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.

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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.

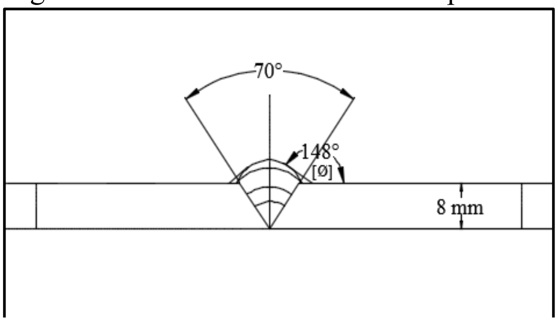

Figure 1.'V' Butt weld geometry

Table 1.Articulator capability and error in travel speed

Sr. No.	Stepper motor speed(RPM)	Gear ratio (GR)	Wheel diameter (D) (mm)	Theoretical Linear travel (mm/min) T_{th} $T_{th} = (RPM * GR)(\pi D)$	Actual travel with load in (mm/ min) * T_{act}	Error in travel speed (mm/min)	% Error in travel speed $\% E = \left\{\frac{T_{th} - T_{act}}{T_{act}}\right\} x\ 100$
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

SVNIT, MED

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	WPS NO :	**DDS14ME005 -1** Rev : 00
Welding Process(es) :	GMAW	Date :	6/12/2016 By : CHETAN
Supporting PQR No :	**DS4ME005-2 TO 8**	Type -	Manual [X] Semi-Automatic [ ]
			Machine [X] Automatic [ ]

JOINT (QW-402)		**PREHEAT (QW-406)**	
Joint Design :	Refer attached Annexure-1 for applicable joint design	Preheat Temp. Min. :	Ambient Dry
Backing :	√ NO FOR GMAW [ ] No For GTAW	Interpass Temp. Max. :	350^0 C
Backing Material :	NA	Preheat maintenance :	None
Back Gouging :	Not Applicable	**POST WELD HEAT TREATMENT (QW-407)**	
Retainers :	None	Soaking Temp. :	None
Root spacing :	Not Applicable	Time :	None
Others :	Not Applicable	Heating Rate :	None
BASE METALS (QW-403)		Cooling Rate :	None

BASE METALS (QW-403)	
Matl P No. :	P1
Matl Spec: :	ASME A 36 / IS 20162
Type or Grade :	ASME A 36 / IS 20162
Thk Range : Groove :	1.6 - 18.54 mm Fillet : All
Pipe Diameter :	NIL
Other :	Single pass shall not be more than 13.0mm
:	Not Applicable

GASES (QW-408)	Gas(es)	Mixture	Flow Rate	Remarks
Shielding	CO2	99.99%	12-20 L/M	N/A
Backing	Argon	NA	NA	N/A
Trailing	None	None	None	N/A

ELECTRICAL CHARACTERISTIC (QW-409)			
Current :	Reverse polarity	Polarity:	See table Below
Amps:	See table Below	Volts :	See table Below
Tungsten Electrode size & Type :			NA
Pulsing Current :			None
Heat Input :			See table Below

FILLER METALS (QW-404)	GTAW	GMAW
Spec No. (SFA)		5.18
AWS No. (Class) .		E 70C -3X
A.No.		1 (QW-442)
F.No.		6 (QW-432)
Size of Filler Metals		Φ 1.2 mm
Weld Metal Thk. Range		
Groove (Max.)	NA	12.54 mm
Fillet	NA	All
Filler Metal Product form	NA	Solid Wire
Suplplemental Filler Metal	Not Applicable	With Out
Consumable Insert	None	Not Applicable
Flux	None	Not Applicable
Alloy Elements	Not Applicable	With Out

TECHNIQUE (QW-410)	
String or Weave Bead :	Stringe / Weave
Orifice or Cup Size :	NA
Initial & Interpass Cleaning :	Chipping/Grinding
Method of Back Gouging :	Not Applicable
Oscillation :	Not Applicable
Contact tube to work distance :	15 - 25 mm (GMAW)
Multiple or Single Pass :	Multiple
Multiple or Single Electrode :	Single
Closed or Out Chamber :	Not Applicable
Electrode Spacing :	Not Applicable
Peening :	Shall not be done
Manual or Machine :	Semi Auto(GMAW)

POSITION (QW-405)	
Position(s) of Groove :	1G Position(s) of Fillet : FLAT
Vertical Progression : Up	[X] Down [ ]

WELDING PROCEDURE

Pass or Weld Layer (s)	Process	Filler Metals: Class	Filler Metals: Diam. In mm	Current: Type & Polarity	Current: Amps	Current: Volts	Bead Width	Travel Speed mm/Min.	Heat Input (Max.) KJ/mm	Remarks
Root	GMAW	E70C-3X	1.2	DCEP	90-110	20-25	4-7	180-250	0.833	
Hot Pass	GMAW	E70C-3X	1.2	DCEP	100-120	20-25	5-8	180-280	1	
Fill	GMAW	E70C-3X	1.2	DCEP	135-185	20-30	7-10	300-500	1.1	

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Table 3. Experimental apparatus and conditions

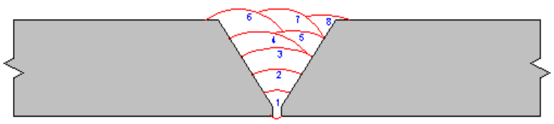
Base material composition and thickness	IS 2062 6 mm thick
Test piece size	200 mm x 500 mm
MIG wire	1.2 mm diameter solid wire as per E70 C- 3X
Shielding gas	CO_2
MIG wire extension	20 mm
Electrode angle	10 °± 1°(Approximate)
Power Source MIG	ESAB K 400

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 inFigure **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 andFigure 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	Angle	35°± 5°		Pipe Dia		NA
Electrode polarity:	Electrode positive	Thickness	8 mm		Root face		0.5-1 mm
Filler wire diameter:	1.2 mm	Root gap	1.5 – 2 mm		Backing		None
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	Ambient Dry	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

4-2	108	24.2	3	8	230.0	0.68
4-3	127	29	2	10	300.0	0.74
5-1	131	25.8	3	4-6	230.0	0.88
5-2	138	29	3	8	300.0	0.80
5-3	135	29	2	10	300.0	0.78
6-1	127	30	3	4-6	230.0	0.99
6-2	168	28.2	3	8	300.0	0.95
6-3	135	29	2	10	300.0	0.78
7-1	132	30	3	4-6	300.0	0.79
7-2	162	28	3	8	300.0	0.91
7-3	175	27.8	2	10	381.0	0.77
8-1	149	30	3	4-6	230.0	1.17
8-2	148	30.6	3	8	300.0	0.91
8-3	145	24.4	2	10	300.0	0.71

Table 5. Results of MIG process validation using Articulator

Test sample ID No.: DS14ME 005 / XX	Visual Inspection	Macro examination with at 20 X magnification	Tensile Test Ultimate tensile strength value in N/mm^2 (Min. required is 410 N/mm^2)	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

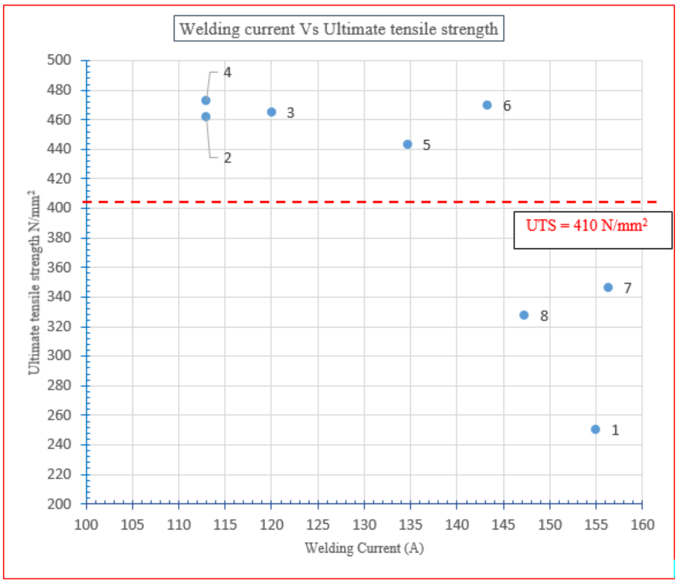


Figure 2. Graph of welding current and ultimate tensile strength

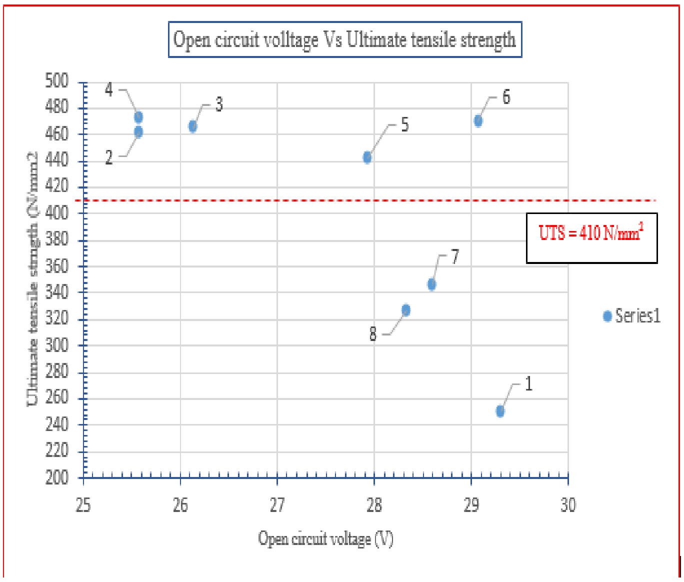


Figure 3. Graph of open circuit voltage and ultimate tensile strength

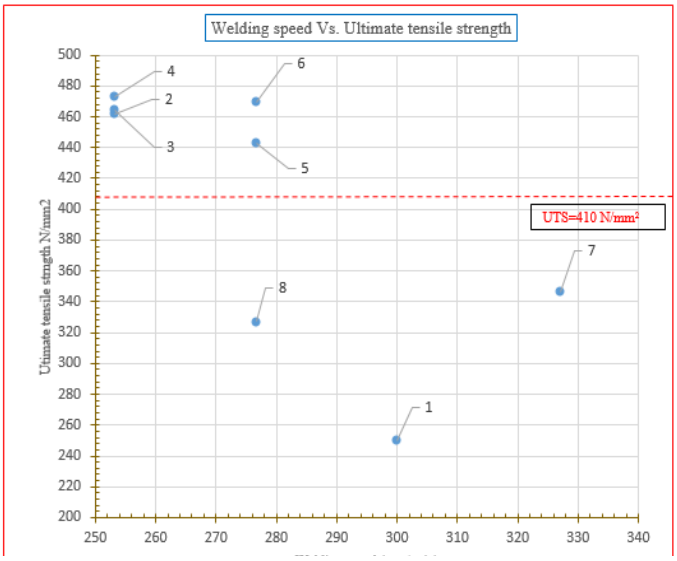


Figure 4. Graph of welding speed and ultimate tensile strength

References

[1] Chang and Babkin 2016 Calculation of Solid Wire Melting Rate in CO 2 Welding *Weld. Res.* **95** 163–73

[2] Babkin and Gladkov 2016 Identification of Welding Parameters for Quality Welds in GMAW *Weld. J.* **95** 37–46

[3] American society for Mechanical Engineers 2017 ASME BPVC section IX *ASME* 1–403

[4] American society for Mechanical Engineers 2017 ASME BPVC Section ii A 2017 1–813

[5] Graf 2005 LaserHybrid process at Volkswagen 1–9

[6] Kanemaru S, Sasaki T, Sato T, Era T and Tanaka M 2015 Study for the mechanism of TIG-MIG hybrid welding process *Weld. World* **59** 261–8

[7] Lu Y, Chen S, Shi Y, Li X, Chen J, Kvidahl L and Zhang Y M 2014 Double-electrode arc welding process: Principle, variants, control and developments *J. Manuf. Process.* **16** 93–108

[8] Kanemaru S, Sasaki T, Sato T, Mishima H, Tashiro S and Tanaka M 2014 Study for TIG–MIG hybrid welding process *Weld. World* **58** 11–8

[9] Mishra R R and Tiwari V K 2014 A study of tensile strength of MIG and TIG welded dissimilar joints of mild steel and stainless steel *Int. J. Adv. Mater. Sci. Eng.* **3** 23–32

[10] Mahto D and Kumar A 2008 Application of root cause analysis in improvement of product *Joural Ind. Eng. Manag.* **01** 16–53

[11] Melicher R, Meško J, Novák P and Žmindák M 2007 Residual stress simulation of circumferential welded joints *Appl. Comput. Mech.* **1** 541–8

[12] Meng X, Qin G, Zhang Y, Fu B and Zou Z 2014 High speed TIG–MAG hybrid arc welding of mild steel plate *J. Mater. Process. Technol.* **214** 2417–24

[13] ASME 2015 Specifications for Welding Rods, Electrodes, and Filler Metals 1–2159

[14] Nanekar P P, Shah B K, Division A F and Atomic B 2003 Characterization of Material *National Seminar on Non- Destructive Evaluation* pp 25–38

[15] Natarajan U, Veerarajan T and Ananthan S S 2014 Quality Level Assessment for Imperfections in GMAW **93** 85–97

[16] Ogawa Y 2012 Visual Analysis of Welding Processes *Welding Processes* pp 277–304

[17] Pouriamanesh B B and R 2015 Effect of Filler Metal on Mechanical Properties of HSLA Welds *Weld. Res.* **94** 334–41