Experimental Investigation of Gas Metal Arc Welding (GMAW) Process Using Developed Articulator

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Abstract. Gas Metal Arc Welding (GMAW) process is used in fabrication of structures and welding of pressure vessel components because of some advantages, such as higher weld metal deposition rate, requirement of lower welder skill, and good quality of weld in versatile positions. Further, GMAW process can be automated for achieving higher rate of production. In present work, GMAW process is automated using an articulator that can control welding speed. Experiments are carried out using welding process specification prepared as per ASME section - IX. Weld samples are manufactured using single “V” butt weld joint design. Welding parameters, such as welding current, open circuit voltage and welding speed, are varied in the range of values as per ASME section - IX. Further, the test samples are subjected to physical and chemical testing for evaluating welding process capability. Desirable quality characteristics of weld are assessed based on the value of ultimate tensile strength, chemical composition and root penetration. An effective range of welding current, open circuit voltage and welding speed is identified for sound quality of weld with constraint over maximum heat input.

1. Introduction

New innovation for effectively utilizing existing equipment technology that can improve quality of welded joint with higher productivity is in demand. A semiautomatic drive for achieving uniform welding speed control with Gas Metal Arc Welding (GMAW) process is developed. GMAW process is considered for experiment to assess the process capability with semiautomatic drive. Chang and Babkin[1] proposed that the melting rate of solid wire is one of the major factors that determines the productivity of welding process. Welding current and welding speed are considered as factors that determine the melting rate in GMAW welding process. The procedure adopted for manufacturing butt welded joint is common in all manual processes. In the present experimental work, uniform welding speed and constant angle of welding torch are maintained using an articulator that replaces the welder skill. Babkin and Galdkav[2], stated that welded joint quality criteria is multifaceted, such as geometric quality, absence of defect and strength quality criteria. Each such criterion estimates only certain areas of weld quality. In the present experimental work, weld quality criterion considered is strength, chemical composition of weld joint and root penetration are considered as quality criteria. Subsequently, the set of parameters are obtained and verified for sound quality of weld as per ASME Section-IX[3]. Further, the manufactured welded test samples are subjected to visual examination and radiographic test to detect surface and subsurface defects in weld.

Various methods are available to determine welding parameters for manual GMAW process, such as mathematical equation for heat input, imperial relations method, based on standard hand book data.
Industry follows a simple relation between heat input and welding parameters, this is called Welding Process Specification (WPS), in this process a range of welding process parameters is selected from ASME section IX, which is based on the combination of welding process, material to be welded, filler wire diameter and welding speed. Welding Process Specification (WPS) is a link in the chain of documents required to demonstrate welding process control. Compliance of welding with required welding procedure qualification is done for quality assurance of welding process. Thus, test samples are manufactured as per Welding Process Specification (WPS) and tested to check the conformance of quality requirements to ascertain the welding procedure qualification.

Further, different values of control parameters are used to estimate different quality criteria. In present work ultimate tensile strength, root penetration and equivalence of chemical composition of weld are studied using semiautomatic articulator with GMAW processes per developed welding process specification.

2. Experimental Methodology

Semiautomatic articulator is used for experimentation on GMAW process, single ‘V’ groove butt weld geometry, in flat position with IS 2062 material is considered. IS 2062 Gr B is a plain carbon steel material widely used in structural fabrication and low pressure non corrosive applications like storage tanks etc. Articulator is capable of holding a GMAW torch and tracing the weld path with uniform speed is considered. Details of articulator speed and error are given in Table 1. Further, control parameters, such as open circuit voltage, welding current and welding speed are in conformance with ASME section IX for GMAW process. Exact values of parameters are noted while manufacturing test samples. Test samples are manufactured over complete range of parameters for detailed study of best value of quality criteria. Details of welding process specifications are given in Table 2. Values of quality criteria, such as ultimate tensile strength, chemical composition and root penetration of the weld metal, are obtained and reported in reference to the control parameters to estimate process capability. Radiographic testing is also carried out to evaluate the presence of defects in weld joint.

![Figure 1. 'V' Butt weld geometry](image)

| Sr. No. | Stepper motor speed (RPM) | Gear ratio (GR) | Wheel diameter (D) (mm) | Theoretical Linear travel (mm/min) \(T_{th}\) | Actual travel with load in (mm/min) \(T_{act}\) | Error in travel speed (mm/min) \(E\) | % Error in travel speed \(\% E = \left| \frac{T_{act} - T_{th}}{T_{act}} \right| \times 100\) |
|--------|-----------------|----------------|--------------------------|-----------------------------|-----------------------------|-----------------------------|----------------------------------|
| 1      | 23              | 30             | 100                      | 231.22                      | 230                         | 1.22                        | 0.53%                            |
| 2      | 30              | 30             | 100                      | 300.02                      | 300                         | 0.02                        | 0.01%                            |
| 3      | 38              | 30             | 100                      | 380.03                      | 381                         | -0.97                       | -0.26%                           |
| 4      | 68              | 30             | 100                      | 680.05                      | 686                         | -5.95                       | -0.87%                           |
| 5      | 90              | 30             | 100                      | 900.07                      | 880                         | 20.07                       | 2.28%                            |

* Rounded value
3. Experimental Apparatus

Experimental apparatus used is ESAB K 400 MIG power source with an auto feed articulator. Details of apparatus are as per Table 3. Articulator linear travel speed error is recorded in Table 1. Validation of Welding Process Specification (WPS) is done by performing eight trial experiments. Experiments are conducted with different parameter mix covering the entire range of current, as per ASME Section IX guidelines. Details of experimental parameter are maintained in Procedure Qualification Records (PQR), in accordance with ASME section IX guidelines. Detailed observations of control parameters is as per Table 4. Quality of welded samples is ascertained using subjective and objective evaluation of welded test pieces. In subjective evaluation, visual inspection and radiographic testing is carried out for evaluating surface defects and volumetric defects respectively. The objective evaluation is done by conducting tensile test and macro test.

### Table 2: Welding process specification as per ASME section IX

| WELDING PROCEDURE SPECIFICATION (WPS) | (As per QW 200.1 of Section IX, ASME Boiler and Pressure Vessel Code. Ed. 2004) |
|--------------------------------------|---------------------------------------------------------------------------------|
| Company Name/Location               | SVNIT, MED                                                                       |
| Welding Process(es)                 | GMAW                                                                             |
| Supporting PQR No                   | DS4ME005-2 TO 8                                                                 |
| Joint Design                        | Refer attached Annexure-1 for applicable joint design                            |
| Backing                             | NO FOR GMAW                                                                      |
| Preheat Temp. Min.                  | Ambient Dry                                                                      |
| Backing Material                    | NA                                                                               |
| Preheat maintenance                 | None                                                                             |
| Back Gouging                        | Not Applicable                                                                   |
| Interpass Temp. Max.                | 350°C                                                                            |
| Retainers                           | None                                                                             |
| Heat Input                          | None                                                                             |
| Others                              | Not Applicable                                                                   |
| Heating Rate                        | None                                                                             |
| BASE METALS (QW-403)                | Cooling Rate                                                                     |
| Mat P No.                           | P1                                                                               |
| Mat Spec:                           | ASME A 36 / IS 20162                                                             |
| Type & Grade                        | ASME A 36 / IS 20162                                                             |
| Tth Range : Groove                  | 1.6 - 18.54 mm                                                                   |
| Pipe Diameter                       | Nil                                                                             |
| Other                               | Single pass shall not be more than 13.0mm                                        |
| ELECTRICAL CHARACTERISTIC (QW-409)  |                                                                                 |
| Current                             | Reverse polarity                                                                 |
| Welding Technique                   | TECHNIQUE (QW-410)                                                               |
| Spec No. (SFA)                      | GTAW                                                                             |
| AWS No. (Class)                     | E70C-3X                                                                          |
| A No.                               | 1 (QW-442)                                                                       |
| F No.                               | 6 (QW-432)                                                                       |
| Size of Filler Metals               | String or Weave Head                                                             |
| Weld Metal Thk Range                | String / Weave                                                                   |
| Groove (Max.)                       | 1.2 mm                                                                           |
| Initial & Interpass Cleaning        | Orifice or Cup Size                                                              |
| Filter                              | NA                                                                               |
| Method of Back Gouging              | NA                                                                               |
| Filler Metal Product form           | Solid Wire                                                                       |
| Oscillation                         | Not Applicable                                                                   |
| Supllemental Filler Metal           | With Out                                                                         |
| Not Applicable                      | Contact tube to work distance 15 - 25 mm (GMAW)                                   |
| Consumable Insert                   | Multiple / Single Pass                                                           |
| Multiple                            | Single                                                                           |
| Flux                                | None                                                                             |
| NA                                  | Not Applicable                                                                   |
| Alloy Elements                      | closed or Out Chamber                                                            |
| Not Applicable                      | Electrode Spacing                                                                |
| POSITION (QW-405)                   | Open                                                                            |
| Position(s) of Groove               | PLAT                                                                             |
| Vertical Progression                | Up                                                                               |
| Pass or Weld Layer(s)               | Manual or Machine                                                                |
| Filler Metals                       | Semi Auto(GMAW)                                                                  |
| Current                             |                                                                                 |
| Bed Width                           |                                                                                 |
| Travel Speed                       |                                                                                 |
| Heat Input (Max.)                   |                                                                                 |
| Remarks                             |                                                                                 |

### Table 3: WELDING PROCEDURE SPECIFICATION (WPS)

| Process | Diam. in mm | Type & Polarity | Amps | Volts | Travel speed | Heat Input (Max.) | Remarks |
|---------|-------------|-----------------|------|-------|--------------|-------------------|---------|
| Root    | E70C-3X     | 1.2             | DCEP | 90-110 | 20-25        | 180-250           | 0.833   |
| Hot Pass| E70C-3X     | 1.2             | DCEP | 100-120 | 20-25       | 180-280          | 1       |
| Fill    | E70C-3X     | 1.2             | DCEP | 135-185 | 20-30       | 300-500          | 1.1     |
Table 3. Experimental apparatus and conditions

| Base material composition and thickness | IS 2062 6 mm thick |
| Test piece size                        | 200 mm x 500 mm    |
| MIG wire                               | 1.2 mm diameter solid wire as per E70 C-3X |
| Shielding gas                          | CO₂                |
| MIG wire extension                     | 20 mm              |
| Electrode angle                        | 10° ± 1° (Approximate) |
| Power Source MIG                       | ESAB K 400         |

4. Results and discussion

Experiments are carried out and results are reported for visual inspection, ultimate tensile strength in relation to welding voltage, welding current and welding speed:

1. Visual inspection is done for each test sample for visual weld defects, weld bead reinforcement over base metal and penetration of weld metal into the root of weld groove, visually samples are found to be acceptable in terms of weld bead appearance and reinforcement. Minimum reinforcement observed is 2 mm and maximum to 3.5 mm over cap of the weld, this meets the requirements of ASME section IX, as the angle Ø is greater than 120° as shown in Figure 1. Sufficient penetration is observed and same is confirmed by results of macro examination at 20 X magnification.

2. Five samples out of eight samples are found acceptable for ultimate tensile strength requirements. Working range of welding parameters are obtained (Table 5).

3. Behavior of ultimate tensile strength with respect to control parameters is plotted, the effect of welding current, open circuit voltage and welding speed, on ultimate tensile strength is shown in Figure 2, Figure 3 and Figure 4.

4. Radiographic test results indicate undercut and porosity as volumetric defects present in the weldment.

Table 4. Welding parameter observation table

| SVNIT | PQR-DS14ME005-02-08 |
|-------|---------------------|
| Date of test: | 19/Dec/2016 |
| Name of welder: | Articulator Machine |
| Welder ID No.: | DS14ME005 |
| WPS No.: | DS14ME005-01 |
| Material Specification: | IS 2062 / SA 36 |
| Position: | 1G |
| Size: | 200 X 500 X 8 mm |
| Process: | GMAW |
| Electrode polarity: | Electrode positive |
| Filler wire diameter: | 1.2 mm |

| Sequence (Sample-run) | Current (A) | Volt (V) | Bead thickness (mm) | Bead width (mm) | Welding speed (mm/min) | Interpass temperature | Heat input (kJ/mm) |
|-----------------------|-------------|----------|---------------------|----------------|------------------------|----------------------|-------------------|
| 2-1                   | 101         | 23       | 3                   | 4-6            | 230.0                  |                      | 0.61              |
| 2-2                   | 115         | 24.6     | 3                   | 8              | 230.0                  |                      | 0.74              |
| 2-3                   | 123         | 28.8     | 2                   | 10             | 300.0                  |                      | 0.71              |
| 3-1                   | 110         | 23.4     | 3                   | 4-6            | 230.0                  |                      | 0.67              |
| 3-2                   | 125         | 28       | 3                   | 8              | 230.0                  |                      | 0.91              |
| 3-3                   | 125         | 27       | 2                   | 10             | 300.0                  |                      | 0.68              |
| 4-1                   | 104         | 23.5     | 3                   | 4-6            | 230.0                  |                      | 0.64              |
| Test sample ID No.: DS14ME 005 / XX | Visual Inspection | Macro examination with 20 X magnification | Tensile Test Ultimate tensile strength value in N/mm² (Min. required is 410 N/mm²) | Average current (A) | Average voltage (V DC) | Average welding speed (mm/min) |
|-----------------------------------|------------------|------------------------------------------|---------------------------------------------------------------------------------|-------------------|-----------------------|-----------------------------|
| 01                                | Not OK           | Not Done                                 | Not Done                                                                         | 155               | 29.30                 | 300                         |
| 02                                | O.K.             | O.K.                                     | 461.63                                                                           | 113               | 25.57                 | 253.3                       |
| 03                                | O.K.             | O.K.                                     | 464.59                                                                           | 120               | 26.13                 | 253.3                       |
| 04                                | O.K.             | O.K.                                     | 472.7                                                                            | 113               | 25.57                 | 253.3                       |
| 05                                | O.K.             | O.K.                                     | 442.8                                                                            | 134.67            | 27.93                 | 276.7                       |
| 06                                | O.K.             | O.K.                                     | 469.5                                                                            | 143.33            | 29.07                 | 276.7                       |
| 07                                | O.K.             | O.K.                                     | 346.4 (FAIL)                                                                     | 156.33            | 28.60                 | 327.0                       |
| 08                                | O.K.             | O.K.                                     | 327.2 (FAIL)                                                                     | 147.33            | 28.33                 | 276.7                       |
Figure 2. Graph of welding current and ultimate tensile strength

Figure 3. Graph of open circuit voltage and ultimate tensile strength
Figure 4. Graph of welding speed and ultimate tensile strength

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