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EFFECT OF REPETITIVE WELDING USING ORBITAL GMAW ON TENSILE PROPERTIES OF AISI 304 AUSTENITIC STAINLESS STEEL PIPES

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Abstract: *Repair welding is often carried out in steel structural components. The main intention of repair welding is by providing a cure for existing welding defects during initial stages or weld deterioration during their services that can increase the service lives or performance of components. Repair welding is a better choice as compared to replacing the parts because it is a more economical, faster and reliable method to make a part come back to its services when failure of the parts is identified. In this study, the effect of welding parameters on tensile properties of AISI 304 austenitic stainless steel pipes was investigated. The best set of parameters was suggested by using Taguchi method as the design of experiment and analysis. Results showed that the optimum set of parameters for achieving highest ultimate tensile strength (UTS) values was when arc current, arc voltage and welding at 160 A, 22 V and 50 mm/min, respectively. On the other hand, the optimum set of parameters for achieving highest elongation percentage was when arc current, arc voltage and welding speed at 160 A, 22 V and 40 mm/min. Based on the optimum set of parameters, the repetitive welding to replicate a repairing process was performed. It was evidenced that the UTS showed an increasing trend up to the second repair (RW2) before decreased after the third repair (RW3). The highest value of UTS obtained at second repair (RW2) was 525.51 MPa. The repair welding has caused dynamic changed in the microstructure of the weldment. Therefore, the number of optimum repetitions for the AISI 304 austenitic stainless steel pipes was proposed up to second repair.*

Keywords: *Gas Metal Arc Welding, AISI 304 Stainless Steel, Repetitive Welding, Repair, Tensile Testing.*

1. Introduction

Gas Metal Arc Welding (GMAW) is a welding process in which an electric arc forms between a consumable wire electrode and the work piece metal, which will heat the work piece metal causing them to melt and joint together. Both the arc and weld pool are protected from the atmospheric contamination by an inert gas as a shield which is sent through a nozzle that is concentric with the welding wire guide tube. GMAW has been commercially available around 60 years. It is commonly used as industrial welding process. One of the main factors of this happen are because of its versatility, speed and the ease of adapting the process even to robotic automation.

Definition of orbital welding is the circular movement of welding tool or welding torch around the workpiece to be welded. This orbital welding process mainly involve in industries such as pharmaceutical, aircraft, food and beverage, chemical, fossil and nuclear power plant. It is often used to join tubes or pipes over the other types of joining methods. Whenever advance quality weld is required, orbital welding is the most chosen process for the joining of tubes. This is not only because it provides best weld quality, it also can perform easily and smoothly in a cramped working environment [1].

The demand on stainless steel usage in industry increase drastically as a result of rapid growth, combined with the limitations in production routes and dynamic raw materials price of major alloying addition such as nickel, molybdenum, and chromium have stimulated

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engineering companies and fabricators to create alternative grades to the commercial austenitic stainless steel with attractive corrosion and mechanical properties as well as stable price. Austenitic stainless steel (ASS) has good trade carrying into action in corrosive working environment [2]. This type of stainless steel is suitable in either conducive or high temperature service environment. Other than that, they also convey good mechanical properties, especially toughness and ductility, so that it shows exceptional elongation during tensile testing.

Repairs are generally carried out by removing a non-acceptable welding defect, re-welding and then reinstating the original geometry of the component. Repair welding is often carried out in steel structural components. The main intention of repair welding is by providing cure for existing welding defects during initial stages or weld deterioration during their services that can increase the service lives or performance of components. Repair welding is a better choice compared to replacing the parts because it is more economical, faster and reliable method to make a part come back to its services when failure of the parts is identified [3]. Wrong processes and poor handiwork such as excess or incomplete weld penetration at fabrication stage can cause failure to the weld. Besides that, inappropriate selection of filler metal used in welding operation also can cause failure to the weld. Another cause that leads to the failure of weld is stagnation during services, where the working environment is corrosive or emphasizes by stress corrosion [4]. The Welding Institute (TWI) conducted an industry survey on repair rates in 2011 and came up with the average repair rates for different welded products/parts based on typically used material grades [5] as shown in Table 1 and Figure 1.

Repair welding is also often required in industry to extend the service life or to increase performance of the parts or components by giving remedy for existence of welding damages during primary stage or weld deterioration during their services [6]. Besides, performing repair welding is low-cost rather than purchasing new parts or components which will increase the cost. Furthermore, repair welding is comparatively cost-effective than replacing the parts because delay time during waiting of the replacement parts might bring irretrievable lost to a company [7]. In conclusion, repair welding is significant for reduce cost, minimize break down time and extending the service life of a part or component.

Table 1. Average Repair Rates for Different Welded Products and Materials [5]

Type of product	Average repair rate, any material grades, %	Average repair rate per material grade, %					
		Mild steel	Stainless steel	Low alloy steel	Ni alloy	Low temperature steel (eg Ni steel)	High strength steel
All products	-	2.0	2.2	3.1	3.4	2.2	-
Offshore structures	2.0	2.1	1.1	-	2.0	2.2	-
Other welded structures	1.0	1.5	0.7	-	-	-	-
Piping systems	3.0	1.7	3.5	4.2	-	-	-
Pressure vessel	2.0	2.8	1.1	0.5	-	1.7	-
Offshore pipelines	2.0	0.9	7.5	-	-	1.8	-
Onshore pipelines	3.0	2.5	-	2 – 5	-	2 – 5	-
Cryogenic storage tanks	0.5	-	0.5	-	-	-	-
Hydroelectric turbines	1 - 2	1 - 2	-	-	-	-	--

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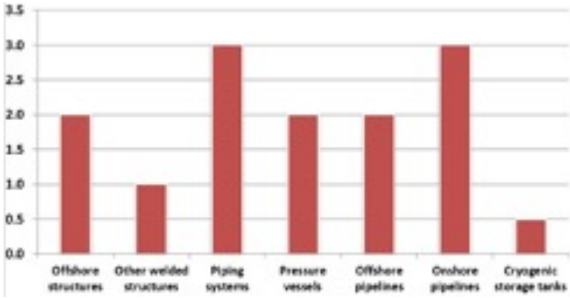

Figure 1. Average repair rates for different types of products/parts [5]

According to Agha Ali et al. [8] metallurgical properties of the steel had undergone changes with the number of welding. When number of weld repair increased, ferrite precipitate was also gradually getting finer and shorter together with some carbide precipitation. Lin et al. [9] stated the primary phases of AISI 304L also comprised of austenite matrix and lathy ferrite precipitates. The lathy ferrite was also become shorter and thinner in accordance to increasing of weld repair. For every repair welding, the material is subjected to additional heat input and the heat input is accumulated in the weldment. On the other hand, Kumar and Shahi [10] clearly stated heat input is a function for both dendrite size and interdendritic spacing. Slower cooling rate due to high heat input facilitates formation of coarser dendrites and they are separated in wider distance compared to low heat input.

Agha Ali et al. [8] also mentioned that grain size number in HAZ is increased corresponded to the number of weld repair that had done on the same location. Therefore, it was evidence that ultimate tensile strength (UTS) tend to increase only up the first repair and UTS begin to decrease after that. Elongation of specimen was also associated to its tensile properties, since it is a measure of changes in the specimen length to original length under tensile test. On the contrary, Vega et al. [11] reported that the tensile strength of API X-52 micro alloyed steel pipe can be increased up to second weld repair, where a maximum value is reached. However, both researchers are concluded that changes of tensile strength are due to reason of grain refinement occurred in the materials.

In this study, the effect of welding parameters on tensile properties of AISI 304 austenitic stainless steel pipes will be investigated. The best set of parameters will be suggested by using Taguchi method as the design of experiment and analysis. At the end of this study, the number of optimum repetitions for the AISI 304 austenitic stainless steel pipes will be proposed.

2. Experimental Methods

Stainless steel pipes of AISI 304 type with thickness of 4 mm were used in this study. The outer diameter of the pipe was 60.5 mm and it was cut to 60 mm long. The nominal composition of the AISI 304 pipe material and AWS E308 filler wire is given in Table 2. Wire of 308L (including ER308LSi) is predominately used on austenitic stainless steels, such as types 301, 302, 304, 305 and cast alloy. Therefore, AWS E308L wire with 1.2 mm was used as the consumable wire electrode. The ultimate tensile strength (UTS) and elongation of the E308 wire were 379 MPa and 40%, respectively.

Table 2. Nominal Composition (wt.%) of AISI 304 Pipe Material and AWS E308 Filler Wire

Chemical Composition (wt%)	AISI 304	AWS E308
C	0.050	0.04 max
Cr	18.545	18.0 – 21.0
Ni	8.211	9.0 – 11.0
Mn	1.600	0.50 – 2.50
Si	0.500	0.90 max
Mo	-	0.75 max
Cu	-	0.75 max
P	0.034	0.04 max
S	0.001	0.03 max
N	0.120	-

Taguchi method is a systematic tool for designing high quality of manufacturing system developed by Dr. Genichi Taguchi, a Japanese quality management consultant. It is based on the orthogonal array experiment, which reduced variance for experiments with optimal parameter setting process control. After that, the design integration with parametric optimization process to get the required outcome is achieved in Taguchi method. In this experiment, L9 orthogonal array was used with 3 parameters

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setting and 3 variables for each parameter. Table 3 shows the planning matrix for this experiment generated for the L9 orthogonal array using a Minitab software.

Table 3. Planning matrix of L9 orthogonal array generated by the Minitab software

Sample	Arc Current (A)	Arc Voltage (V)	Welding Speed (mm/min)
1	150	20	40
2	150	21	50
3	150	22	60
4	160	20	50
5	160	21	60
6	160	22	40
7	170	20	60
8	170	21	40
9	170	22	50

TransSynergic 4000 welding machine equipped with jig as shown in Figure 2 was used in this study. The function of the jig was to hold and rotate the pipe specimen and also to secure the movement of welding nozzle during welding process. Welding speed in this experiment was taken from the speed of the rotating jig. Before the welding process according to the setting parameters were performed, the pipes were tack welded in order to restrict their movement. Tack weld was performed at four locations along the pipes perimeter as shown in Figure 3.

Figure 2. Welding Torch Transsynergic 4000 Attached To A Rotating Jig

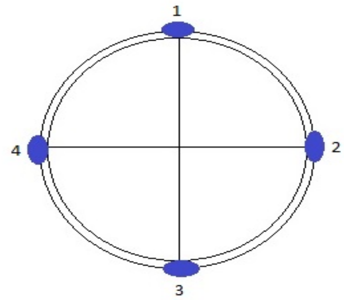

Figure 3. Tack Weld Along The Pipes Perimeter

Tensile specimens were cut from the welded pipes by using wire electrical discharge machining (WEDM) as shown in Figure 4. They were cut into dog bone shape with the dimension in accordance to the ASTM E8M-04. Filing was performed to flatten the gripping sections of the tensile specimens. Tensile testing was performed by using Shimadzu AG1 universal testing machine (UTM) with load capacity of 100kN and speed of 5mm/min. The ultimate tensile strength (UTS) were recorded. Percentage of elongation was measured from the difference of gauge length before and after tensile testing divided by the initial gauge length times with 100. Average value of each of tensile properties was measured from two samples.

After the optimum set of parameters was obtained from the first objective, repair welding was performed on the welded pipes. Table 4 shows schematic diagram on how the repair welding was performed on the pipes. Basically, the pipes started with the as-welded condition which designated as RW0. The weld bead height was measured and the value of 1.5 mm was recorded. The weld bead height was then machined with a lathe machine to replicate the preparation before repair welding was performed. Then, welding process using the optimum set of parameters was performed on top of the as-welded weldment. This was to replicate the first repair welding process as designated as RW1. The procedure was repeated for second repair (RW2) and third repair (RW3). Tensile testing was conducted on RW0, RW1, RW2 and RW3 samples. The change in trend of the tensile properties were observed. At the end of this study, number of optimum repetitions for the AISI 304 austenitic stainless steel pipes was proposed.

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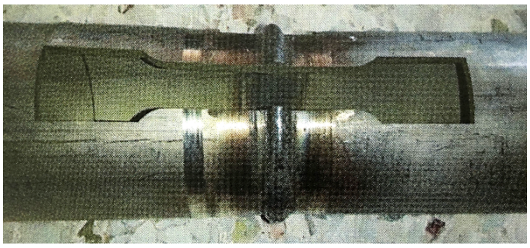
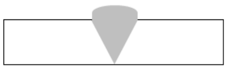
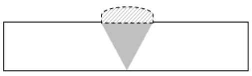
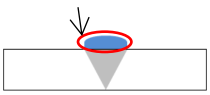


Figure 4. Cut off tensile specimens from the welded AISI 304 pipes by WEDM

Table 4. Schematic Diagram and Illustration of The Repair Welding Process

Image	Description
	As welded specimen (zero repair) Denotation: RW0
	Remove weld bead on the surface of specimen
	First repair welding Denotation: RW1

3. Results and Discussion

3.1. Effect of Tensile Properties

Results of tensile testing on AISI 304 stainless steel pipes are shown in Table 5. Results show that failure location mostly occurred at the weldment (WM). On the other hand, only for sample 1 and sample 3, the failure location occurred at the heat affected zone (HAZ).

In order to analyze the Taguchi method, Signal to Noise (S/N) ratio was calculated by using the Minitab software. Larger is better option was selected. This is due to the highest UTS is required for the sample. Table 6 and Table 7 shows the response table for S/N ratios of UTS values for the UTS and elongation, respectively.

From the graph of Main Effects Plot for Means in Figure 5, the optimum parameters to achieve the highest UTS when the arc current, voltage and welding speed were at 160 A, 22 V and 50 mm/min, respectively.

Table 5. Results of Ultimate Tensile Strength (UTS), Elongation and Failure Location of AISI 304 Stainless Steel

Sample 1	Arc Current (A)	Arc Voltage (V)	Welding Speed (mm/min)	Ultimate Tensile Strength (MPa)	Elongation (%)	Failure Location
1	150	20	40	302.539	1.45	HAZ
2	150	21	50	406.185	2.54	WM
3	150	22	60	490.121	3.99	HAZ
4	160	20	50	440.169	4.71	WM
5	160	21	60	349.317	0.36	WM
6	160	22	40	420.248	6.16	WM
7	170	20	60	345.117	0.36	WM
8	170	21	40	447.526	5.07	WM
9	170	22	50	376.726	2.17	WM

Table 6. Response Table for S/N Ratios of The UTS Values

Level	Arc Current (A)	Arc Voltage (V)	Welding Speed (mm/min)
1	51.87	51.08	51.70
2	52.07	52.02	52.19
3	51.77	52.60	51.81
Delta	0.30	1.52	0.49
Rank	3	1	2

Table 7. Response Table For S/N Ratios of the Elongation

Level	Arc Current (A)	Arc Voltage (V)	Welding Speed (mm/min)
1	7.781	2.605	11.040
2	6.793	4.441	9.429
3	3.985	11.513	-1.909
Delta	3.796	8.909	12.949
Rank	3	2	1

From the graph of Main Effects Plot for Means in Figure 6, the optimum parameters to achieve the highest elongation are when the arc current was at 160 A, voltage was at 22 V and welding speed was at 40 mm/min.

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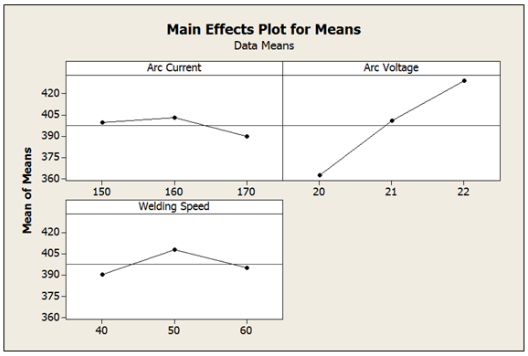

Figure 5. Main Effects Plot for Mean of the UTS Values

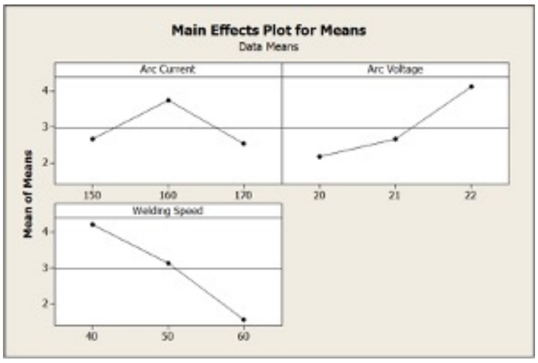

Figure 6. Main Effects Plot for Mean of the Elongation

For the validation test, the regression equation obtained for UTS is as Eq. 1. For the validation test, the regression equation obtained for elongation is as Eq. 2

UTS = – 233 – 0.49 (*Arc Current)* + 33.2 *(Arc Voltage)* + 0.24 *(Welding Speed)* (1)

Elongation = – 9.7 – 0.0063 *(Arc Current)* + 0.967 *(Arc Voltage)* – 0.133 *(Welding Speed)* (2)

3.2. Effect of Repair Welding

Table 8 shows the results of UTS obtained for as-welded (RW0) sample and repaired samples to first (RW1), second (RW2) and third (RW3) number of repair. Based on the table and bar chart in Figure 7, it was evidenced that the UTS showed an increasing trend up to the second repair (RW2). Similar trend of result was observed by Hussein et al. [12]. After that, after the third repair (RW3), the UTS value decreased. The highest value of UTS obtained at second repair (RW2) was 525.51 MPa. The repair welding has caused dynamic changed in the microstructure of the weldment. The grain growth substantially affected the tensile strength of the weld metal [2][13].

Table 8. Schematic Diagram and Illustration of the Repair Welding Process

Number of repair welding	UTS (MPa)
RW0	445.4
RW1	496.06
RW2	525.51
RW3	482.89

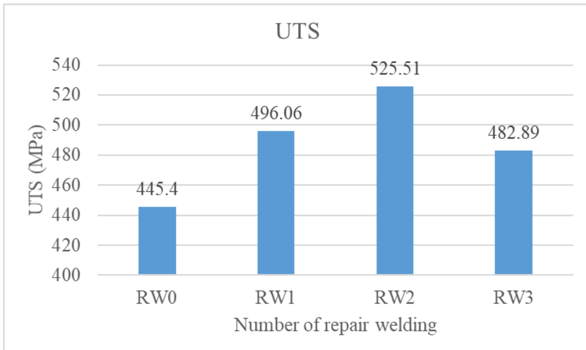

Figure 7. Ultimate tensile strength (UTS) of as-welded (RW0) and repaired samples (RW1 – RW3)

3. Conclusion

In this study, the effect of welding parameters on tensile properties of AISI 304 austenitic stainless steel pipes was investigated. The best set of parameters was suggested by using Taguchi method as the design of experiment and analysis. Results showed that the optimum set of parameters for achieving highest ultimate tensile strength (UTS) values was when arc current, arc voltage and welding at 160 A, 22 V and 50 mm/min, respectively. On the other hand, the optimum set of parameters for achieving highest elongation percentage was when arc current, arc voltage and welding speed at 160 A, 22 V and 40 mm/min. Based on the optimum set of parameters, the repetitive welding to replicate a repairing process was performed. It was evidenced that the UTS showed an increasing trend up to the second repair (RW2) before decreased after the third

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repair (RW3). The highest value of UTS obtained at second repair (RW2) was 525.51 MPa. The repair welding has caused dynamic changed in the microstructure of the weldment. Similar result was observed by Agha Ali et al. [8]. Therefore, the number of optimum repetitions for the AISI 304 austenitic stainless steel pipes was proposed up to second repair.

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