EXPERIMENTAL INVESTIGATION OF
THE EFFECT OF VIBRATION ON
MECHANICAL PROPERTIES OF AISI 1018
MILD/LOW CARBON STEEL WELDED
JOINT USING SMAW

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Abstract- This paper investigates the effect of mechanical vibrations on the mechanical properties of welded joint. In this research, an attempt is made to improve the mechanical properties of the weld metal through vibratory treatment. Finer grain structures can be produced during the welding of metals along with mechanical vibrations. The auxiliary vibration produces disturbance in weld pool during solidification.

In this work, we induced auxiliary mechanical vibrations during the Arc welding process on mild steel pieces having 10 mm thick butt joints. The outcome from the current study pointed out that the butt welded joints prepared with vibratory conditions are found to possess relatively high tensile strength as compared to the same without vibratory conditions.

Keywords- Heat Affected Zone (HAZ), Manual Arc Welding (MAW), Vibratory Weld Conditioning (VWC), Shielded Metal Arc Welding (SMAW), American Welding Society (AWS), American Iron and Steel Institute (AISI)

I. INTRODUCTION

Shielded metal arc welding (SMAW), also known as manual metal arc welding (MMA or MMAW) is a manual arc welding process that uses a consumable electrode covered with a flux to lay the weld. An electric current, in the form of either alternating current or direct current from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined. The work piece and the electrode melt forming the weld pool that cools to form a joint. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapours that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination.

Due to the low cost of the equipment, the low operating costs of the process and the ease of transporting the equipment, this flexible process is ideally suited to repair work benefits of MMA Welding are: Flexible, Low Cost, and ease of Repairs. Butt welding is used to connect parts which are nearly parallel and don't overlap.

Properties of weld metals are greatly influenced by type of microstructure and grain size. Fine grained materials normally have higher strength and are more ductile than similar coarse grained materials.

It is often intended to achieve fine grain structure in the weld bead because fine grain help improve mechanical properties like ductility and toughness of weld metal.

II. LITERATURE SURVEY

This chapter discusses the literature review carried out in order to identify the research gaps in the broader area of micro structural modifications for enhancing the mechanical properties, so that the problem could be identified and accordingly, the objectives be formulated to accomplish using a systematically devised methodology/approach.

Many researchers have analyzed the effect of vibrations on microstructure and mechanical properties of welded joints and have reached a generic conclusion that vibrations are able to alter/enhance the microstructure thus improving the mechanical properties of welds and cast elements due to the fundamental reason that mechanical properties of welds are influenced by the microstructure and grain size of welds.

Mechanism of Solidification of Weldments under Vibratory Condition

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Shashi Prakash Dwevedi (2014) [1] performed an experimental study on the tensile strength of 1018 mild steel plates joined by microwave welding. Three different microwave ovens with rated power of 800, 850, and 900 W and fixed frequency of 2.45 GHz were used in the present investigation. A nickel (Ni)-based metallic powder (50 μm) was used as an interfacing material between the bulk pieces. Charcoal was used as a susceptor material to facilitate microwave hybrid heating. The rated power of the microwave oven and the welding time and temperature were the principal variables that were controlled to provide the necessary combination of heat to form the weld. The response surface methodology (Box–Behnken method) was chosen to design the experiments. The results show that, with increasing rated power of the microwave oven, the tensile strength decreases, while the tensile strength increases with increasing welding time and temperature. From analysis of variance it is concluded that the welding temperature contributes most, followed by the rated power and welding time. The optimum values of rated power and welding time and temperature were found to be 800 W, 1,000 s, and 800 °C to obtain the maximum tensile strength (predicted 245.2 MPa). There was approximately 4.06 % error between the experimental and modeled results for tensile strength.

Alaa Raad Hussein et al. (2011) [2] studied the enhancement of the welding mechanical properties and the quality of the fusion metal is considered recently by using vibration during welding. In this study, the effect of induced harmonic vibration during welding is employed to improve the welding mechanical properties and to reach the best shape of welding line on the surface. The harmonic vibration method is examined experimentally by using four values of mechanical frequency during welding on the ductility, tensile strength and the homogeneity of the welding line. The frequencies were specified according to the natural frequency of the plate. Five simply supported rectangular plates are supported on the supporting stand and welded using a manual arc-welding machine. The experimental results show that the vibration applied during welding generally improved the bend property of the welding line, as well as the tensile strength has been improved distinctively at the resonance case when compared with that one welded without vibration. The morphology of the fillet metal after welding and for each value of frequency show an enhancement in the distribution of the fusion fillet metal, with gradually disappearing of the micro crack that may shown inside the metal with increasing the mechanical frequency. A comparison between the properties of welding without vibration and welding with vibration is discussed.

Jaskirat Singh et al. (2012) [3] employed dynamic solidification technology, by applying mechanical vibrations during the solidification in SMAW process. It has the advantages of less investment, more convenient operation, less pollution and shorter manufacturing period. Studies using 10 mm thick stainless steel (AISI202) butt joints. Low and high heat input combinations were used to study the effect of mechanical vibrations on small sized and large sized fusion zone respectively. The results from the present study indicate 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 conducted show that weld metals under vibratory condition possessed relatively finer microstructure and hence high micro hardness, owing to dendrite fragmentation.

Madhusudhan R., et al. (2013) [4] conducted a study on effect of weld parameters on mechanical and microstructural properties of dissimilar aluminium alloy FS welds. Friction stir welding (FSW), a solid state joining technique is widely used for joining Aluminium alloys in marine, aerospace, automotive and many other applications of commercial importance. In the present study, dissimilar Aluminum alloy (AA 6262-T6 and AA 7075-T6) plates were FS welded by varying the weld parameters such as Tool rotational speed, weld speed and axial force with square tool pin profile. The mechanical properties (hardness and tensile strength) of the Dissimilar Friction Stir welded (DFS welded) specimens were tested and compared with the base materials. The observations have been elaborated in detail along with microstructures of parent and welded specimens through Optical Microscopy and it is observed that the weld parameters have a significant effect on mechanical and micro structural properties of the welds.

Kuo Che-Wei, et al. (2007) [5] performed Gas Tungsten Arc Welding (GTAW) on AISI 304 stainless steel; steady-state vibration was produced by a mass-eccentric motor. The vibration weld shows a very small δ-ferrite structure, uniform composition distribution, less residual stress and less δ-ferrite content relative to the weld without vibration. The results illustrate that the vibration reduces the micro supercooling and improves the nucleation of δ-ferrite to form a grain refined structure. Vibration-induced stacking faults are identified as the major cause of the line broadening of X-ray diffraction profile. Correlating the literature and the result in the study, the mechanism of vibratory stress relief can be represented as the breakdown of dislocation into a pair of partial dislocations. This mechanism can comprehensively explain all the phenomena that take place during vibratory stress relief.

joint is analyzed in their work. An important segment occurring as a result of welding is the phenomena of residual stresses in the welded joint zone. Residual stress measurements are conducted both on butt-welded plates that were not vibrated during welding on plates simultaneously welded and vibrated. It is concluded that the vibration process noticeably decreases the level of stresses in the zone of butt weld i.e. the result is relaxation and plane stress state. Impact energy tests have shown that vibration favorably affects the total impact energy by increasing it both in specimens notched in weld metal (WM) and in the heat-affected zone (HAZ). It is also concluded that the correlation between the distribution of crack initiation and crack propagation energy, as vital components in the assessment of welded joint ductility, is improved.

S. P. Tewari (1993) [7] studied the effects of specimen thickness on tensile properties of medium carbon steel welds prepared under longitudinal oscillation were investigated. Medium carbon 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 40µm, respectively. Specimens were made for tension tests and microstructure examinations from stationary and oscillatory welded work pieces. Test specimens 8mm, 10mm and 12mm thick were tested and yield strength, ultimate tensile strength, percentage of elongation, breaking strength, impact strength and hardness were determined. Metallographic examination of the test specimens was carried out. Yield strength, ultimate tensile strength, breaking strength, improves significantly but percentage of elongation (+5.5%) reduces in oscillatory (longitudinal) prepared welds in comparison to stationary welded test specimens. The maximum increase in tensile properties (yield strength-21%, U.T.S.-26% and breaking strength-39%) in oscillatory prepared welds is at 400Hz - 5µm and the minimum increase is at 80Hz - 5µm condition. The oscillatory prepared weld grain size in the case of stationary prepared weld was 38 µm. With increase in specimen thickness from 8mm to 12mm there was some change in values of tensile properties for oscillatory prepared welds. The values are significantly more than the values obtained from stationary prepared welds. The increase in values of tensile properties under longitudinal oscillation is attributed to grain refinement, dendrite fragmentation and grain detachment mechanisms.

Hornsey, J.S. (2004) [10] found that the Vibratory stress relieving can be employed for stabilisation of the size of suitable weldments prior to their machining and servicing as a replacement of stress relief annealing. The VSR process is used for lowering of residual stresses and stabilisation of the size of different weldments such as frames of forming machines, machine frames, grey cast iron castings, etc. which were up to now subjected to stress relief annealing. VSR does not negatively affect the static dynamic strength of welded joints and weldments, fracture and notch toughness and homogeneity of welded joints. Based on the attained data the implementation of VSR procedures as a replacement of stress relief annealing for the stabilisation of weldments, castings and forging leads to high savings of production costs to our national economy.

Verma, Akanksh et al. (2011) [9] studied that welding processes induce a state of residual stress into materials and jobs. This poses a series of problems, in terms of dimensional stability, corrosion cracking, reduced fatigue life and structural integrity. Thermal cycle produced near weld line generates residual stress and inhomogeneous plastic deformation in weldments. Understanding of grain nucleation and grain growth becomes necessary that are influenced under welding conditions. After completion of nucleation, the solidification process will continue with nucleus growth. With vibratory weld conditioning, the enhancement of weld metal microstructure can be achieved. The mechanical properties, level of residual stresses, and deformation can also be affected. Structural changes of the welds prepared under vibratory conditions affects the mechanical properties of the welds. The vibration during welding benefits energy absorbed in impact toughness test of weld metal and improves fracture behaviour. The work presents the microstructure, solidification behaviour and residual stress relaxation under vibratory welding condition.

Qinghua, Lu et al. (2007) [12] studied that the microscopic structure has dramatically changed after V-SAW. Vibratory energy breaks up the growing dendrite grains in the weld and the HAZ. A Significantly higher weld pool velocity which leads to a faster the heat removal during solidification is produced in VWC. Thus, the higher the cooling rate, the more the nuclei coming into play and the smaller the grain size. And a finer grain size benefits the mechanical properties.

Dvornak et al. (1991) [13] while studying the solidification under vibratory conditions concluded that the grain refinement so observed was due to the lower energy required for the nucleation of the solid phase. However, the rapid removal of latent heat of solidification from the solid-liquid interface played a minor part in the grain refinement under vibration.

P Sakhthivel and P Sivakumar (2014) [14] studied the effects of vibration on properties of welded joints. Studies have revealed that welding of metals along with mechanical vibrations result in uniform and finer grain...
structures. A number of methods utilizing external force have been applied to induce fluid flow during solidification of molten metal in welding processes. These include electromagnetic stirring, mechanical vibration etc. Also extensive studies have been made in the study of effect of vibration on welding in horizontal position. This project has been planned to study the effect of vibration on mechanical properties and microstructure process and application of the procedure offer extensive scope for significant cost saving and defect free welding.


III. AIM OF THE OBJECTIVES
Based upon the research gaps identified the following objectives were formulated:-
1. To manufacture a setup for inducing auxiliary mechanical vibrations into the weld pool during welding
2. To study the effect of auxiliary mechanical vibrations on the mechanical properties of butt welded joints using SMAW process on mild steel combination

IV. METHODOLOGY
Experimental Setup
An auxiliary mechanical vibration during welding is provided with the help of vibratory set up shown in figure 1. Vibrating tables are capable of transmitting vibrations to the materials placed or clamped on the table top. The vibrating tables do not include shock tables which pulsate at low frequency and operate on the principle of gravity fall with the help of rotating cams.

Material:-
Steel sections, plates and bars for construction of the vibrating table are made from Structural Steel (Standard Quality).

Springs are manufactured from suitable grade of wire conforming to IS: 727-1955 Specification for Hard Drawn Wire for springs (Tentative).
V-belts for belt drives are conformed to IS: 2494-Specification for V-Belts.
All other materials used in the construction of vibrating table are conformed to relevant Indian Standards.

Size and Capacity:-
Size Designation-The size of the vibrating table is designated by the overall length and breadth of the table top expressed in metres as given in Table No.1, and its load carrying capacity is 140 kg.

<table>
<thead>
<tr>
<th>Length, m</th>
<th>Breadth, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Size of given set up = 0.5 × 0.5 m

Height - For all sizes of the vibrating table, the height of the table from the ground level shall be sufficient to allow for easy placing and removal of the moulds and shall not exceed 0.75 m.

Motive Power:-
The vibrating table shall be capable of being operated either through an eccentric rotor driven by a prime mover, such as electric motor, internal combustion engine, pneumatic power, or directly by electromagnetic pulsators. Electric motor is used in our setup.

Selection of Material
Mild steel (AISI 1018) is selected for this experiment. The dimensions of the plates are 100×100 mm each and 10 mm thick. Mild steel is the most common high volume steel in production. Mild Steel is used for almost all non-specialist steel products- cars, domestic goods, constructional steel work etc.

Its chemical composition is shown in Table No.2.
Table 2: Chemical Composition of AISI 1018 MS

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.12-0.20</td>
</tr>
<tr>
<td>Mn</td>
<td>0.50-0.80</td>
</tr>
<tr>
<td>Fe</td>
<td>98.81 - 99.26</td>
</tr>
<tr>
<td>P</td>
<td>0.040</td>
</tr>
<tr>
<td>S</td>
<td>0.060</td>
</tr>
</tbody>
</table>

Selection of Electrode

The selection of electrode for welding the mild steel is based on the composition of the MS being welded. E6013 electrode is used for the welding of mild steel.

Table 3: Description of Electrode

<table>
<thead>
<tr>
<th>Model</th>
<th>E 6013</th>
</tr>
</thead>
</table>
| Deposited metal chemical composition (%) | C = 0.8  
Mn = 0.45  
Si = 0.18  
P = 0.012  
S = 0.009 |
| Shape    | Stick Electrode |
| Type     | Mild Steel |
| Coating Type | High titanic coated |
| Length (mm) | 350 |
| Diameter (mm) | 2.5, 3.15, 4.0, 5.0 |
| Current (amp) | 80-110, 90-130, 140-190, 170-230 |

Selection of type of joint & weld type

The butt joint is used to join the ends or edges of two plates located approximately in the same plane with each other. Light gauge section requires 90° sheared edges with no spacing between them. Materials ranging from 8 to 13mm thick, which can be welded from one side, should be reduced either as a single-V or a single –U joint. It is generally more expensive to prepare a U-shape rather than the straight edged V or bevel. So, single V- butt joint-with gap is selected as shown in fig. 3.

Now, Edge is prepared with the help of End mill cutter on milling machine such that the bevel angle becomes 30° and 1 mm is left at the bottom of plate to make root face. The plates are kept at a distance 1-2 mm apart from each other to accommodate root opening as the plates are greater than 6 mm thick.

Experimental process design

Now, two MS plates each of dimension 100×100 mm are placed with the help of C-clamps as shown in figure 5. The plates are kept 1-2 mm apart from each other so that the weld pool fills completely between the two plates during welding.
Now, Shielded Metal Arc Welding is to be carried out in order to make butt joint on MS plates. First of the vibration table is earthed in order to have MS plate conducting. A current of 140-190 amperes is supplied, and then arc is created by striking in between the plates.

Fig.6: During Welding Process

Fig.7: Welded Plates Marked- C1 (With Auxiliary Vibrations) & A1 (Without Auxiliary Vibrations)

V. RESULT AND DISCUSSION
To measure the mechanical properties that is considered vital to the satisfactory performance of the welded joint in service. These tests include tensile test, hardness test, impact test etc. Here tensile test has to be carried out to determine the ultimate tensile strength and yield point under static loading of base metal, weld metal and welded joint. Percentage elongation has also determined. For determining the tensile strength of weld metal alone or welded joint, the samples are to be prepared from both the welded plates i.e. SMAW and vibratory SMAW.

Outcomes of Tensile Test:
From the Tensile test of A1 specimen (without vibration):
Gauge length = 25.51 mm
Final gauge length = 28.73 mm
Percentage elongation = \( \frac{28.73 - 25.51}{28.73} \times 100 = 12.623 \% \)
Tensile strength = 342.13 MPa

From the Tensile test of C1 specimen (with vibration):
Gauge length = 24.22 mm
Final gauge length = 28.48 mm
Percentage elongation = \( \frac{28.48 - 24.22}{28.73} \times 100 = 17.589 \% \)
Tensile strength = 404.56 MPa

Table 4: Comparison Table of Mechanical Properties

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Mechanical Properties</th>
<th>Sample A1</th>
<th>Sample C1</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maximum Force (Fm)</td>
<td>63.960 KN</td>
<td>82.620 KN</td>
<td>29.17 %</td>
</tr>
<tr>
<td>2</td>
<td>Tensile Strength (Rm)</td>
<td>342.12 MPa</td>
<td>404.56 MPa</td>
<td>18.25 %</td>
</tr>
<tr>
<td>3</td>
<td>Elongation</td>
<td>12.623 %</td>
<td>17.589 %</td>
<td>39.34 %</td>
</tr>
<tr>
<td>4</td>
<td>Reduction in Area (Z)</td>
<td>21.212 %</td>
<td>31.922 %</td>
<td>50.14 %</td>
</tr>
<tr>
<td>5</td>
<td>Yield Stress</td>
<td>330.25 MPa</td>
<td>319.65 MPa</td>
<td>3.21 %</td>
</tr>
</tbody>
</table>

VI. CONCLUSION
In this study, auxiliary vibrations are induced with SMAW for improving the mechanical properties of the base material and the weld metal. The small grain structure is attained due to the effect of vibration. During manual butt weld joints, uniform long dendrites are formed which show that a uniform solidification process took place with uniform dendrites. Due to auxiliary mechanical vibrations, long dendrites break and form a new nucleation sites and a non-uniform solidification process took place. The oscillatory conditions modify and/or change the grain nucleation and grain growth that are influenced under welding conditions. Thus the higher the cooling rate, the more the nuclei coming into play and the smaller the grain size. Finer grain size benefits the mechanical properties.

Following are the findings of this research work:
- Tensile strength of the material AISI 1018 during vibration welding is 18.25 % more as compared to the tensile strength of same material during SMAW.
- Elongation of the specimen is 39.34 % more during vibration welding than SMAW.
- C1 specimen can bear 29.17 % more force as compared to A1.
- Reduction in area is approximately 50 % more in sample C1 as compared to sample A1.

REFERENCES


