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Development of Welding Parameters to Perform Root Pass Welding Using a Mechanised GTAW Process: A Case Study

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Abstract: *Due to a lack of skilled manual welders especially during peak production times, a local welding and fabrication firm in Trinidad was prompted to search for an alternative method to execute their welding operations. In order to address this issue the capital-intensive mechanised gas tungsten arc welding (GTAW) process was identified as an option. The objective of this paper is the development of welding parameters for an effective implementation of a mechanised GTAW process in the local industry in accordance with global welding standards. For experimental purposes, through an extensive literature search, operational parameters such as wire speed, weld current and travel speed were considered to perform root pass welding of the specimens. The selected welding parameters were successfully studied for both the 8″ and 10″ test coupons that produce good root reinforcement in accordance with international standards. The experimental results showed that performing root pass welding becomes much easier as the pipe diameter increases. The results indicate that the wire speed varies to a significant extent in the case of 8" diameter test coupons. Moreover, the weld current varied to a significant extent in the case of welding smaller diameter pipes. It was also observed that the travel speed was constant for 8″ diameter test coupons, and decreased for 10″ diameter pipes.*

Keywords: *GTAW process, welding parameters, wire speed, weld current, travel speed, root pass.*

1. Introduction

Welding is an essential process in fabricating a variety of products in industry. The welding arc has been successfully used in the welding industry for many years. The weld-bead geometry produced by gas tungsten arc welding (GTAW) plays an important role in determining the mechanical properties of the weld and its quality (Vasudevan et al., 2007). Consequently, there arises a need to investigate the work of the GTAW processing (Weglowski, 2005; Vasudevan et al., 2007). Its shape parameters such as bead width, depth of penetration, and reinforcement height are decided according to welding process parameters such as wire speed, current, voltage, torch speed, and arc gap (Vasudevan et al., 2007). However, not all physical phenomena associated with it have been fully understood and explained to date. Moreover, it is not easy to obtain optimal parameters of the GTAW process (Lin and Chou, 2010). Thus, there arises a need to further investigate the GTAW process to achieve the target weld-bead geometry.

A welding and fabrication firm in Trinidad was set-up in 1987 to provide welding and fabrication services during the construction and operational phase of various chemical plants at an industrial estate. Since then, the company has grown into one of the primary providers for welding and fabricating services throughout the country both on-shore and off-shore to manufacturing, energy and petrochemical industries.

The company has been instrumental in the construction of several major ammonia and methanol plants in Trinidad, which include the CNC ammonia plant, the N2000 Ammonia plant and the M5000 Methanol plant. Additionally, the company provides services for a number of petrochemical plants. With the knowledge and experience gained by the company from these major projects, the management of the company deemed it necessary to upgrade the company’s human and physical resources to ensure the company's competitive edge in the market for future expansion.

The lack of skilled welders especially during peak production time prompted the firm to search for an alternative method to execute their welding operations. Taking this into consideration the company's management in consultation with its various clients saw a need to decrease its reliance on manual skilled welders from the locally diminishing labor pool. To tackle this problem, the capital intensive mechanised GTAW process was identified as the solution. However issues of development and proper implementation of the welding systems on par with global standards is a major concern that has to be investigated to ensure that the company could increase productivity, improve quality and reduce the system cost.

The development of a mechanised GTAW system with standard industrial welding codes (ASME Section IX and Section B31.3) allows for practitioners to use equipment to perform welding at various industrial plants that would normally permit welding operations through a manual welder. This involves the development of welding parameters to perform root pass welding. The objective of this paper is to study parameters such as weld current, wire and travel speed to perform root pass welding using a mechanised GTAW process. The rest of the paper is organised as follows: In section 2, a review of literature on the GTAW process related issues, parameters and approaches developed so far is presented. The research methodology can be seen in section 3. This is followed by experimental results in section 4. Section 5 gives the analysis and discussion of the study results. Finally, section 6 concludes the paper.

2. Literature Review

Although most welding tasks have already been automated, high reliability of the manual welding fabrication is still demanded (Sakuma et al., 2001). However, disturbances and changes in the welding work environment can lead to possible variations in the output variables associated with weld quality (Kim and Rhee, 2003). In this section, a brief review of the subject developments took during the last two decades is presented in order to get an overview of the GTAW process related issues, parameters and approaches developed so far.

Root pass welding trials using automatic GTAW, both in the upward and downward directions, were conducted in the past (Renelt, 1988). It was found that welding carried out with a non-current-carrying filler wire and a modulated welding current resulted in much better control over the weld pool. Furthermore, researchers (Khromchenko et al., 1990) conducted experiments to investigate the effect of the parameters of manual arc welding with modulated currents on the technological characteristics of the welding process and examination of the effect of welding arc parameters and wire tip end on start of the welding process (Neustadt and Grutka, 1991). In addition, improved approaches can also be seen in the literature for calculating the parameters of the heat affected zone for controlling the welding process (Meshcheryakov et al., 1994).

Within the context of integrated welding process design, researchers proposed new approaches for off-line programming of welding robots by interfacing a CAD modeler through a geometric database and an artificial intelligence system. This showed how CAD features can be used to determine the welding process, the welding wire and then to compute welding parameters (Legoff and Hascoet, 1998). Moreover, the authors proposed a new approach to generate welding parameters automatically in the GMAW process with neural networks. Mathematical models for grove and circumferential GTAW of pipes with single V grooves were developed to examine the effects of various welding parameters, such as welding positions and joint geometries, as well as the effect of the arc pressure on the welding process. The results suggest that the proposed numerical model is suitable for estimation of welding process parameters during groove welding (Yokogawa et al., 1999) and circumferential welding (Miyasaka et al., 1999) of pipes.

Welding sequences in shielded metal arc welding process were studied in the past to eliminate local brittle welding zones (LBZ) and to evaluate the microstructure produced in the heat affected zone (HAZ) of steel weldments used in pipelines (Zalazar et al., 2000). The welding process was characterised by multiple runs and low heat input, LBZ were present in the HAZ, which originated from a complex mechanism influenced by welding parameters and the chemical composition of the steel.

In order to clarify the skill for manual welding in engineering workshops, the necessity of the in-process monitoring of manual welders' performance was addressed adequately (Sakuma et al., 2001). In this regard the study ascertained the behaviour of welders at different skill levels during the manual welding process and confirmed that parameters such as movement of the welding torch and the viewpoint of the welders reflected the welders' skill level. Moreover, Koga et al. (2001)'s study explored the relationship between welding position and proper welding parameters in an electron beam welding environment on all position welding of large diameter pipeline joints.

The GTAW process is frequently used in welding of aluminum alloys, because of its possible heat input control. Suitable combinations of tungsten electrode parameters and process variables can lead to optimum GTAW bead dimensions. The effect of electrode diameter, vertex angle, and the welding current and speed on the bead dimensions were investigated thoroughly by Aesh (2001). The study results revealed that the rate of increase of bead width with increase in current is greater than that produced by decreasing travel speed. In addition, it was found that the bead width can be controlled more efficiently by welding current rather than by welding speed. Furthermore, the average HAZ width decreased as the welding current and/or speed increased. It was also noticed that the influences of electrode diameter and apex angle on the bead width were similar to their effects on the arc size. The bead width was found to decrease with an increase in the electrode diameter to a certain extent, and increase slightly with an increase of the apex angle.

In order to enhance weld quality, it is essential to optimise the welding process by taking the variance as well as the average value of the output variables into consideration. In this regard, the dual response approach was adopted by the researchers to determine the GMAW welding process parameters, which produce the target value with minimal variance (Kim and Rhee, 2003).

Identification of a suitable combination of GTAW process parameters to produce the desired weld-bead geometry required many trials, and the optimisation of the welding process was indeed time consuming and costly. In this regard, the study of Vasudevan et al. (2006) had focused on genetic algorithm (GA) based computational models to determine the optimum/near optimum process parameters (such as current, voltage, torch speed, and arc gap) to achieve the target weld-bead geometry in stainless steel welds produced by the GTAW process.

Manti and Dwivedi (2007) proved that the pulsed GTAW process parameters such as pulse duration, peak current, and pulse frequency had a noticeable impact on the microstructure of HAZ, fusion line, and weld metal of Al-Mg-Si joints. It was also observed that a significant change in microstructure takes place in moving from the base metal to the weld centerline.

The design of experiments has been used to optimise the pulsed current GTAW process to attain maximum impact toughness (Balasubramanian et al., 2008) in a plasma arc welding (Hsiao et al., 2008) environment. However, regression analysis approach has been used in the study of Balasubramanian et al. (2008) to predict the impact toughness of titanium alloy joints under the pulsed current parameters.

Based on the knowledge gained through the survey of literature, it can be stated that many parameters affect the quality of the GTAW process. Furthermore, it is not easy to obtain optimal parameters of the GTAW process (Lin and Chou, 2010). Recently, researchers applied an integrated approach using the Taguchi method combined with artificial neural network (ANN), and genetic algorithm (GA) to optimise the weld bead geometry of GTAW specimens. It was proved that the GTAW with flux process is the feasible option to obtain greater penetration of the weld bead while employing the same welding parameters as conventional GTAW (De-Azevedo et al., 2010).

3. Need for Development of Welding Parameters

The root is defined as the "portion of a joint to be welded where the members approach closest to each other where in the cross section of the joint root may be a point, line or area (ANSI/AWS D10.11-87R)". However, industrial pipe welding operations should meet certain industrial standards (ANSI/AWS D10.11-87R) while welding the root pass. In order to ensure the quality in weldments, a weld must completely penetrate through the pipe. In addition, cracks or crevices, where stress propagation can be initiated have to be eliminated by a sound root pass.

Welding defects such as melt-through, lack of fusion are very common in root pass welding of industrial pipe. In root pass welding, "all minute hand movements the welder practiced are to pave a sound continuous supporting surface to let subsequent depositions be easily placed on." (Hung and Kuan, 2000). When welding is performed manually, the weld quality is totally controlled by the skill of the welder who can directly monitor the flow pattern in the molten puddle and make immediate adjustments in arc length, weaving, handling pattern and so on to obtain a sound weld. For mechanised welding, the torch and wire feed angle will remain fixed. However, to perform such a function with a machine would require a tight control on welding parameters such as current, voltage, oscillation speed and amplitude.

One of the requirements of the mechanised GTAW process was the achievement of a root and subsequent hot pass with 37.5 degree bevels, which is standard end geometry available at industrial pipe fitting suppliers. In practice it was recommended by the manufacturers that a J-bevel with industrial pipe ends butted is the most suitable to perform a root pass.

Based on the literature review, it has been found that optimising the root pass welding parameters such as current, wire speed and travel speed enhance GTAW process quality (Renelt, 1988; Khromchenko et al., 1990; Neustadt and Grutka, 1991; Aesh, 2001; Sakuma et al., 2001; Koga et al., 2001; Aesh, 2001; Vasudevan et al., 2006; Manti and Dwivedi, 2007; Balasubramanian et al., 2008; Lin and Chou, 2010; De-Azevedo et al., 2010). Moreover, the identified root pass parameters (welding current, wire speed and travel speed) are useful in order to perform GTAW in the outdoors especially to conduct visual inspection on the internal root surface and develop the ideal conditions under which it can be performed consistently. This forms the motivation for this research project.

4. The Research Methodology

The welding power supply used in the study was the Pipemaster Model 510 GTAW power source with an integral weld head controller. For the welding parameter development the T-head was used.

The wire type used was ER70S manufactured by

EWI with a wire diameter of 0.035″. In this study, only double V-groove bevels were selected for investigation. These grooves were machined on test coupons using a portable pneumatic lathe as per the specifications presented in Figure 1.

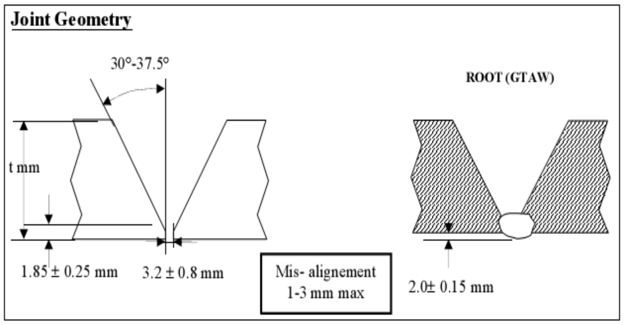

Figure 1. Joint geometry for the root pass welding

Results were obtained through visual observation and electronic data logging of welding parameters and recorded as per the format shown in Figure 2. For the convenience of the welding, the circumference of the pipe was divided into two regions (A and B), with each further divided into 3 sectors i.e. 1A, 2A, 3A and 1B, 2B, 3B (see Figure 3), and the relevant welding parameters controlled in each section accordingly to obtain a sound weld during each pass.

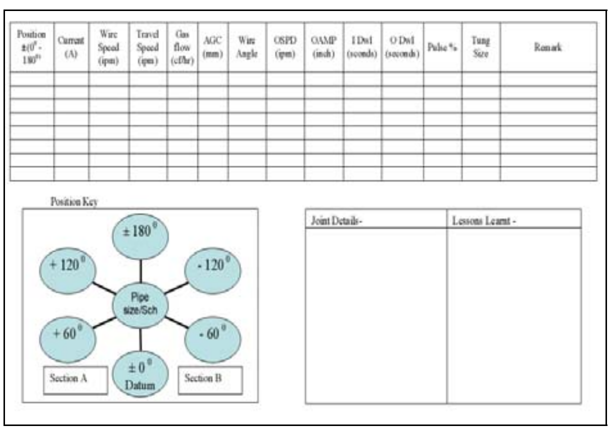

Figure 2. Test sheets used to collect data

In order to understand the influence of weld parameters on the joint properties, pilot experiments were conducted to optimise the welding parameters to perform the root pass welding. Tests were conducted on 8″ and 10″ diameter coupons (as per Schedule 80: Carbon Steel, ASTM A106) to identify the welding parameters that produce an acceptable weld quality. The results (as presented in Tables 1, 2 and 3) represent the data collected for the root pass development.

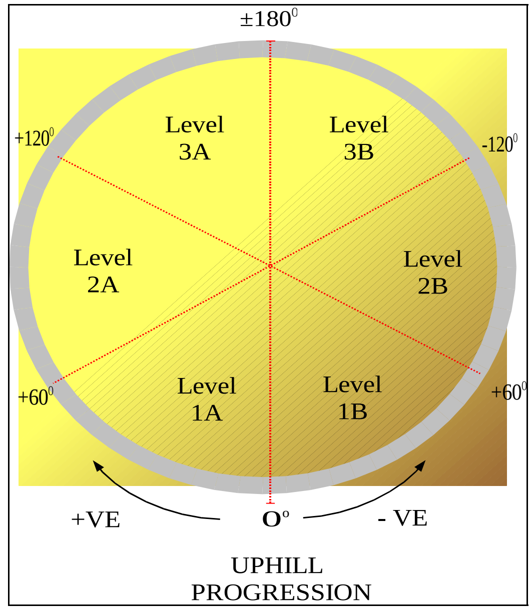

Figure 3. Test sectors for the selected pipe

Table 1. Results obtained for the 8” test coupons

	Position (degree/level)		Average Value	Maximum	Minimum	Mean
Current (amps)	± 0 - 60	3	131.0	141.5	115.1	128.3
	± 60 -120	2	127.3	133.7	120.9	128.3
	± 120 -180	1	128.3	148.3	113.7	128.3
Wire Speed (ipm)	± 0 - 60	3	48.2	57.8	38.5	48.8
	± 60 -120	2	49.3	51.2	47.4	48.8
	± 120 -180	1	48.8	58.6	39.0	48.8
Travel Speed (ipm)	± 0 - 60	3	2.2	2.3	2.1	2.22
	± 60 -120	2	2.2	2.3	2.1	2.22
	± 120 -180	1	2.2	2.3	2.1	2.22

Table 2. Results obtained for the 10” test coupons

	Position (degree /level)		Average Value	Maximum	Minimum	Mean
Current (amps)	± 0 - 60	3	157.3	182.6	131.9	162.9
	± 60 -120	2	153.1	179.9	126.3	162.9
	±120 -180	1	162.9	204.7	121.0	162.9
Wire Speed (ipm)	± 0 - 60	3	36.8	47.1	18.6	39.0
	± 60 -120	2	30.3	47.2	22.0	39.0
	±120 -180	1	39.0	60.6	17.4	39.0
Travel Speed (ipm)	± 0 - 60	3	2.0	3.5	0.6	1.7
	± 60 -120	2	1.5	2.2	0.8	1.7
	±120 -180	1	1.7	2.0	1.4	1.7

4. Results

From the welding tests conducted on the 8” and 10” diameter test coupons, welding parameters were identified that produced a sound root pass. Five tests (refer Table 4) produced an inner and outer root bead geometry that was acceptable on the 8″ test coupons whilst four tests produced an inner and outer root bead geometry that was acceptable on the 10″ test coupons. The results are shown in Table 5. From these results average values were obtained for various welding parameters and graphs were plotted. The graphs (see Figure 4 to Figure 8) represent a plot of wire speed, weld current and travel speed at various locations along the circumference of the pipe joint.

Table 3. The selected welding parameters to perform root pass

Welding Parameters	**Magnitude**
Oscillation Speed	0.6 - 0.65 ipm
Oscillation Amplitude	0.07″
Pulse	75 - 80%
Arc Gap Control (AGC)	0.003” – 0.060”
Tungsten Electrode Diameter	3/32″
Inner Dwell Time	0.25 - 0.32 second
Outer Dwell Time	0.25 - 0.32 second

Table 4. Root pass development results for the 8” test coupon (106-b carbon steel)

Section	Position	Level	Test -1			Test -2			Test -3			Test -4			Test -5		
			Current (amps)	Wire Speed (ipm)	Travel Speed (ipm)	Current (amps)	Wire Speed (ipm)	Travel Speed (ipm)	Current (amps)	Wire Speed (ipm)	Travel Speed (ipm)	Current (amps)	Wire Speed (ipm)	Travel Speed (ipm)	Current (amps)	Wire Speed (ipm)	Travel Speed (ipm)
A	- 0~60	3	123	47	2.2	130	50	2	169.1	70.7	2	125	40	2.3	124	44	2.2
	- 60 ~120	2	124	47	2.3	130	50	2	132	63	2	127	39	2.6	124	48	2.2
	-120 ~180	1	124	47	2.4	130	50	2	135	60	2	121	42	2.6	124	47	2.2
B	+ 0~60	3	126	44	2.2	130	50	2	130	50	2	125	42	2.6	128	44	2.2
	+ 60 ~120	2	128	48	2.3	130	50	2	125	60	2	125	40	2.3	128	48	2.2
	+120 ~180	1	128	48	2.3	130	50	2	125	45	2	138	47	2.5	128	52	2.2

Table 5. Root pass development results for the 10” test coupon (106-b carbon steel)

Section	Position	Level	Test -1			Test -2			Test -3			Test -4		
			Current (amps)	Wire Speed (ipm)	Travel Speed (ipm)	Current (amps)	Wire Speed (ipm)	Travel Speed (ipm)	Current (amps)	Wire Speed (ipm)	Travel Speed (ipm)	Current (amps)	Wire Speed (ipm)	Travel Speed (ipm)
A	- 0~60	3	167	49	2.3	115	30	1.5	193	37	1.1	150	40	2.4
	- 60 ~120	2	150	20	2	125	25	1.2	159	29	0.6	152	30	2.3
	-120 ~180	1	160	36	1.5	125	22	1.5	172	48	1.1	150	35	2.4
B	+ 0~60	3	144	43	1.5	145	32	1.5	194	30	1.5	150	40	2.4
	+ 60 ~120	2	159	45	1.2	125	30	1.2	205	28	1.2	150	35	2.3
	+120 ~180	1	186	54	2.2	170	37	1.5	188	40	1.1	152	40	2.4

5. Analysis of Data and Discussion

The analysis of the data with regard to the wire speed, weld current and travel speed parameters is dealt with in this section. The maximum and minimum values obtained in a given test sector for various levels (refer Figure 3) were plotted for each of the 8″ and 10″ test coupons.

5.1 Wire Speed

(i) For the 8″ Diameter Test Coupon

From the graph (refer to Figure 5), it can be seen that as the weld head orbited the perimeter of the pipe, the operating range constricted at level three significantly such that the range of wire speed in level one was 19.32 ipm whilst the range in level 2 constricted to 3.73 ipm and the range at level 3 was re-established to 19.52 ipm. The graph indicates that as the weld head progresses along the circumference of the pipe from level 1 to level 3 the wire speed varies to a significant extent such that the degree of control tightens significantly at level 2 and more attention is required. Also, the average wire speed for levels 1 to 3 is relatively constant as shown in the Figure 5.

(ii) For the 10″ Diameter Test Coupon

The shape of the graph (refer to Figure 8) for the wire speed of the 10″ test coupon is similar to the 8″ test coupon in terms of the maximum and minimum points. From the graph the maximum and minimum wire speeds at each level vary such that the range of wire speed in level one was 28.5 ipm whilst the range in level 2 constricted to 25.2 ipm and the range at level 3 increased significantly to 43.2 ipm. From the graph, the control required between levels 1 and 2 was similar with no major convergence. However, for level 3, a significant divergence in the operational range can be seen. The average wire speed varies to a significant extent for the 10 ″ test coupon as the wire speed is decreased at level 2 and then increased again at level 3.

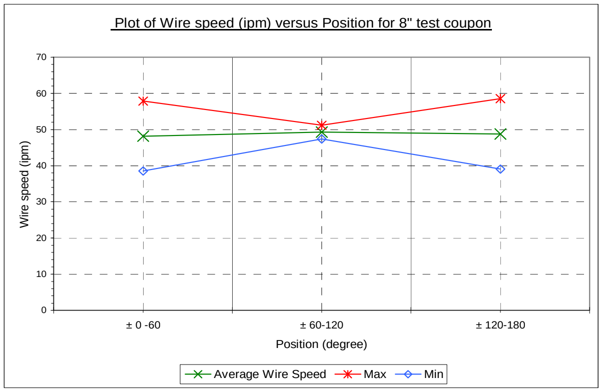

Figure 4. Plot of wire speed versus weld position for the 8” test coupon

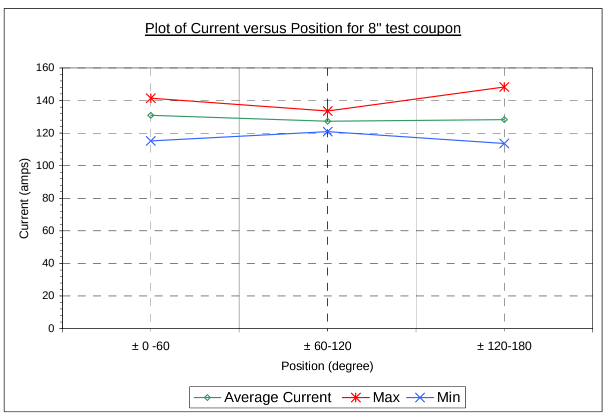

Figure 5. Plot of current versus weld position for the 8” test coupon

5.2 Weld Current

(i) For the 8″ Diameter Test Coupon

As shown in Figure 5, it can be observed that the maximum and minimum current values at each level vary such that the range of current in level 1 was 19A whilst the range in level 2 converges to 3.3A and the range at level 3 increased to 20.5A. As the weld head progresses from level 1 to level 3, the current varies to a significant extent such that the degree of control tightens significantly at level 2, and more attention is required.

(ii) For the 10″ Diameter Test Coupon

Figure 9 shows that the operating range from which a sound weld can be obtained with current values of 50.76A, 53.58A and 83.66A for levels 1, 2 and 3 respectively. The average current was relatively constant for the three levels with a slight increase from 157.25A for pass 1 to 162.80A for pass 3.

Figure 6. Plot of travel speed versus weld position for the 8” test coupon

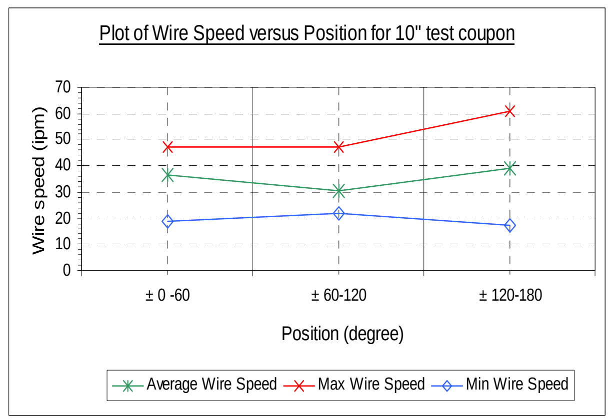

Figure 7. Plot of wire speed versus weld position for the 10” test coupon

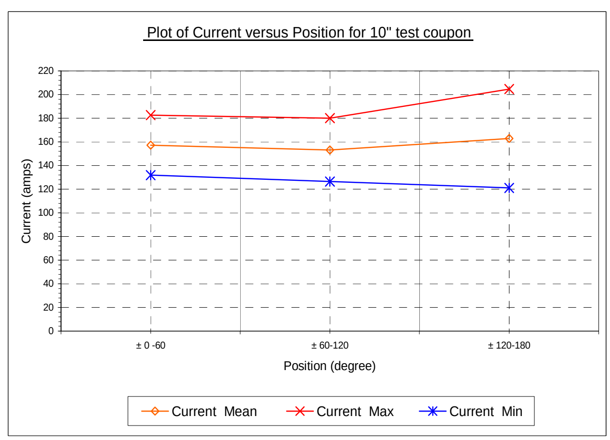

Figure 8. Plot of weld current versus weld position for the 10” test coupon

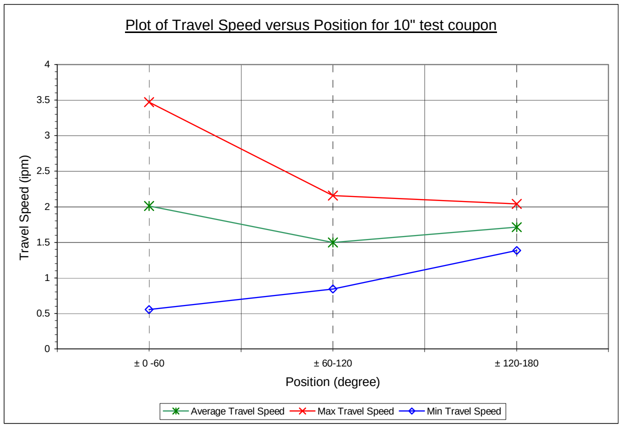

Figure 9. Plot of travel speed versus weld position for the 10" test coupon

5.3 Travel Speed

(i) For the 8″ Diameter Test Coupon

From the graph (see Figure 7), it can be observed that the travel speed is relatively constant in addition to the average travel speed at the three levels.

(ii) For the 10″ Diameter Test Coupon

It is shown in Figure 10 that the operational range of the travel speed produces good weldment converge significantly (from 2.90 ipm to 1.31 ipm and 0.66 ipm) for levels 1, 2 and 3 respectively. The average travel speed decreased as the weld head progressed from levels 1 to 2, and an increase can be found from levels 2 to 3.

It can also be observed that there is no violation of international standards in the development of welding parameters to perform root pass welding using mechanised GTAW process. To meet the aim of the study, special attention was paid in the selection of the equipment and preparation of the test coupons. Also the root spacing between all the test coupons (see Figure 1) were held constant at 1/ 16″ with the aid of spacers to avoid variations in the weld quality. Spacers were initially placed and then removed as the root pass progressed to prevent the pipe sections from pulling towards each other due to expansion and contraction from the heat input as the weld head circumnavigates the pipe.

Welding parameters were successfully developed for both the 8″ and 10″ root pass test coupons. From the observations and experience gained, performing root pass welding becomes much easier as the pipe diameter increases. This can be inferred from Figures 5 to 8, which show that the range over which a sound weld can be obtained is wider for the 10″ test coupons. The root pass parameters for the 8″ test coupons produced weldment that were on par with code requirements with both the inner and outer surfaces having uniform bead geometry with complete joint penetration and fusion of weld metal. Similar results were obtained for the 10″ test coupons.

6. Conclusion and Future Research

The development of welding parameters to perform the root pass welding using a mechanised GTAW system at a local welding firm in Trinidad was successful in accordance with international welding standards. The root pass parameter development was successfully undertaken as part of an overall project objective to identify the issues associated with a mechanised GTAW system with ideal conditions and operating parameters attained. Specifically, it was found that the range over which a sound weld can be obtained is larger for the 10″ test coupons than for the 8″ test coupons.

The results indicate that as the weld head progresses, the wire speed varies to a significant extent in the case of 8" test coupons and more attention is required. As the weld head progresses, the current varies to a significant extent and thus, more attention is required in the case of smaller diameter test coupons (8"). For larger test coupons, the average current was relatively constant.

Furthermore, it was observed for the 8″ diameter test coupons that the travel speed was relatively constant, whereas for the 10″ diameter test coupons, the average travel speed decreased as the weld head progressed. Thus, the information obtained through this experimental study would allow managers to make specific strategic decisions on future projects. This research can be extended to investigate in an inert gas environment that can aid in obtaining a better root pass weld in a cost effective and feasible manner.

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