2 universal milling machine to the required dimensions (250 mm x 70 mm x 10 mm) as shown in Fig. 1, was prepared to fabricate GMA welded joints. Work-pieces were straightened in a fitting shop.

![Fig. 1 Dimensions of joint configuration](image)

Experimental set up had been fabricated in the workshop. The set-up shown in fig. 2 consists of a hollow rectangular base plate (640mm x 410mm x 40mm). The base plate and the oscillatory table were made of mild steel plates. The oscillatory table rests on two shafts which are mounted on four bearings fixed over the base plate. The oscillatory table has a hole in the vertical plate for coupling the vibration exciter rigidly. The workpieces to be welded were clamped on the oscillatory table with
the help of C-clamps and angle iron pieces. During welding the workpieces were oscillated at
different frequencies and amplitudes of vibration with the help of an audio oscillator/power amplifier
and vibration exciter. Work pieces were welded in the middle by making a single V-groove by
machining. The frequency range of oscillation was 0-400 Hz at amplitudes of 0µm, 5µm, 10µm,
20µm and 30µm. Voltage and current were maintained in the range of 25-30 volts and 130- 140
amps. respectively. During experimentation, input energy, arc length, speed of electrode travel and
other electrode parameters were kept almost the same. During investigation, the frequency and the
amplitudes of longitudinal oscillations were increased from 400Hz to 600Hz and 30µm to 60µm.
Deterioration of mechanical properties were obtained, therefore, all experiments were done up to
400Hz frequency and 30µm amplitude of oscillations. metal-cored wire E70C-6M of Ø1.6 mm was
selected for welding steel workpieces. Since little-to-no slag formation occurs in metal cored wires,
an efficiency range of 93-96% for Ø1.6 mm is commonly achieved. Subsize flat tensile specimens
were prepared from the weld metal region (longitudinal direction) alone as per the ASTM E8M
standard to evaluate all weld metal tensile properties. These specimens were machined on a shaper
and a milling machine. Sharp corners were smoothed to avoid stress concentration. The central
portion was reduced in cross section compared with the end portion to ensure fracture at weldments.
The End shape was made to suit the gripping device of the tensile testing machine. A Test specimen
was long enough to ensure that necking does not take place near the ends. All surface irregularities
were removed in machining the test specimens. Microstructure study samples (cross section 10mm x
10mm) were cut from welds of plate thickness 10mm with a hacksaw. Rough grinding of these
specimens was carried out on a belt sander and specimens were kept cool by frequent dipping in
water. Rough grinding was followed by fine polishing. For micro-structural studies of these polished
specimens, the structural characteristics were made visible by dipping the specimen in an etchant
(2% nital solution) for about 10 seconds and later washed with methanol. Etched specimens were
used for micro structural studies.
TABLE 1 Chemical composition of IS 2062-2006 steel

<table>
<thead>
<tr>
<th>C</th>
<th>S</th>
<th>P</th>
<th>Mn</th>
<th>Si</th>
<th>Al</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.14</td>
<td>0.14</td>
<td>.024</td>
<td>0.82</td>
<td>0.20</td>
<td>.024</td>
<td>&lt;0.02</td>
</tr>
</tbody>
</table>

TABLE 2 Chemical composition of Metal-cored wire E70C-6M

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.12</td>
<td>1.75</td>
<td>0.90</td>
<td>0.03</td>
<td>0.03</td>
<td>0.50</td>
</tr>
</tbody>
</table>

TABLE 3 Mechanical properties of IS 2062-2006 steel + E70C-6M filler metal weld

<table>
<thead>
<tr>
<th>LWPO parameters</th>
<th>Weld Properties</th>
<th>Comparison of without and with LWPO welds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq. (Hz)</td>
<td>Amp. (µm)</td>
<td>0.2 % YS (MPa)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>382.75</td>
</tr>
<tr>
<td>400 (Optimum Value)</td>
<td>5 (Optimum Value)</td>
<td>464.58</td>
</tr>
</tbody>
</table>

TABLE 4 Measured value of FZ attributes for IS 2062-2006 steel + E70C-6M filler metal weld

<table>
<thead>
<tr>
<th>LWPO Parameters</th>
<th>Fusion Zone Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (Hz)</td>
<td>Amplitude (µm)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>400 (Optimum Value)</td>
<td>5 (Optimum Value)</td>
</tr>
</tbody>
</table>

The tensile specimens were prepared to evaluate yield strength, tensile strength, elongation and reduction in cross sectional area. V notched charpy specimens were prepared to evaluate the toughness of the joints. Tensile testing was carried out using a 5 T Instron Machine. The 0.2% offset yield strength was derived from the load-displacement diagram. Vicker’s microhardness tester was
used for measuring the hardness of the weld metal. Microstructural examination was carried out using a light optical microscope incorporated with an image analyzing software metallurgy plus. The specimens for metallographic examination were sectioned to the required sizes from the joint comprising weld metal, HAZ and base metal regions and polished using different grades of emery papers. Final polishing was done using the diamond compound (1 µm particle size) in the disc polishing machine. Specimens were etched with 2% nital solution to reveal the microstructure.

3. RESULTS AND DISCUSSION

3.1 Tensile properties

The tensile properties such as yield strength, ultimate tensile strength, percentage elongation, reduction in area of IS 2062-2006 steel joints were evaluated and presented in Table 3. The yield strength and ultimate tensile strength of GMAW joints (stationary) are 382.75 MPa and 489.91 MPa respectively. However, the yield strength and tensile strength of GMAW joints (optimum oscillatory condition) are 464.58 MPa and 592.16 MPa respectively. This indicates that there is a 21.37% increment in strength values due to oscillatory GMA welding compared to stationary weld. Elongation and reduction in the cross-sectional area of the weld prepared under stationary GMA welding are 22.80% and 60.93% respectively. However, the elongation and reduction in the cross-sectional area of GMAW joints (optimum oscillatory condition) are 3.20% and 11.67% respectively.

![Fig. 3 Effect of amplitude and frequency on (a) Yield strength (b) Ultimate tensile strength](#)

![Fig. 4 Tensile test specimen](#)
3.2 Microhardness

The microhardness across the weld cross section was measured using a Vickers Microhardness testing machine, and the values are presented in Table 4. The microhardness of the weld metal prepared under stationary condition is 173 VPN. However, the microhardness of the GMAW joints under oscillatory condition in the weld metal region is 193VPN (optimum). This suggest that the hardness is increased in the weld metal region of GMAW joints due to weld pool oscillation.

3.3 Microstructure

Microstructure of all the joints was examined at different locations, but most of the tensile specimens failed in the weld metal region, and the optical micrographs taken at the weld metal region alone are displayed in Fig. 7 for comparison purpose. The stationary weld metal contains coarse and elongated grains with uniformly distributed very fine precipitates. Better grain refinement is obtained in the case of weld pool oscillation of mild steel welds. In weld pool oscillation the dendrite fragmentation and better mixing together with higher cooling are the mechanisms of grain refinement. Dendrite arm spacing plays an important role to increase in mechanical properties.
4. CONCLUSION

In this paper, the mechanical properties of GMAW joints of IS 2062-2006 were evaluated. From this investigation, the following important conclusions have been derived:

i) Percentage increase in yield strength for welded specimens (IS 2062-2006 steel + E70C-6M filler welds) prepared under longitudinal oscillatory conditions at 400 Hz frequency and 5 \( \mu \text{m} \) amplitude of oscillations is about 21.37\% higher than stationary welded specimen respectively.

ii) There is appreciable increase in ultimate tensile strength of welds fabricated under longitudinal oscillatory condition with respect to the ultimate tensile strength of stationary prepared welds. For 100 Hz the maximum ultimate tensile strength is at 30 \( \mu \text{m} \) whereas for 400 Hz the maximum value of ultimate tensile strength is at 5 \( \mu \text{m} \) amplitude of oscillation. Percentage increase in ultimate tensile strength for longitudinal oscillated test specimens when compared with stationary welded specimens are about 20.87\% at 400 Hz frequency and 5 \( \mu \text{m} \) amplitude of oscillation.

iii) The percentage reduction in area and percentage elongation in case of welds prepared under oscillatory conditions increases significantly when compared with stationary prepared welds.

iv) Microhardness of welds fabricated under oscillatory conditions show increased values at extreme ends of welds along transverse direction.

v) The best results are obtained at 400Hz-5\( \mu \text{m} \) for longitudinal oscillated welds.
5. REFERENCES


