Prediction of Weld Bead Geometry for Small-Wire Submerged Arc Welding in 1G position

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ABSTRACT

Small-wire Submerged Arc Welding (SAW) is a low-cost alternative to the conventional SAW. In robotic or mechanized welding system, the welding bead geometry and welding parameter have to be known before welding. Developing them by trial and error is costly and wasteful practice in the long run. Therefore, there is a need to develop a tool to predict the correct bead geometry. A robotic small-wire SAW was employed to deposit bead-on-plate on carbon steel in 1G position, using a range of welding parameter permitted by the power source. Quality welded samples were cut at cross-section, polished and etched to display their macrostructure. The bead geometry was measured; the correlation between bead geometry and heat input was plotted. Without considering the bead penetration, the measured values of bead geometry are found to be quite scattered about the trend line, except the bead width. By applying the trend-line equations in prediction of bead geometry, only the bead width can be predicted accurately, where the deviation between predicted bead width and measured bead width is consistently less than 1mm. By grouping the measured bead geometry data based on 5 levels of bead penetration, when plotting the bead geometry with respect to heat input, all the bead geometry data aligned closely along their respective trend-lines, thus all elements of bead geometry can be predicted with high accuracy. The deviation of all elements of bead geometry and the values of mean average deviation (MAD) is less than 1mm.

Keywords*:* *Small-Wire SAW, Weld Bead Geometry, Weld Parameter*

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Introduction

Welding is a process of creating homogeneous joint between the base materials in terms of materials, chemical composition, metallurgical properties and physical characteristic [1]. In the beginning part of the 20th century, welding process were carried using bare steel wires which caused poor quality of weld bead due to air contamination. In order to overcome the problem, inert gas such as helium and argon gas were used as shielding. Robinoff patented the SAW process in 1938. SAW process used the flux to shield the weld from air [2]. Submerged arc welding was good at welding at high speed, at high current and high deposition [3]. Nevertheless, a conventional submerged arc welding is a high heat input process which mean that it is not suitable for short length welding or welding on thin plate [4]. The weld joint cannot be made on thin metal plate since the thin metal plate will melt due to excessive heat input. Due to these reasons, small-wire submerged arc welding is a recent innovation from metal inert gas process to overcome all the problems in conventional submerged arc welding. Small-wire submerged arc welding used small filler wire which is 1.2mm diameter compare to conventional submerged arc welding which is used filler wire above 2.4mm diameter.It is low in cost, perform like conventional submerged arc welding, but can weld in short length, low heat input and suitable for a thin plate [5]. Like any mechanized welding processes, the major issue in small-wire submerged arc welding application is the selection of welding parameter and getting the desired weld bead geometry. Traditional approach is to develop the welding parameter by trial and error, a procedure which leads to high wastage of material and labour cost, and the best welding condition may not be achievable [6].

This project focused on a procedure to predict the desired bead geometry from heat input data so that the output will be within the accuracy of 1.0 mm in 1G welding position. A similar research was experimented by Shahfuan [7], where the heat input was used in prediction. The material used was low carbon steel. Successful prediction of the bead geometry in this process will support and popularize the application in welding industry. The quality and beauty of small-wire submerged arc welding and the benefits of robotic metal inert gas can be realized, thus contributing toward a new welding trend in the future[8].

Methodology

The welding parameter of small-wire SAW was selected based on the common range of weldable parameter for Kempi metal inert gas welding power source as shown in Table 1. Current increment at 25A, voltage increment at 2V and speed increment at 2mm/s.

Table 1: Welding Parameter range

Parameter	**Range**	**Units**
Current	150-350	ampere, A
Arc Voltage	25-35	volts, V
Travel Speed	4-16	mm/s
Contact Tip-to-Work Distance	15	Mm

The base material for experiment was carbon steel bar, 25mm width 300 mm length with thickness of 9 mm, each bar was welded with six welding parameters; the length of each welded sample was 50mm. The consumable for small-wire SAW was 1.2mm diameter wire, ER70S-6 and OK Flux 10.78. The depth of flux was 25-30mm. The welding deposition was bead-on-plate in 1G position. To weld the carbon steel, a robot namely, ABB IRB 2400 was employed, it can be programmed to weld at the selected current, voltage and speed. Wire extension was 15mm.

After welding, all weld samples were inspected, graded and quality deposits were tagged with the actual welding parameter, lacquered to prevent rust formation, photographed to capture the visual profile. All quality samples were cut by high-speed cutter for macro-examination of their cross-section. The samples are ground and polished to mirror-finished with sand paper, and diamond powder. Then macro-etched with NiTal reagent to display their bead geometry. Finally, the weld samples are coated with lacquer and tagged for identification.

The analysis was conducted by investigating the correlation of bead geometry with respect heat input, where heat input = current x voltage / welding speed. The trend-line equations will be used to predict each element of weld bead geometry. (7)

Results And Discussion

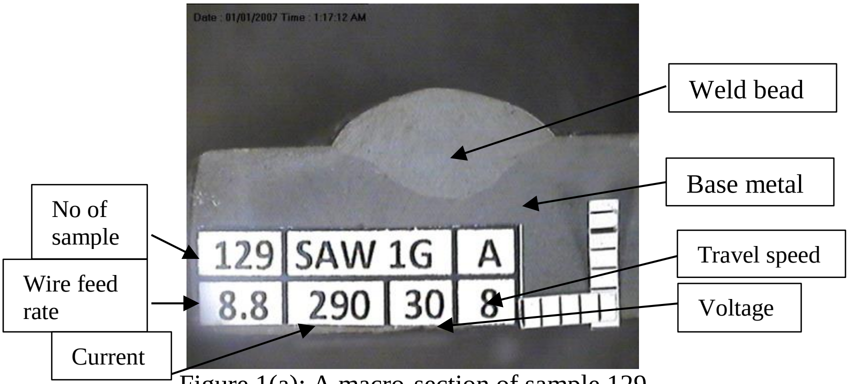

Figure 1(a): A macro-section of sample 129

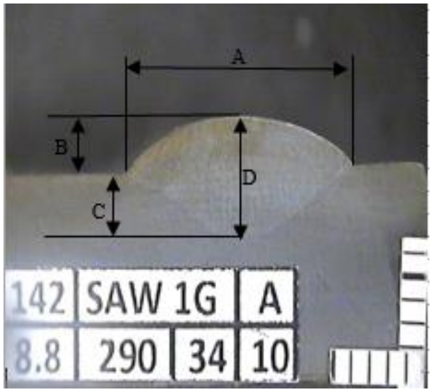

Figure 1(b): A cross-section of sample 142
Notes: A= Bead Width, B=Cap, C=Penetration and D=Throat

Figure 1(a) and (b) are two typical samples that passed the quality requirements

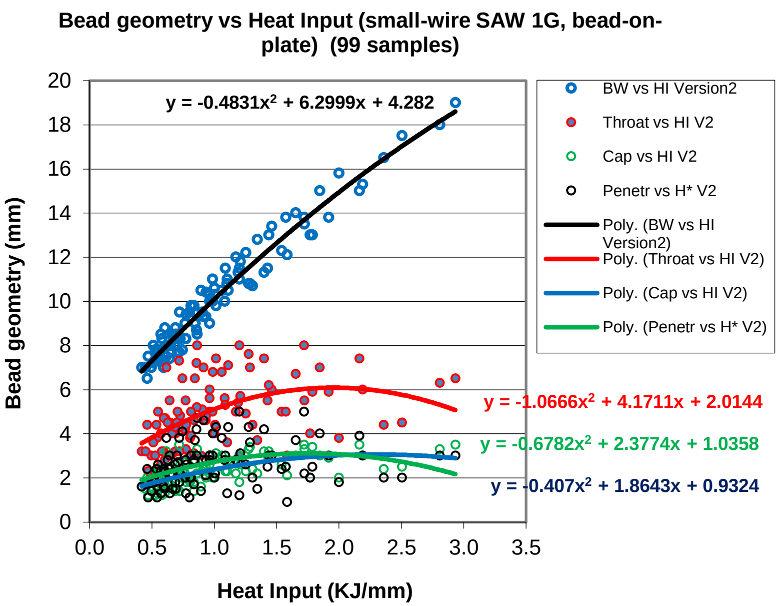

Figure 2: Correlation of bead geometry and heat input, small-wire SAW 1G (Without grouping of bead penetration) Notes: BW(Bead Width), HI(Heat Input)

Table 2: Accuracy of prediction of bead geometry (without grouping of bead penetration) Note: MAD(Mean Average Deviation)

99 samples	Bead Width	Throat	Cap	Penetration
MAD (mm)	0.48	1.00	0.47	0.73
Max Deviation (mm)	1.00	3.17	1.33	2.46
No of samples >1mm	0	42	7	24

Figure 2 and Table 2 show that only the measured data of bead width is distributed closely along the trend-line, while the measured data of other elements of bead geometry are scattered about their respective trend-line. Thus, without considering of bead penetration, only the bead width can be predicted but the rejection of the others has to hold since there is something can be done. Note that, the correlation in this graph is between bead geometry vs heat input. Where heat input is come from heat input = (current x voltage) / travel speed. By using heat input, it gives the variety to the welder to determine their own welding parameter (current, voltage and travel speed) as long as it gives the desire heat input. For example, based on the above graph, if the welder needs a 12mm of bead width so the desire heat input will be around above 1.30Kj/mm. So, the welder can choose their own current, voltage and travel speed as long as the heat input is above 1.3Kj/mm.

This graph using mean average deviation (MAD) where the purpose of MAD is to see how much the experimental result is deviate from actual value from equation. 1mm was set up as the maximum deviation. One of the examples is, the value of experimental bead width is 8mm while for the predicted from the equation is 8. 05mm. Thus, the deviation is 0. 05mm which is below than 1mm. Therefore, the experimental is considered accurate since the deviation is low. The fourth column is representing the number of samples that exceed 1mm. In this table, only samples of bead width have zero samples that exceed 1mm. In other words, the data of bead width is accurate.

The MAD for bead width is 0. 48mm, and 100% of the predicted bead width had deviation less than 1mm when compared to values measured from experimental samples. In contrast, the measured values of throat, cap and bead penetration is scattered about their respective trend-line. The accuracy of prediction throat, cap and penetration is therefore, poor. The MAD for Throat, Cap and Penetration is between 0.5mm to 1. 0mm, maximum deviation is between 1.3mm to 3. 2mm. It's shown that 42% of throat, 7% of cap and 24% of bead penetration had deviation exceeding 1mm. Therefore, there is a need to review the method of analysis so that all elements of the geometry can be predicted accurately. Despite the inaccuracy in predicting the values of throat, cap and bead penetration, this system offers only one equation, a very convenient tool in accurate prediction of bead width, most widely applied element in weld design. If the weld bead penetration was taken into consideration, the measured values of bead geometry were grouped under the respective value of bead penetration. In this experiment, we can group the data into 5 levels of penetration. By plotting the correlation of bead geometry and heat input for the respective bead penetration, 5 sets of trend-line equations were generated, to be used in predicting the bead geometry for the respective penetration group. The result of prediction of weld bead geometry for all levels of bead penetration was very successful and accurate.

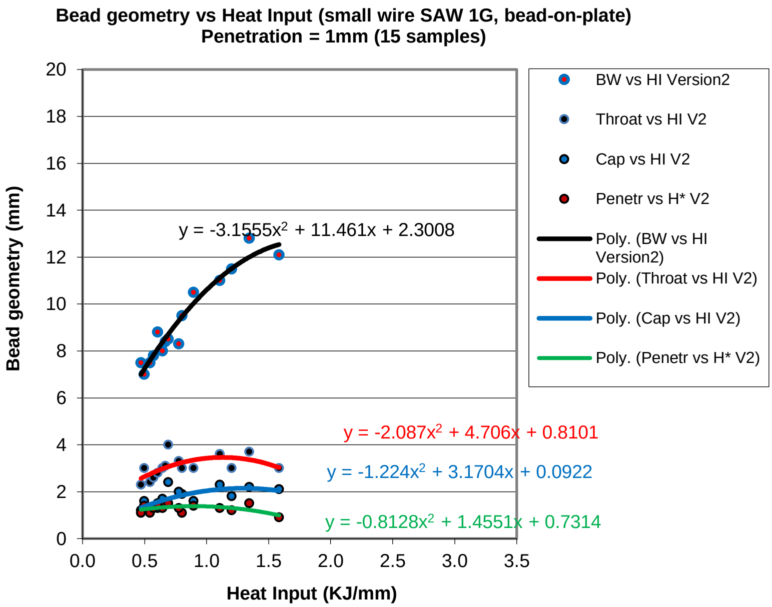

Figure 3: Bead geometry vs Heat Input (small wire SAW 1G, bead-on-plate) Penetration = 1mm (15 samples)Notes: BW(Bead Width), HI(Heat Input)

Table 3: Prediction accuracy of weld bead geometry for samples with1mm penetration. (small-wire SAW 1G) Note: MAD(Mean Average Deviation)

Small-wire SAW 1G		Bead Width	Throat	Cap	Penetration
Penetration=1 mm 15 samples	MAD (mm)	0.34	0.26	0.21	0.13
	Max Deviation (mm)	0.98	0.94	0.70	0.28
	No of samples >1mm	0	0	0	0

Figure 3 and Table 3 shows the accuracy of predicted bead geometry on 15 samples with 1mm penetration. All MAD values of predicted bead geometry are less than 1mm and the maximum deviation of predicted bead geometry from measured values of bead geometry is less than 1mm. The bead geometry of all samples in this penetration group is therefore, accurately predicted.

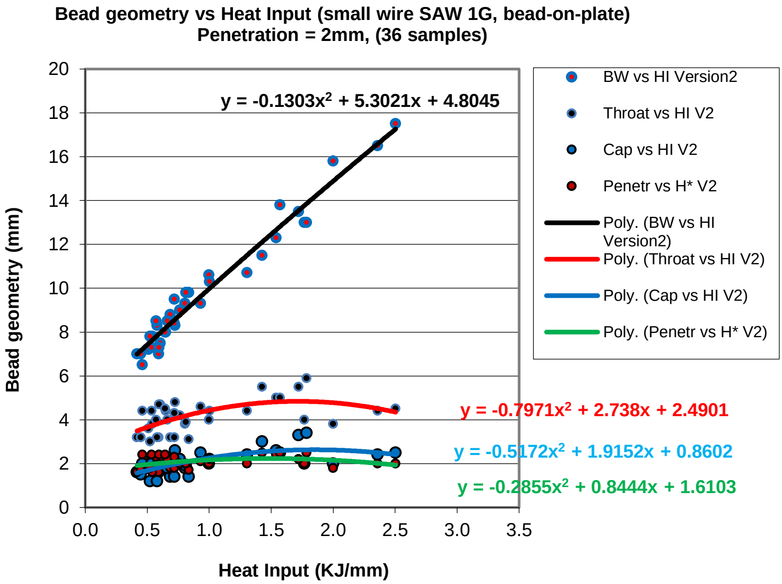

Figure 4: Bead geometry vs Heat Input (small wire SAW 1G, bead-on-plate)Penetration = 2mm, (36 samples)Notes: BW(Bead Width), HI(Heat Input)

Table 4: Prediction accuracy of weld bead geometry for samples with 2mm penetration. Note: MAD(Mean Average Deviation)

Small-wire SAW 1G		**Bead Width**	**Throat**	**Cap**	**Penetration**
Penetration=2 mm 36 samples	MAD (mm)	0.45	0.48	0.31	0.22
	Max Deviation (mm)	0.98	0.98	0.68	0.46
	No of samples >1mm	0	0	0	0

Figure 4 and Table 4 shows the accuracy of predicted bead geometry on 36 samples with 2mm penetration. All MAD values of predicted bead geometry are less than 1mm and the maximum deviation of predicted bead geometry from measured values of bead geometry is less than 1mm. The bead geometry of all samples in this penetration group is therefore, accurately. predicted.

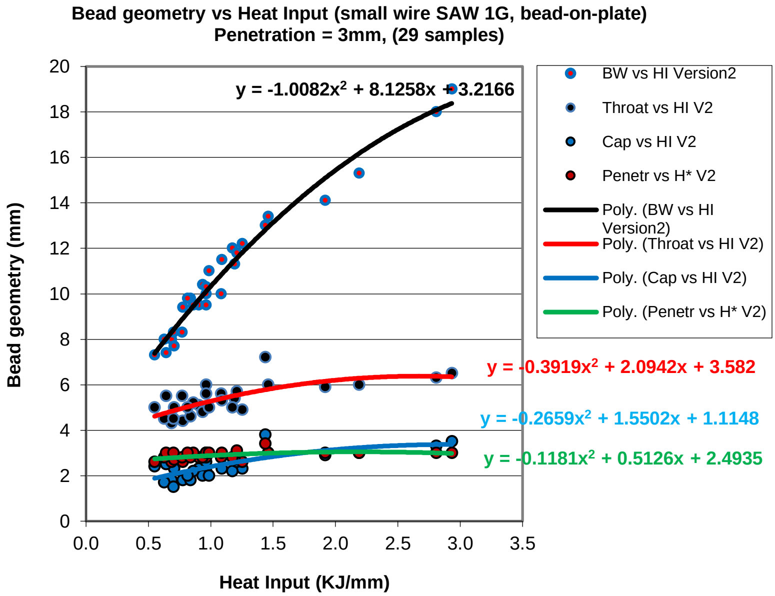

Figure 5: Graph of Bead geometry vs Heat Input (small wire SAW 1G, bead-on-plate) Penetration = 3mm, (29 samples) Notes: BW(Bead Width), HI(Heat Input) Note: MAD(Mean Average Deviation)

Table 5: Prediction accuracy of weld bead geometry for samples with 3mm penetration Note: MAD(Mean Average Deviation)

Small-wire SAW 1G		**Bead Width**	**Throat**	**Cap**	**Penetration**
Penetration=3 mm 29 samples	MAD (mm)	0.44	0.32	0.28	0.11
	Max Deviation (mm)	0.99	0.77	0.64	0.35
	No of samples >1mm	0	0	0	0

Figure 5 and Table 5 show the accuracy of predicted bead geometry on 29 samples with 3mm penetration. All MAD values of predicted bead geometry are less than 1mm and the maximum deviation of predicted bead geometry from measured values of bead geometry is less than 1mm. The bead geometry of all samples in this penetration group is therefore accurately predicted.

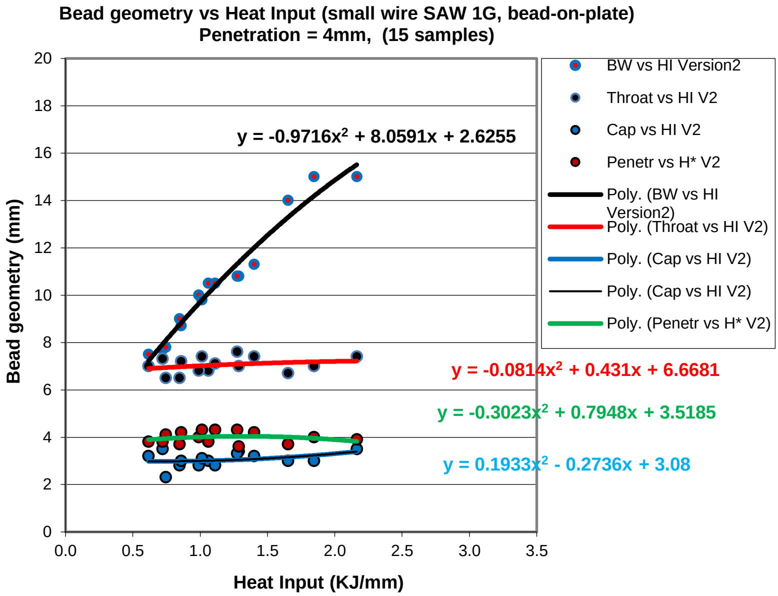

Figure 6: Graph of Bead geometry vs Heat Input (small wire SAW 1G, bead-on-plate) Penetration = 4mm, (15 samples) Note: BW(Bead Width), HI(Heat Input)

Table 6: Prediction accuracy of weld bead geometry for samples with 4mm penetration. Note: MAD(Mean Average Deviation)

Small-wire SAW 1G		Bead Width	Throat	Cap	Penetration
Penetration=4 mm 15 samples	MAD (mm)	0.39	0.28	0.22	0.20
	Max Deviation (mm)	0.81	0.51	0.68	0.44
	No of samples >1mm	0	0	0	0

Figure 6 and Table 6 show the accuracy of predicted bead geometry on 15 samples with 4mm penetration. All MAD values of predicted bead geometry are less than 1mm and the maximum deviation of predicted bead geometry from measured values of bead geometry is less than 1mm. The bead geometry of all samples in this penetration group is therefore accurately predicted.

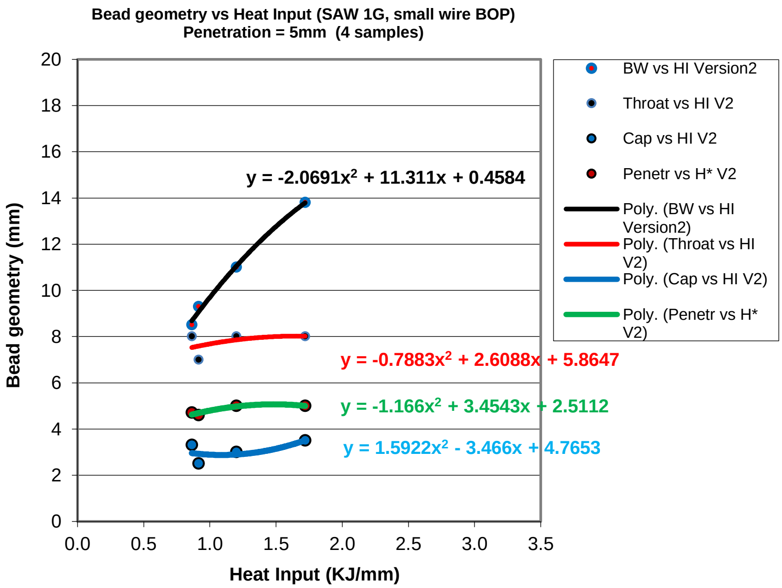

Figure 7: Graph of Bead geometry vs Heat Input (small wire SAW 1G, bead-on-plate) Penetration = 5mm, (4 samples) Notes: BW(Bead Width), HI(Heat Input)

Table 7: Prediction accuracy of weld bead geometry for samples with 5mm penetration Notes: MAD(Mean Average Deviation)

Small-wire SAW 1G		**Bead Width**	**Throat**	**Cap**	**Penetration**
Penetration=5 mm 4 samples	MAD (mm)	0.12	0.31	0.22	0.05
	Max Deviation (mm)	0.23	0.59	0.43	0.10
	No of samples >1mm	0	0	0	0

Figure 7 and Table 7 show the accuracy of predicted bead geometry on 4 samples with 5mm penetration. All MAD values of predicted bead geometry are less than 1mm and the maximum deviation of predicted bead geometry from measured values of bead geometry is less than 1mm. The bead geometry of all samples in this penetration group is therefore, accurately predicted. The accuracy of predicted weld bead geometry for small-wire SAW has been achieved by grouping the measured data of experimental welded samples by the bead penetration level. The correlation of bead geometry and heat input of the respective bead penetration, Figure 3, 4, 5, 6 and 7 show, that the data of every bead geometry is all aligned with the respective trend-line. Applying the trend-line equation in prediction of bead geometry, then comparing with measured bead geometry, the accuracy of prediction of bead geometry is shown in Table 3, 4, 5, 6 and 7. The deviation of all samples for all levels of bead penetration is less than 1mm.

Conclusion

The prediction of weld bead geometry of small-wire SAW in the 1G position by using heat input as a tool was successfully developed. Only the prediction of bead width is accurate, when the measured data from samples were bundled together. However, when they grouped under different weld bead penetration, the accuracy of prediction on all elements of bead geometry was very good, where the maximum deviation of all predicted welded bead geometries does not exceed 1mm from experimentally measured values. The prediction accuracy within 1mm maximum deviation from actual samples is reliable because the large number of sample was predicted successfully.

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References

[1] D. Cho, W. Song, M. Cho, and S. Na, “Journal of Materials Processing Technology Analysis of submerged arc welding process by three-dimensional computational fluid dynamics simulations,” J. Mater. Process. Tech., vol. 213, no. 12, pp. 2278–2291, 2013.

[2] S. U. I. Shao-hua and S. Tian-ge, “Effect of Submerged Arc Welding Flux Component on Softening Temper at ure,” vol. 13, no. 2, pp. 65–68, 2006.

[3] D. V Kiran, B. Basu, and A. De, “Journal of Materials Processing Technology Influence of process variables on weld bead quality in two wire tandem submerged arc welding of HSLA steel,” vol. 212, pp. 2041–2050, 2012.

[4] S. Shen, I. N. A. Oguocha, and S. Yannacopoulos, “Effect of heat input on weld bead geometry of submerged arc welded ASTM A709 Grade 50 steel joints,” J. Mater. Process. Technol., vol. 212, no. 1, pp. 286–294, 2012.

[5] B. Zhang, “Chapter 6 - Impact Parameters and Deposition Rate BT - Amorphous and Nano Alloys Electroless Depositions,” Oxford:

Elsevier, 2016, pp. 323–381.
[6] J. E. Raja and S. Kumanan, "Optimization of parameters of submerged arc weld using non conventional techniques," Appl. Soft Comput. J., vol. 11, no. 8, pp. 5198–5204, 2011.
[7] S. H. A. Hamidi, G. Tham , Y. H. P. Manurung , S. K. Abas, "Predicting Bead Geometry of 2F-Fillet Joint Welded by Small Wire SAW" M. Engineering and U. T. Mara, vol. 576, pp. 185–188, 2012.
[8] A. Kumar and S. Maheshwari, "Optimization of Vickers Hardness and Impact Strength of Silica based Fluxes for Submerged Arc Welding by Taguchi method," Mater. Today Proc., vol. 2, no. 4–5, pp. 1092–1101, 2015.