Tensile Strength of Orbital Welded Mild Steel Tubes with Dissimilar Thickness

N. I. S. Hussein, M. N. Ayof, and S. Nordin

***Abstract*—Lightweight trend leads to new trend of welding in which optimizing tubes or pipes thicknesses due to its respective workloads. Thinner tube can be used in parts with low working loads and thicker tube for high working loads parts. In order to obtain a good weld, controlling the process parameters such as welding current and welding speed become very crucial as it significantly influences the mechanical properties. Thus, the purpose of this study is to investigate the process-properties relationship of welded mild steel tube of dissimilar thickness by using Metal Inert Gas (MIG) orbital welding. The effects of weld current and jig rotational speed to the tensile properties of welded mild steel tubes were studied. MIG welding was used to weld 26.70 mm diameter of mild steel tubes, which has dissimilar inner diameter of 2.87 mm and 3.90 mm, respectively. The mechanical properties were tested using Universal Tensile Machine (UTM) Instron 8802 model. Design of Experiment (DoE) was used to design the experiment as well as to analyze the data. It was found out that, tensile properties of welded tubes increase with increasing of welding current between 60 and 80 A. On the other hand, increasing in jig rotational speed between 40 and 50 rpm decreases the tensile properties of the welded tubes. Empirical mathematical model was generated and verified.**

***Index Terms*—Mild steel, orbital welding, metal inert gas welding, tensile strength and empirical mathematical modeling.**

I. Introduction

Lightweight automobiles become trend nowadays which can profit manufacturers by saving cost and indirectly makes cars eco-friendlier by reduces the emissions of CO_2 [1]. ThyssenKrupp [1] and WISCO [2] found that varying wall thickness of tube used in exhaust system or in chassis depending on their workloads can help to reduce overall weight of the car. Tailored orbital welding is a technology that has capability of joining up to five tubes together and each individual tube can be of different materials, diameters, wall thickness and even coatings [3]. One of the success stories of tailored orbital welding by ThyssenKrupp [1] is they has successfully developed a tailored orbital alternative for a rear seat back reinforcement made from conventional tube. The structure is made from a tube of uniform wall thickness, which determined by the highest loads occurring in the part. The new solution successfully reduces weight by around a kilogram because the part made form a tailored orbital of different wall thickness. In other cases, tailored orbital for shock absorber reservoir tubes claimed weight reductions of up to 30 % [3].

There are several heat sources available for joining pipe and those that widely used in orbital welding includes shielded metal arc welding (SMAW) and MIG processes. Arunkumar *et al*. [4] and Olawale *et al*. [5] found that parameters of welding process give great influences to mechanical behaviour of the welded tubes.

Singh *et al.* [6] have done a study about effect of welding current to the welding depth of penetration of 5 mm thickness mild steel by using SMAW welding process. They found that the penetration depth increased in increasing of welding current. Lian [7] and Karadeniz *et al*. [8] found that when the weld current is increased, the depth of penetration will also increase. MIG welding was used in their experiment but with different materials. Lian [7] used 2.5 mm thickness of stainless steel tube while Karadeniz used the same thickness of Erdemir 6842 steel. Using ST-37 mild steel plates of 25 mm thickness as weld material and MIG welding as heat source, Bahman and Alialhosseini [9] founds that the higher the weld current will caused the decreasing in mechanical properties of weld metal.

In regards to dissimilar thickness tubes, Alenius *et al*. [10] found that thicker thickness will give higher fatigue strength of welded structure when non-stainless steel sheets of 1.5 mm and 0.7 mm thickness were weld by using spot welding. Darwish and Samhan [11] also state that thinner part of joint have higher stress concentration than in thicker part.

This study investigates the effect of MIG welding current and jig rotational speed to the tensile strength of mild steel tubes in which joint at dissimilar inner diameter. Empirical mathematical model of the ultimate tensile strength is then developed and optimum set of parameters for these orbital welding processes are then suggested.

II. Experimental Methods

A. Material Preparation

Mild steel, which also known as low carbon steel contains fine grain with ferrite phase structure. Low carbon steel has good mechanical properties as it has soft metric ferrite with good ductility. Taking the average size and commonly used of mild steel in go-kart chassis tube, mild steel pipes of 26.70 mm diameter having thicknesses of 2.87 mm and 3.90 mm are used in this experiment. The pipes are first cut into 112.5 mm length each. There will be 24 specimens in total, 12 pipes of 2.87 mm thickness and another 12 pipes of 3.90 mm thickness, for 12 sets of experiments. The tubes were first to be cut into

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smaller tubes by using abrasive saw. The tubes were cut into 110 mm long each using disc cutter machine. The tubes were then cleaned by removing burr and rust. Fig. 1 shows the schematic diagram of dissimilar thickness tubes joint.

B. Welding Processes

The mild steel tubes were clamped at the rotating jig and the MIG welding operations were performed by Fronius TS 4000C MIG welding machine with VR 4000 model of wire feeding system. Torch angle was set to 60°. Wire electrode of mild steel material with 1.0 mm diameter was used as filler material and argon was used as shielding gas. Anyeke welding positioner of APL-100 model was used for clamping pipes in 1G position as shown in Fig. 2. Jig rotates the steel tube while nozzle static in place during the welding process, while performing the orbital welding process. The available speed for the jig is between 1 to 100 rpm.

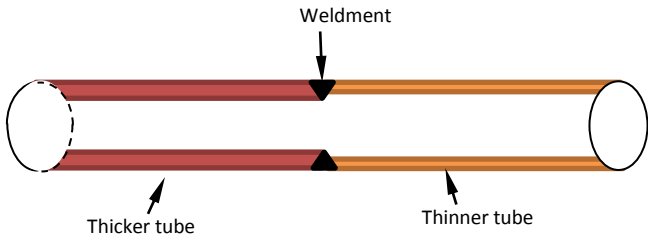


Fig. 1. Dissimilar thickness tubes joint.

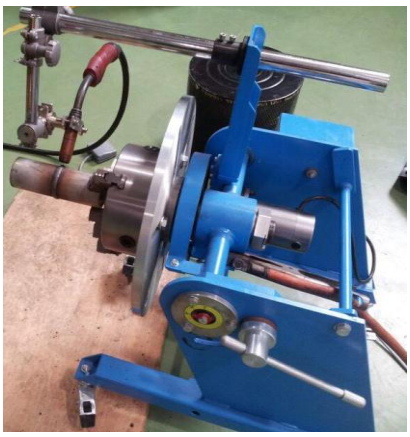


Fig. 2. Welding positioner holds the pipes at 1G position.

C. Design of Experiment

Dependent welding parameters for this study were welding current and jig rotational speed. Welding current was set for low and high level at 60 A and 80 A, respectively. While for jig rotational speed, 40 rpm and 50 rpm were set as low and high level, respectively (refer to Table I). By using full factorial formula, number of tests is y^x where y is number of conditions and x is number of factors. Hence, number of tests for this experiment was 2^2 in which equals to 4. The experiment was replicated thrice so the number of tests was 12 in total. By setting the welding current, the welding voltage and wire feeding speed were automatically calculated by machine are shown in Table II.

TABLE I: WELDING PARAMETERS AND THEIR VARIABLES

Welding Parameter	Unit	Low Level (-1)	High Level (+1)
Welding current	A	60	80
Jig rotational speed	rpm	40	50

TABLE II: WELDING VOLTAGE AND WIRE FEEDING SPEED AUTOMATICALLY SET BY THE MACHINE IN REFERENCE TO THE WELDING CURRENT

Welding Current (A)	Welding Voltage (V)	Wire Feeding Speed (m/min)
60	17.6	2.0
80	17.9	2.4

D. Tensile Testing

Universal Tensile Testing Instron 8802 model was used for tensile testing. Full-size tubular sections were used as tension test specimen. Based on ASTM A370-03a, for small tubes particularly having 25 mm diameter and below, and frequently for larger sizes, it is standard practice to use the full-size tubular section for test, unless there are limited with machine restrictions. The length of the tube must long enough to allow machine to grip the tube without extend beyond the gage length. The gage length for full-size longitudinal test steel tubular specimen is 2 inch or 50 mm, except that having 9.5 mm diameter or below (ASTM A370-03a). The length required for testing must be over than 156.8 mm since the diameter of the specimen tubes are 26.7 mm. Empirical mathematical model for ultimate tensile strength was generated using Minitab.

III. RESULTS AND DISCUSSION

Ultimate tensile strength in MPa has been recorded for each set of experiment as shown in Table III. Main effect plot as shown in Fig. 3 was used to understand the effect of welding current and jig rotational speed to the tensile strength values. Increase in welding current apparently increases the tensile strength of the welded tubes. Similar trend of results were observed by Serope and Steven [12]. Higher welding current leads to higher depth of penetration thus significant increases the strength of the welded joint [13]-[15]. On the other hand, increasing values of jig rotational speed decreases the tensile strength of the welded tubes. Singh *et al.* [6] states that the increasing in welding speed resulting the depth of penetration to be decreased. The depth of penetration has significant effect on the strength of welded joints as stated by Robb [14].

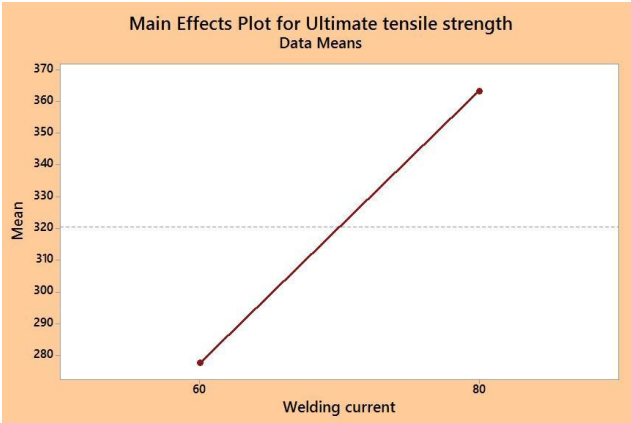
TABLE III: ULTIMATE TENSILE STRENGTH (MPA) OF THE ORBITAL WELDED MILD STEEL TUBES WITH DISSIMILAR THICKNESS

Std order	Run order	Weld Current (A)	Jig Rotational Speed (rpm)	Ultimate Tensile Strength (MPa)
2	**1**	80	40	408.50
6	**2**	80	40	412.16
5	**3**	60	40	199.71
8	**4**	80	50	385.10
7	**5**	60	50	256.42
3	**6**	60	50	297.76
10	**7**	80	40	317.59
9	**8**	60	40	333.48
12	**9**	80	50	337.83
1	**10**	60	40	318.29
11	**11**	60	50	260.03
4	**12**	80	50	317.42

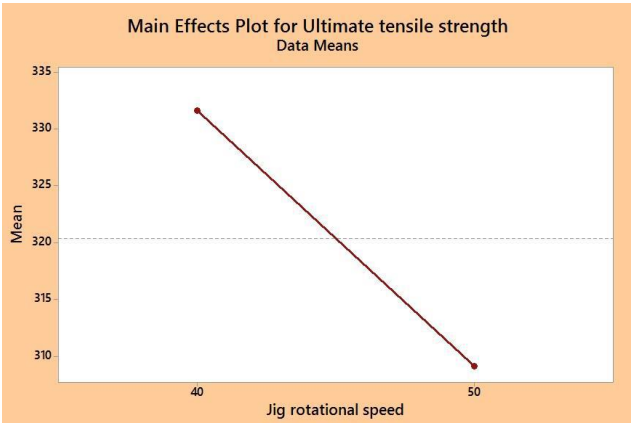
Based on the Pareto Chart of the Standardized Effects in Fig. 4, welding current is the most influential factor as compared to the jig rotational speed. Abbasi *et al.* [16] states that welding current is the most significant parameter for welding as it control the depth penetration of welding as well

as the fusion depth, the burn rate of electrode and also the weld geometry.

Response Optimizer in Minitab was to determine the best factors in which to optimize the response. The goal is to maximize the response. Five solutions were listed and the solution with the nearest composite desirability to 1.000000 is better. The best set of parameter to get maximum tensile strength is 80 A welding current and 50 rpm jig rotational speed.



(a)



(b)

Fig. 3. Effect Plot of (a) welding current and (b) jig rotational speed against the ultimate tensile strength of the weldment.

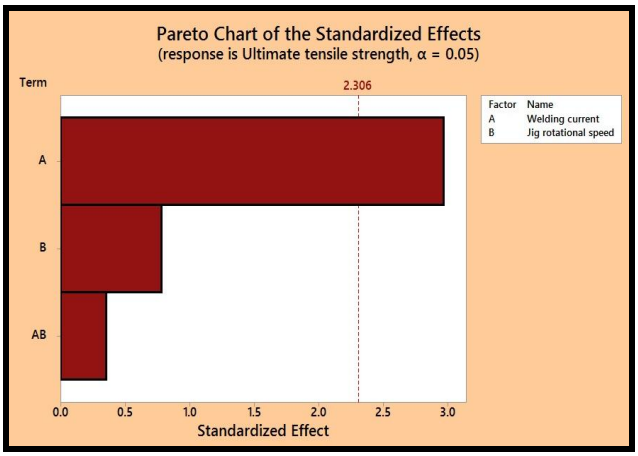


Fig. 4. Pareto Chart of the Standardized Effects for the ultimate tensile strength of the weldment.

Minitab calculated the empirical mathematical model for the response. The equations represent the relation between the factors; as the selected values, and response; as the observed values, which permits the prediction of the most probable values of the response. Empirical mathematical model for the ultimate tensile strength is shown in Eq. 1. Verification of the model was performed and it shows high accuracy of 96.8% (refer to Table IV).

$$\text{Ultimate tensile strength} = -196 + 8.8\,(\text{welding current}) + 4.8\,(\text{jig rotational speed}) - 0.101\,(\text{welding current})\,(\text{jig rotational speed}) \quad (1)$$

TABLE IV: EMPIRICAL VALUES VERSUS ACTUAL VALUES

Factors	Weld Current (A)	Jig Rotational Speed (rpm)	Ultimate Tensile Strength (MPa)
Empirical Value	80	40	376.80
Actual Value	80	40	389.42
Accuracy (%)			96.8

IV. CONCLUSION

It can be concluded that, tensile strength of the welded tubes increase with increasing of welding current between 60 and 80 A due to deeper penetration which leads stronger weld joint. On the other hand, increasing in jig rotational speed between 40 and 50 rpm decreases the tensile properties of the welded tubes due to decreases in penetration which resulting weaker weld joint. This study also indicates that welding current is the most significant parameter which influenced tensile properties of welded mild steel tubes by MIG orbital welding compared to jig rotational speed. The optimum parameter setting to get the maximum tensile strength for this study was 80 A welding current and 40 rpm jig rotational speed. The mathematical empirical model was developed and verified. Accuracy of the model was 96.8%.

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