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Prediction of Welding Bead Geometry & Welding Parameter for GMAW in 1G Position

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Abstract: The prediction of welding parameter and weld bead geometry for GMAW process in 1G position is presented in this paper. In the absence of reliable weld bead geometry predictor and welding parameter advisor, welding operator will resort to past welding record or apply 'trial and error' approach to determine the desired welding parameter and weld bead geometry. The development of weld predictor as a useful tool can to increase productivity and quality of fabrication industry. This study investigates the influence of 3 welding parameters; current, travel speed and voltage on weld bead geometry using robotic GMAW. The study focuses on Bead on Plate (BOP) in 1G position with CO_2 shielding gas and low carbon steel material. Only weld coupons are analyzed by macro-etching and butt geometry is plotted graphically to display the correlation with respective weld parameter, particularly the heat input. The trend lines with mathematical formula are selected to develop the BOP geometry predictor. The BOP geometry predicted is validated by comparing with the values from actual welded coupons. The mean absolute deviation (MAD) of the predicting calculator is less than 1.00 mm, it is therefore accurate and valid for industrial application.

Keywords: Bead geometry, Welding parameter prediction, GMAW prediction.

Abstract (Malay): Kajian ini adalah berkaitan ramalan parameter kimpalan dan bentuk geometri untuk proses Arka Kimpalan Gas (GMAW). Ketiadaan peramal parameter dan peramal kimpal manik sebagai penasihat menyebabkan operator kimpal akan menggunakan rekod lepas dan eksperimen secara cuba jaya untuk mendapatkan bentuk geometri dan parameter kimpal yang dikehendaki. Pembangunan peramal parameter kimpal sangat penting untuk meningkatkan produktiviti dan kualiti dalam industri fabrikasi. Tiga faktor pengaruh dikaji sebagai parameter kimpal iaitu arus, kelajuan dan voltan larian pada geometri kimpal manik menggunakan robot GMAW. Kajian ini memfokuskan kajian terhadap kimpal manik (BOP) keluli karbon rendah pada kedudukan 1G dan gas CO_2 sebagai gas pelindung. Kupon diuji secara ujian punaran makro dan bentuk geometri direkodkan untuk diplotkan secara grafik bagi menunjukkan korelasi antara parameter dan masukan haba. Garis tren terarah akan terjana formula matematik untuk membangunkan peramal manik BOP. Peramal manik BOP yang dibangunkan disahkan dengan membandingkan dengan nilai dari kupon yang sebenar. Sisihan mutlak min (MAD) yang dihasilkan untuk ramalan kimpal ini adalah kurang daripada 1.00 mm supaya ia tepat dan sah untuk kegunaan industri.

Kata kunci: Geometri bead, parameter ramalan kimpalan, ramalan GMAW

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1. Introduction

Gas Metal Arc Welding (GMAW) is a popular welding process used in the automotive, ship building, oil and gas, and metal production industries. It has high deposition efficiency, can be easily adapted to automation (Murugan & Gunaraj, 2005; Li & Zhang, 2008). The employment of robotic welder to handle GMAW welding increases the productivity and reduces the operation cost.

In 2012, a published article entitled Prediction Bead Geometry of 2F-Fillet Joint Welded by Small Wire SAW demonstrated a novel method in predicting the weld bead geometry. The prediction developed the graphical correlation between the bead geometry and heat input, the trend-line equations obtained from the correlation graph were used to predict the bead geometry. The accuracy of prediction was satisfactory based on the limited number of samples made. However, in a later finding, the formula was applied to predict another set of welded samples which were 10 times the quantity, the prediction was not satisfactory. The supervisor of the small-wire research team had since then developed a more accurate prediction formula, the accuracy was tested and validated over a large number of welded samples.

Yaakub et al., (2013) applied the same technique as Ahmad Hamidi et al., (2012) in predicting the bead geometry of GMAW fillet in 2F, 3F and 4F positions. Applying the research findings, he managed to weld 5F and 6F pipe joint. A year later, the prediction equations were applied to predict a larger set of samples, welded in 2F position, by another operator employing a different welding robot; the result of the prediction was not satisfactory. The supervisor of research had since improved the system of prediction.

Abd Rahman et al., (2014) have applied the similar approach as Ahmad Hamidi et al., (2012) in prediction of GMAW 1G samples and FCAW 1G samples respectively. Both of them have successfully predicted the bead width, but they have not proved the accuracy of prediction on other elements of bead geometry. The achievement among all the previous researchers has been the prediction of basic bead width in the case of bead on plate and leg size for fillet profile. There was no publication related to successful prediction on all 4 elements of the bead geometry such as bead width, bead height, bead penetration and throat. In fact, Kim et al., (2003) in their research that developed mathematical model that can be applied to estimate the effectiveness of process parameters for a given bead geometry and a change of process parameters affects the bead width and bead height more strongly than penetration relativity using a mathematical model for the selection of process parameters and the prediction of weld bead geometry. Kim & Lee, (2008) in their research, discovered that Taguchi Method contributes to the optimum process parameters to actually attain the desired weld quality that would optimize the process parameters with minimum time and cost implications.

The current research is focused on finding the solution how all elements of bead geometry can be predicted with deviation from real welded samples less than 1 mm accuracy, and that the prediction should be reliable and proven by successful prediction over a large number of welded samples.

2. Experimental Procedure

For welding experiment, the test coupon used is a pair of low carbon steel bar of 9 mm thick, 25 mm width and 300 mm length, butt joint welded. Each coupon is deposited with different GMAW welding parameters, in one stringer pass, by ABB robot welding IRB2400 in Amtex UiTM Shah Alam. Each weld coupon produces six weld samples of 50 mm length each, total welded samples are 130 units. The welding consumables are 1.2 mm ER70S-6 Carbon Steel in diameter and shielded by 100% CO_2 gas. The wire extension is 13 mm. The range of welding parameter for welding voltage is 18V-34V, welding current is 100A-300A and welding speed is 2mm/s-18mm/s. Actual current, voltage and speed were recorded. The parameters can be simplified as Table 1 below.

Table 1: Welding parameters set up for experiment

No	Parameters	Range
1	Current range, (A)	100-300
2	Voltage, (V)	18-34
3	Travel speed, TS (mm/s)	2-18
4	Wire extension, (mm)	13
5	Gas flow, liter/minute (LPM)	15 lpm

3. Results & Discussion

After completion of the welding, the weld coupons were inspected and evaluated visually based on the quality requirement of AWS D1.1 and macro-etching examination.

Weld coupons that are accepted should have good weld profile, no visible defect, no overlap, no excessive concavity, no undercut and regular leg size. Coupons which failed to comply with the quality requirement are rejected. The bead geometry (bead width and leg size) is measured by using Vernier caliper. This experiment produced more than 130 weld samples, about 13 units rejected.

3.1 Weld Bead Geometry

Specimen end faces were then polished using 600, 800 and 1200 grit paper and etched using a nithal solution with 1:5 ratio concentration between nitric acid and water to display the welding profile. The samples were etching by Nithal 5% using Leica microscope. The schematic diagrams of bead geometry generated made using a Leica microscope interfaced with an image analysis system.

The equipment with Leica Material Workstation version software 3.6.2 capable to measure the length of the geometry needed. Figure 1 shows the picture of the bead geometry with measurement scale 1:1.

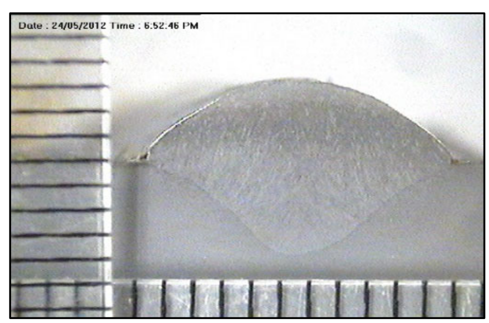

Fig. 1: The bead geometry with measurement scale

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3.2 Prediction of Welding Parameter for Specific Bead Width

The next important requirement in operating a mechanized welding process is the prediction of welding parameter to obtain a weld bead of specific bead width. The welding parameter can be generated if four conditions can be fulfilled:

1) It should fulfill the heat input requirement;
2) It should be within the upper limit and lower limit of welding current;
3) It should be within the upper limit and lower limit of arc voltage;
4) It should be within the upper limit and lower limit of travel speed.

Figure 2 shows the correlation of heat input for the range of bead width. The trend-line equation is **Y= 0.0221x$^{1.6778}$**. The data of Heat Input is distributed in close alignment with the trend-line. The maximum deviation from trend-line is less than 0.2 kJ/mm.

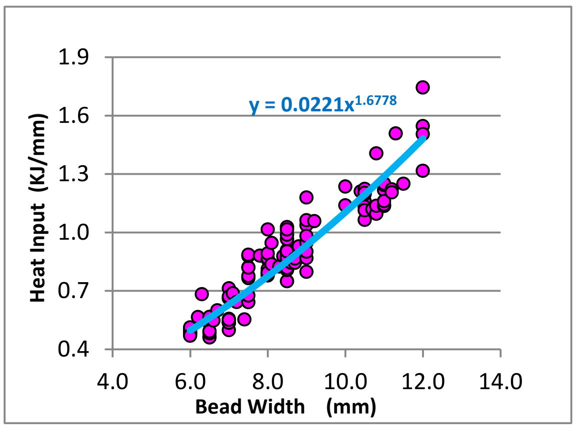


Fig. 2: Heat Input

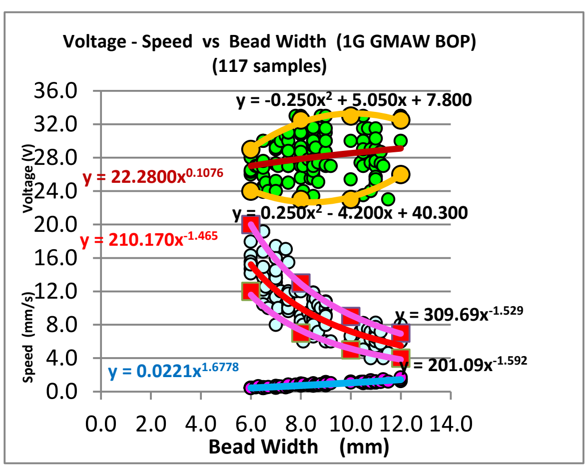
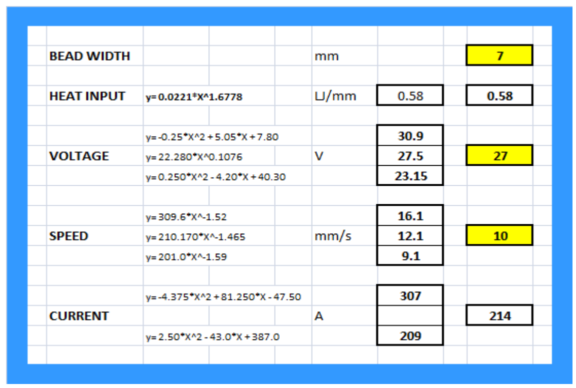


Fig. 3: Voltage -Travel speed

3.3 Welding Predictor

Another requirement in welding prediction is the ability to predict the correct welding parameter that can produce the specific bead width size. For any bead width values, it will generate the specific heat input, the range of current, voltage and speed. Figure 3 shows the upper limit and lower limit for both Arc Voltage and Travel Speed. The equations for the upper limit and lower limit are as displayed in the chart. The population of voltage and speed is found within the upper limit and lower limit range. Welding will not be successful if the voltage and speed fall outside this limit.

To produce three sizes of bead width, we have example calculators on display in Figure 4, which complied with the four conditions of predicting the welding parameter. By applying the prediction formula without grouping the bead penetration, it obviously failed to predict the bead geometry except for the cap height. The cap height was predicted correctly due to strict quality control, where the range of acceptable cap height is between 1.5 mm to 2.5 mm. So obviously, it will always be good when applying the prediction formula.



BEAD WIDTH		mm		7
HEAT INPUT	y=0.0221*X^1.6778	LJ/mm	0.58	0.58
	y=-0.25*X^2+5.05*X+7.80		30.9	
VOLTAGE	y=22.280*X^0.1076	V	27.5	27
	y=0.250*X^2-4.20*X+40.30		23.15	
	y=309.6*X^-1.52		16.1	
SPEED	y=210.170*X^-1.465	mm/s	12.1	10
	y=201.0*X^-1.59		9.1	
	y=-4.375*X^2+81.250*X-47.50		307	
CURRENT		A		214
	y=2.50*X^2-43.0*X+387.0		209	

Fig. 4: Welding Predictor

4. Conclusion

From this experiment, the correlation between heat input and welding bead geometry for Gas Welding Process in 1G position produces a chart to guide the selection of welding parameter. The accuracy of predicted weld bead geometry is good. The MAD or the average difference between predicted bead geometry and the experimental measured values is less than 1.0 mm. Thus, given any values of welding parameter within the permitted range, all the dimensions of Bead Geometry can be predicted accurately. By reversing the application, same calculator can be used to predict the welding parameter.

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