Advance High-Strength Steel for External Diaphragm Box Column Production by Using Robotic GMAW

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***Abstract*—The advance high-strength was widely used for steel construction. The box column production with multi-pass robotic gas metal arc welding (GMAW) for steel construction have been interested. However, the proper welding parameters for GMAW arm robot welding have to examine. This research was assembly the external diaphragm and box column with difference gap 3, 5 and 7 mm. The box column was made from advance high-strength plate thickness 12 and 16 mm for welding multi-pass 3 and 4 pass, respectively. The experiment results reveal that different heat input in range of 25.69 – 28.04 kJ/cm was not affecting to the strength of weld joint comparing with low heat input welding from welder. The elongation was a few decreasing with increasing of weld joint gap and skin plate thickness. The hardness level from GMAW arm robot welding on the weld joint was different based on skin plate thickness. The weld bead penetration of GMAW arm robot welding was lower than the welder welding. The gap size, heat input, number of pass and skin plate thickness were affecting to the yield strength, elongation and hardness of weld joint. However, these parameters were not affected to the tensile strength of weld joint. Therefore, the heat input value from this research can be used in the box column production line with GMAW arm robot welding.**

***Index Terms*—high-strength steel welding, robotic gas metal arc welding, external diaphragm, welding joint preparation**

I. Introduction

Recently, the construction of building was made from high-strength steel for preventing building collapse from earthquake. High-strength steel for construction is divided into three classes based on tensile strength consisting of lower than 450 MPa called conventional high strength, advanced high strength in range 450-800 MPa and more than 980 MPa as ultra-high strength [1]. The high-strength steel was cut and assembled to produce box column and beam as shown an example in Fig. 1. The diaphragm was inserted in the column with 2 patterns consisting of internal and external diaphragm. The connections of two-way frames with concrete-filled steel tubular (CFT) columns usually select the external diaphragm connection [2]. In external diaphragm connections, diaphragm plates are placed and welded outside the steel tube as shown in Fig. 1. This can also avoid difficulties in welding and concrete compaction work. The external diaphragm is employed the solid wire welding method for example gas metal arc welding process (GMAW) or Flux core arc welding process (FCAW) to join the diaphragm and box column. The internal diaphragm is utilized the electro slag welding process (ESW) to weld the diaphragm and box column skin plate [3] .

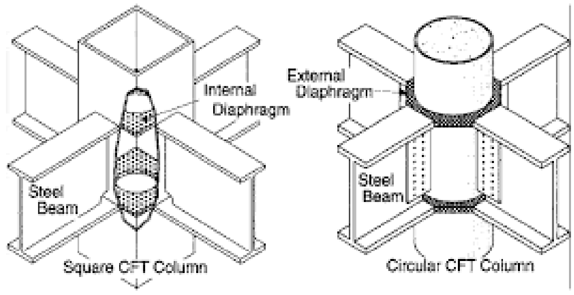

Figure 1. Types of diaphragm in steel construction [4]

In the current time, the GMAW can weld by using arm robot with automatic arc and adjustable the welding arc high. The optimization of welding parameters for robotized gas metal arc welding for high-strength steel was studied to confirm the affecting parameters with heat affecting zone (HAZ) size [5]. The studied was reported that the increasing of voltage was highly significant for increasing HAZ size. The high welding speed was affected to low size of HAZ. The wire feed rate was less affected to change of HAZ size. However, the work pieces were welded with fillet weld in flat position (1F). The effects of welding parameters on butt joints using robotic gas metal arc welding was investigated for low

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carbon steel A1008 [6]. The results reveal that the constant 24 of voltage with 200-220 ampere and 45-50 cm/min of welding speed performed the maximum tensile strength 239.05 MPa and 180 HV. The affecting of welding parameters to penetration was investigated by using robotic gas metal arc welding. The weld bead penetration was increasing by increasing of power source current. The welding speed and arc voltage were also affecting to weld bead penetration. The optimum welding parameters for good weld bead penetration were high current, high welding speed and low arc voltage [7,8,9]

The box column with external diaphragm production made from advance high-strength steel is using the robotic gas metal arc welding in horizontal position (2F) with multi-pass welding. The work pieces are also large and long that has to fix on the turning device or cradle. The assembly of box column and external diaphragm are different gap of joint preparations. Therefore, the welding parameters from multi-pass robotic gas metal arc welding in horizontal position (2F) have to investigate the joint quality consisting of weld bead geometry and some mechanical properties.

This paper aimed to investigate the welding parameters and weld bead quality for multi-pass robotic gas metal arc welding in horizontal position (2F) and turning device on the rails.

II. EXPERIMENTAL APPROCH

A. Materials and Methods

The advance high strength steel based on JIS G3136 was selected to prepare the work pieces with 12 mm and 16 mm of thickness. The 600 mm × 600 mm of box column cross section were prepared and assembled with 22 mm of external diaphragm. Each join with 3, 5 and 7 mm of gap at root of single-V joint were done. The mechanical properties and chemical composition of the base material are given in Table I. The 1.2 mm of solid wire in YGW18 class JIS Z3312 was chosen for filler. The chemical composition and mechanical properties is shown in Table II. The GMAW welding operations was performed by arm robot and welding power source with maximum current 700 ampere and 55 volt of load voltage. The 100% CO_2 was utilized for shielding gas. The torch angle is 5° with 25 mm of nozzle to work distance.

TABLE I. CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF THE BASE METAL

C	Mn	Si	P	S
0.18	0.55	1.65	0.03	0.15
Mechanical Properties				
Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)		
522	366	25		

TABLE II. CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF THE SOLID WIRE YGW 18

C	Mn	Si	P	S
0.06	1.33	0.48	0.009	0.07
Mechanical Properties				
Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)		
610	530	27		

The welding joint preparation was detailed in the Fig. 2. Each external diaphragm were arranged in the box column with 300 mm of distance as shown in the Fig. 3. At the central of diaphragm was drilled 32 mm of diameter to release the pressure and gas inside the box column. After finished the assembly process, the work piece was installed on the turning device for setting the original position and teaching the robot weld bead positon. The plate thickness 12 mm and 16 mm was determined to weld with number of pass 3 and 4, respectively. The control range of current and voltage was followed in Table III. The travel speed of welding torch was separated based on the gap of single-V joint. The inter-pass temperature 350 °C was determined for each welding pass. The spray arc welding mode was fixed for the experiments.

TABLE III. WELDING PARAMETERS AND NUMBER OF PASS

Thickness (mm)	Gap (mm)	Current (A)	Voltage (V)	Travel Speed (cm/min)	Pass
12	3	290	32	40	3
	5	290	32	35	
	7	290	32	30	
16	3	320	33	40	4
	5	320	33	35	
	7	320	33	30	

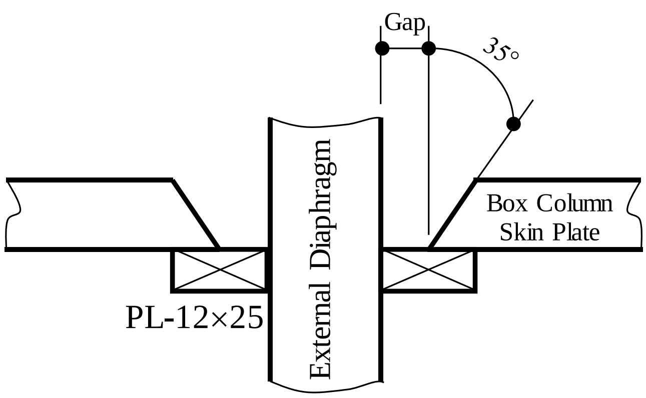

Figure 2. Welding joint preparation

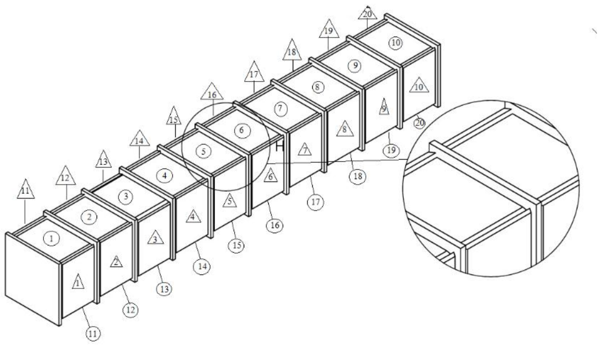

Figure 3. 3D Modeling of work piece for assembly process

Figure 4. Welding the work piece with GMAW robot

B. Mechnical Propeties Test

The mechanical properties consisting of tensile and hardness test was done following the JIS Z2241: 2011 and JIS Z2244: 2009, respectively. The hardness in base metal (BM), weld metal (WM) and heat affecting zone (HAZ) was investigated. The position of tensile specimen and hardness testing line was presented in the Fig. 5. These results were compared with the mechanical properties of weld bead from welder with the same welding parameters. The welding time utilization and heat input also were compared.

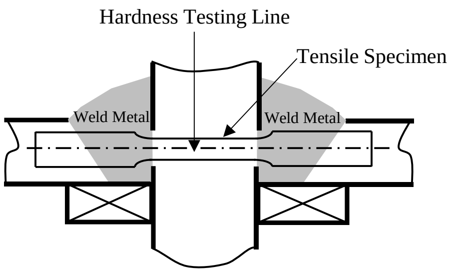

Figure 5. Welding the work piece with GMAW robot

III. Results and Disscusion

A. Heat Input

The heat input for each experiment was recorded as shown in Fig. 6 and 7. The welding GMAW arm Robot presented high heat input parameter represented with continuous line comparing with heat input from welder welding represented with dash line. In Fig. 6, the heat input of GMAW arm robot welding was increasing with increasing of joint gap from 3 to 7 mm. The heat input for welding 16 mm of skin plate thickness form GMAW arm robot welding was roughly constant comparing with heat input form welding by welder as shown in Fig. 7.

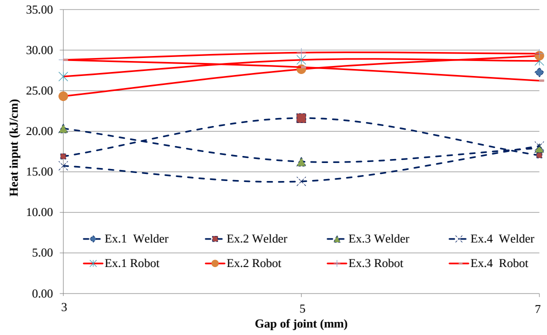

Figure 6. Average heat input for plate thickness 12 mm

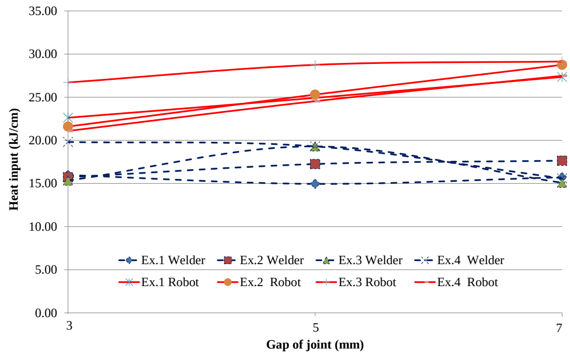

Figure 7. Average heat input for plate thickness 16 mm

TABLE IV. ANOVA Results for Comparing Heat Input

List	Skin Plate 12 mm		Skin Plate 16 mm	
	Robot	Welder	Robot	Welder
Mean	25.69	16.80	28.04	19.30
Variance	7.92	3.22	2.52	16.58
df	11	-	11	-
t Stat	8.57	-	6.75	-
P(T<=t) two-tail	3.3×10^{-6}	-	3.1×10^{-5}	-
t Critical two-tail	2.20	-	2.20	-

The ANOVA statistical analysis results of heat input from form GMAW arm robot and welder welding were presented in Table IV. The both of skin plate thickness showed higher heat input average in 25.69 and 28.04 kJ/cm from GMAW arm robot welding for 12 mm and 16 mm, respectively. Although, the heat input from welder welding obtained 16.80 and 19.30 kJ/cm for 12 mm and 16 mm, respectively. The statistical results express that heat input of GMAW arm robot and welder welding was significant difference.

B. Tensile Testing Results

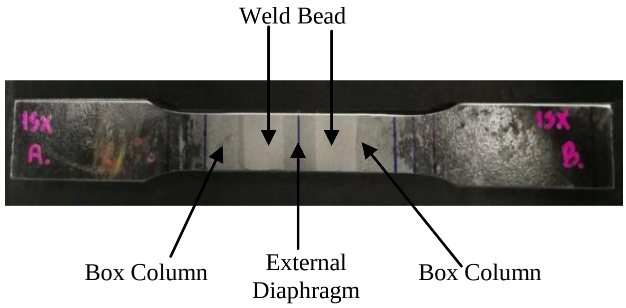

Figure 8. Specimen for tensile testing

TABLE V. AVERAGE OF TENSILE TESTING RESULTS

List	Skin Plate 12 mm		Skin Plate 16 mm	
	Robot	Welder	Robot	Welder
Yield Strength (N/mm^2)	353.91	358.74	378.58	380.46
Tensile Strength (N/mm^2)	520.19	527.53	517.82	538.04
Elongation (%)	21.65	18.66	24.73	22.00
Heat input (kJ/cm)	25.69	16.80	28.04	19.30
Number of Pass	3	3	4	4

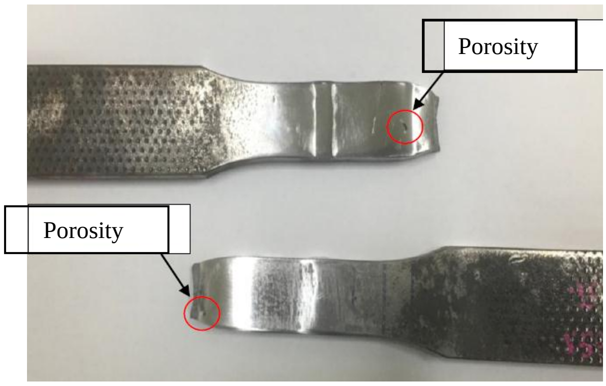

Figure 9. Porosity on tensile specimen

The specimens for tensile were prepared as shown as example in Fig. 8. The external diaphragm was in the center of specimen. The fracture of tension should be fracture in area of external diaphragm or skin plate of box column. The tensile testing results consisted of yield strength, tensile strength and elongation as shown in Table V. The average of yield strength from GMAW arm robot and welder welding was approximately equal result. For maximum tensile strength, the specimen from GMAW arm robot and welder welding was performed equal average value. As the results, the increasing of heat input did not affecting to change of yield and tensile strength. However, the elongation was increased by increasing of heat input level and number of pass. The tested specimen was investigated around the fracture edge. All specimen performed fracture at the diaphragm material. However, the investigation was found that a specimen had a small porosity in the weld bead as shown in Fig. 9. These porosity was affecting to decrease of yield and tensile strength into 332.27 and 490.66 N/mm^2, respectively.

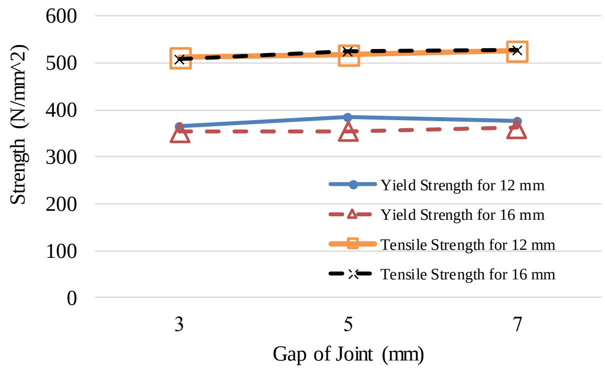

Figure 10. Strength on each joint gap using welding arm robot

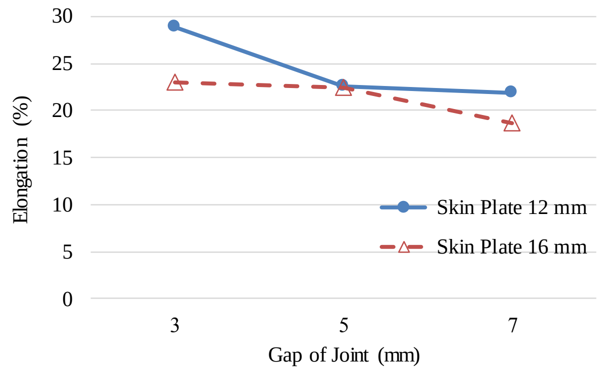

Figure 11. Elongation on each joint gap using welding arm robot

The yield and tensile strength results on each joint gap were presented in Fig. 10. The increasing of gap size was affected the rising of yield and tensile strength. The skin plate thickness was not affecting to change of tensile strength on each gap size. However, the yield strength results presented different level of each skin plate size. The yield strength of skin plate thickness 12 mm were higher than 16 mm approximately 5.5 % of average yield strength. The elongation of tensile testing results from GMAW arm robot welding was exhibited in Fig.11. The elongation of 12 and 16 mm was decreased with increasing of joint gap size. The skin plate thickness was affected to the level of elongation on each gap size. Therefore, number of welding pass and heat input were affecting to different yield strength and elongation by using welding arm robot.

C. Hardness Testing Results

The specimen was examined the hardness along the center line as shown in Fig. 12. The results of average hardness testing were presented in Fig. 13. The base material (BM) stated the average hardness in rang of 155 -165 HV. The range of hardness at weld metal (WM) was expressed range in 165 - 170 HV. However, the heat affecting zone (HAZ) was widely range of hardness value in 155 - 175 HV. However, all hardness value were not over 180 HV. The results showed that the skin plate thickness 12 mm was obtained almost high hardness value comparing with thickness 16 mm by using GMAW arm robot welding. The hardness form this research was lower than the welding with the same composition of based material and filler [10]. The above results were also lower than the welding of modern high strength steels with GMAW process [11]. Therefore, the welding with GMAW robotic following this research determined welding parameters and joint preparation will made the high degree of toughness.

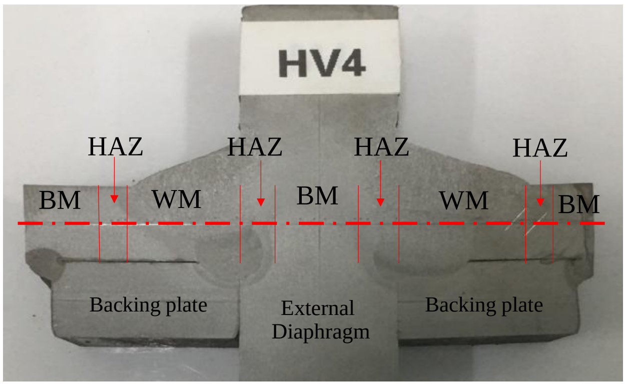

Figure 12. Position of hardness testing

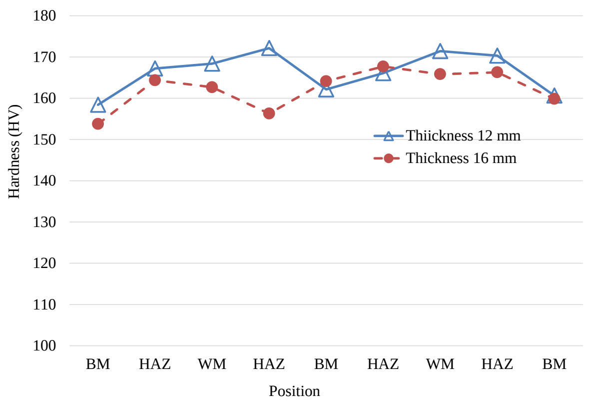

Figure 13. Average hardness testing results for each skin plate thickness

D. Weld Bead Penetration

Weld bead penetration was investigated after from macro structure as shown example in Fig. 14 and 15. The penetration measurement was done from the bottom of box column skin plate to the deepest of weld bead that melted external diaphragm and some part of blacking plate. The investigate found that the penetration of weld bead from GMAW arm robot and welder welding as showed in Fig. 14 and 15 were in range of 2.50 – 2.79 mm and 4.47 - 5.32 mm, respectively. These results confirmed that the determined welding parameters for GMAW robotic can performed full penetration welding for joint penetration. However, the penetration from welding with GMAW robotic performed less than welding by welder. Because, welder can controlled the weld pool during the welding process and depressed the tip of welding torch to make deep weldment penetration.

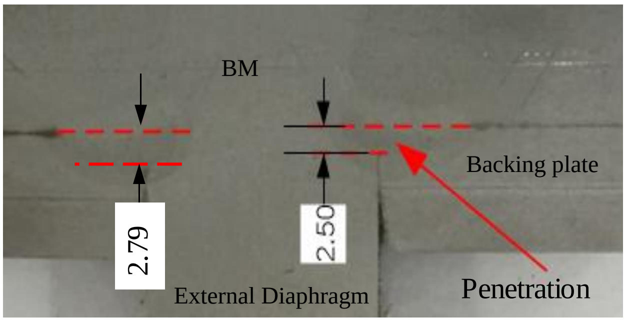

Figure 14. Penetration from GMAW Arm robot welding

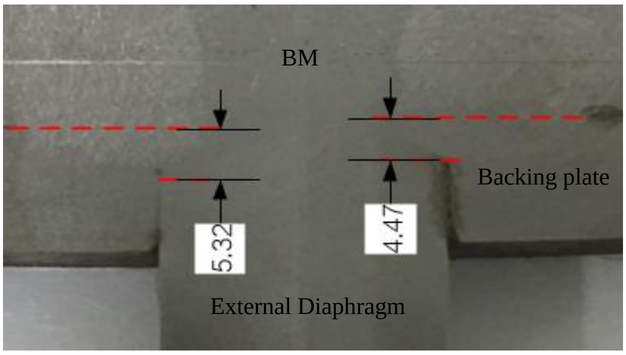

Figure 15. Penetration from welder welding

IV. Conclusion

The following conclusion can obtain from the experiments:

1. The box column with external diaphragm production made from advance high-strength steel with 12 and 16 mm skin plate by using the GMAW arm robot welding in horizontal position (2F) was investigated.
2. The gap of welding joint preparation did not affecting to the tensile strength of weld joint. However, in weld joint gap, skin plate thickness, number of pass and heat input were affected to different yield strength and elongation.
3. The yield and tensile strength from GMAW arm robot and welder welding was not different when the various heat input was applied in the experiment. However, the elongation from both welding method was a few different.
4. The oscillating of hardness on weld joint was presented by using GMAW arm robot welding. However, the hardness of weld joint for 12 and 16 mm was different based on heat input and number of pass.
5. The heat input in range of 25.69 – 28.04 kJ/cm was proper for welding with GMAW arm robot to obtain the same mechanical properties from welder welding with heat input in range of 16.80-19.03 kJ/cm.

Therefore, the welding parameters from this research can applied to use in the production line for welding external diaphragm and box column made from high-strength steel.

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