Investigating the Effects of Welding Parameters on Mild Steel by SMAW Technique

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Abstract. The Shielded Metal Arc Welding (SMAW) is a joining technique in which melting and joining of metals with the help of an arc between the workpiece and the filler rod. The core purpose of the paper is to examine the mechanical characteristics of welded metal under various standalone parameters like type of filler material, electrode diameter, and current for SMAW. This paper employed the half factorial Design of Experiment (DOE) using Taguchi L4 array. Varieties of welding filler materials used were E6013 and E7016, with an electrode diameter of 3.15mm and 4mm and the welding current of 90A and 110A. The desired output variables were tensile strength and Rockwell hardness of the welded joint. This paper found that when electrode diameter increases, the deposition rate increases, and hence HAZ increases, which decreases the weld strength. Using the welding filler E7016, we can obtain the maximum tensile strength for welded metals.

Keywords. SMAW, Design of Experiments, Tensile Strength, Hardness, HAZ

1. Introduction

Welding is a continual process for joining two or more pieces of metal using regional amalgamation derived from a suitable blending of pressure, temperature, as well as metallurgical condition. An electric arc ensures proper fusion and joining of the materials by providing essential heat. The welding process is extensively applied in construction because of its easy applicability, minimum arrangement of equipment and also is inexpensive compared to other processes. However, this paper concentrated primarily on the Shielded Metal Arc Welding Process and the core purpose of the paper is to examine the mechanical characteristics of welded metal under various standalone parameters like type of filler material, current and electrode diameter for SMAW. This paper implemented the half factorial design for the Design of Experiment (DOE). The schematic of the SMAW is shown in figure 1.

The process of melting and joining metals with the help of heat generated by an arc between workpiece and coated electrode, is called as Shielded Metal Arc Welding (SMAW) also known as Stick Welding. The arc generation is assisted by the flux i.e. the outer electrode coating and it also prevents adulteration by enabling slag layer and shielding gas. The weld joint is result of depositing filler material from the core of electrode along the desired area at constant speed.
Kchaou et al. [1] found that the welded joint of material UNS N08028 is ductile in the impact test and tensile test with changing the parameters such as the filler material diameter, number of passes, current, and voltage. Pamnani et al. [2] discussed that the inclusions content of the welded joint of material DMR 249A varies with the welding process, voltage, current speed (mm/s), heat input (kJ/min), number of passes, heat input for final passes. Singh et al. [3] analyzed that vibration applied on the weld pool successfully enhances welded joint mechanical properties of 6mm thick MS plate with varying parameters such as welding speed, frequency of vibration, current, hardness, S/N ratio for hardness. Ganesh et al. [4] analyzed the residual stresses as well as thermal cycles in DMR-249A steel welded joints. Sadeghi et al. [5] analyzed that the probability of crack formation reduces after studying the microstructure in the study of investigating corrosion behavior and abrasive wear of surface repair of grey cast iron of SMAW technique with preheating of electrodes. Tahir et al. [6] found that for optimum tensile strength and optimum hardness, E7016 and E7018 welding filler are responsible respectively. Welding current was also kept as a parameter in the inspection of the welded material mechanical properties.

2. Materials and Methods

The samples were welded initially using the arc welding technique, and parameters varied during welding were combinations of filler material, welding current & electrode diameter. The experiments were designed by using the Taguchi Method. The L4 array of design of the experiment is shown in Table 1 below. After the welding of 4 samples as L4 array is used, Specimens for the tensile test were made according to the ASTM E8M-04 standard. Tensile testing on specimens was carried out, and parameters responsible for the highest tensile strength and lowest tensile strength were noted down. For these parameters, we again welded two specimens and, on these specimens, Rockwell hardness testing was carried out.

| Experiment No. | Parameters       | Current (A) | Filler Material | Electrode diameter (mm) |
|---------------|------------------|-------------|-----------------|-------------------------|
| 1             |                  | 90          | E6013           | 3.15                    |
| 2             |                  | 90          | E7016           | 4                       |
| 3             |                  | 110         | E6013           | 4                       |
| 4             |                  | 110         | E7016           | 3.15                    |
3. Experimental Setup and Procedure

3.1 Sample Preparation

MS Plates were marked and cut with dimensions (100*50*5 mm). Edge preparation of plates was done by using files. Bevel angle of 45° and root face of 2 mm is maintained. The portion near to the weld zone was polished by filing operation to avoid the inclusion of rust in the weld zone. The prepared sample is shown in figure 2. Ten such samples were prepared for welding.

3.2 Experimental Setup

Experiments were designed as per the Taguchi L4 Array shown in Table 1. Root opening of about 1 mm is maintained and welding of specimens was carried out as per the conditions required. Two spot welds at ends were made so that plates will not move during welding. After spot welding was done, actual welding was carried out. Size of the weld is 5 mm and the length of the weld is 50 mm. Four specimens were prepared for tensile testing. After each welding, Specimens were labeled for easy identification for later analysis. The welded specimen is shown in figure 3.

3.3 Tensile specimen preparation

After welding was carried out, samples were allowed to air cool. Making of tensile test specimen according to the ASTM E8M-04 standard for the tensile test was made. As per the dimension, the material was cut by hand cutter and milling machine. Excellent finishing and grinding of weld reinforcement were done by Grinding Machine. Tensile specimens are shown in figure 4 below.
3.4 Tensile Testing

To determine the Ultimate Tensile Strength (UTS), we used the universal testing machine (UTM) machine. Specimen first fitted in the bottom holder, and then it was fitted in the crosshead. In the software, tensile specimen type – PLATE was selected. Width – 20mm, Gauge length – 100mm, and thickness – 5mm was selected. Testing was started after pressing the hydraulic valve. The pressure Relief valve was pressed after breaking of the specimen. The plot of stress vs. strain was plotted by software. Broken specimens after tensile testing were shown in figure 4 (b) below.

![Tensile samples before testing](image1)

![Tensile samples after testing](image2)

*Figure 4. (a) Tensile samples before testing, and (b) Tensile samples after testing.*

3.5 Hardness Testing

Parameters responsible for the highest strength and lowest strength were selected for hardness testing, i.e., parameters for experiment no. 3 and 4 were selected. According to selected parameters, the welding of samples was done. As per ASTM E-18 guidelines, hardness testing on the sample is carried out. For Rockwell's hardness test, specimen dimensions of (50*25*5 mm) were marked on the sample, and hardness specimen were prepared by fine finishing and grinding of reinforcement by grinding machine and the top part of the weld as seen in figure 3 was fine finished. Superfinishing of the specimen is done on a rotary wheel. Scale “B” with load 100 kgf or 980.7 N and 1.588 mm diameter ball indenter was used. With major and minor load hardness testing is carried out on hardness tester. Six readings of hardness by indentation were taken both in fusion zone and in base metal. Average of these readings is calculated for final hardness. Hardness testing specimen after testing is shown in figure 5.

![Hardness specimen testing](image3)

*Figure 5. Hardness specimen testing.*
4. Results and Discussion

4.1 Tensile Testing

Tensile testing of all four specimens according to the L4 array was done. Table 2 illustrates the results of all the experiments.

| Experiment No. | Parameters          | UTS (MPa) |
|----------------|---------------------|-----------|
|                | Current (A)         | Filler Material | Electrode diameter (mm) |
| 1              | 90                  | E6013     | 3.15                  | 293.4     |
| 2              | 90                  | E7016     | 4                     | 373.6     |
| 3              | 110                 | E6013     | 4                     | 229.4     |
| 4              | 110                 | E7016     | 3.15                  | 400.28    |

Stress vs. strain graphs for experiment no. 3 and 4, i.e., minimum and maximum strength, is illustrated in figure 6 and figure 7 below.

![Stress vs. strain graph of specimen 3.](image)
4.2 Hardness Testing

Rockwell hardness testing for specimens having the highest tensile strength and lowest tensile strength in tensile testing was carried out. Data on hardness testing is illustrated in Table 3 below. Hardness testing was carried out in the fusion zone and near base metal. An average of six readings of hardness testing was taken.

| Experiment No. | Rockwell Hardness (HRB) | Current (A) | Filler Material | Electrode diameter (mm) | Fusion zone | Base metal |
|----------------|--------------------------|-------------|-----------------|-------------------------|-------------|------------|
| L              |                          | 90          | E6013           | 3.15                    | 88          | 71         |
| H              |                          | 90          | E7016           | 4                       | 92          | 69         |

The difference in the fusion zone hardness and the base metal hardness is because of the temperature gradient. In the fusion zone, sudden heating and cooling takes place due to which time of heat dissipation is less and as temperature gradient is more, hardness value in the fusion zone is greater than the hardness value at the base metal. Also, it is much evident that due to low amount of hydrogen, tendency of hydrogen embrittlement decreases which inherently increase the strength of the weld joint and hardness in the fusion zone.
5. Conclusions
The research findings demonstrated that the welding filler, welding current, and electrode diameter substantially affect the tensile strength as well as hardness of the welded metal. This experiment found that as electrode diameter increases, the deposition rate increases, and hence HAZ increases, which decreases the weld strength. In this experiment, with E7016 as filler material, it was observed that a low amount of current might cause insufficient deposition of filler material, which causes a decrease in the weld strength. It was also observed that the effect of electrode diameter on tensile strength was more prominent than the current.

1) In tensile testing, optimum parameters for highest tensile strength using SMAW technique are: Current – 110A, Filler material – E7016 and Electrode diameter – 3.15mm

2) Hardness testing reveals that for an increase in the joint’s tensile strength, the weld hardness also rises. The hardness at the fusion zone was higher than the base metal as the low-temperature gradient at base metal, and rapid heating and cooling take place at the fusion zone.

3) The basic Low Hydrogen coated formulation ensures a defect-free quality weld. The superb and well-established flux formulation ensure excellent performance of the electrode in AC.

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