International Journal of Engineering Innovation & Research
Volume 5, Issue 1, ISSN: 2277 – 5668

A Study on Effect of Temperatures and Shielding Gas in Robotic GMA Welding Process

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***Abstract* – The Influence of the temperatures and complex gas mixtures based on argon, helium, oxygen and carbon dioxide on Aluminum Gas Metal Arc (GMA) welding process to the tensile and yield strengths of the welding result has been studied. Four different temperatures and four different mixing shield gas ratios were applied. The result revealed that the tensile and yield strengths significantly increased at -196℃rather than +25℃ to -85℃. Also, the strain tended to increase as the test temperature decreased. It has shown that at lower test temperature, the higher maximum load without any special features of the phase in load-deflection response resulted. On the other hand, the absorption energy increased slightly up to -85℃ but decreased sharply at -196℃. Hence, mixing shield gas ratio did not have a great influence on mechanical properties.**

***Keywords* – GMA Welding, Shielding Gas Composition, Test Temperature, Bead Geometry, Tensile Strength, Heat Input.**

I. Introduction

Welding needs to improve as it has one of the greatest potentials for the application in industry. One of many application of the welding in the industry is the automatic welding of thick wall components; it has become a key process in several important manufacturing areas, including pressure vessel fabrication, production of offshore structures and the nuclear industry. Recently, the manufacture of piles and columns to support wind turbines has grown significantly imported. However, it is difficult for the traditional identification methods to provide an accurate model because the optimized welding process is non-linear and time-dependent [1]. Therefore, trainee welders are referred to the tabulated information relating different metal types and thickness to recommend the desired values of welding parameters. Consequently, incorrect settings of those parameters have contributed to the deviations in the welding characteristics from the desired bead geometry. Basically, the bead geometry including bead height, bead width and penetration depth, plays an important role in determining the GMA mechanical properties of the weld. Also, the bead cross-sectional area with its height and width affects the total shrinkage, which determines largely the residual stresses and thus distortion [2]. Welding of the aluminum base metal is challenging compared to carbon steel base metal. It is because the aluminum develops a tenacious and refractory oxide layer when exposed to the open air, and it must be broken up before or during welding. It is also the aluminum that does not change color when heated to the welding temperature so that it creates difficulty to identify the pool. The steel welding electrode is stiffer, and in most cases, it is stronger than the aluminum electrode, making aluminum more difficult to feed properly. It was reported that material properties of aluminum that makes the GMA welding process substantially more sensitive to variations in the input parameters when compared to steel. There is an increasing range of shielding gases which vary from the pure gases to complex mixtures based on argon, helium, oxygen and carbon dioxide. The commercially available gas mixtures should be considered in terms of their suitability for ensuring arc and metal transfer stability, performance and weld quality. Therefore, welding parameters for the GMA welding are very important and should be well established to get the desirable bead geometry as the welding quality [3]-[5]. Among the aluminum alloys, Al5083-O has been employed in many fields such as Liquefied Natural Gas (LNG) carriers, storage tanks, ships, vehicles, aircrafts, and high pressure vessel due to high strength, good welding properties and wears resistance [6]. Furthermore, the tank receives repeatedly contraction and expansion according to variation of temperature and pressure by carrying in and out LNG. In this case, the low temperature fatigue characteristics as well as the static strength should be considered. Reducing the defects and having good weldability, argon and helium as the shield gases are the most common purging gases, which play an important role in reduction of generation of defects and protection of weld pool. The shielding gas for GMA welding process must be easily ionized to ensure that the arc can be sustained at a reasonably low voltage. Additional requirements of the shielding gas are a stable arc root mechanism, efficient shielding of the weld pool and adjacent area, and good weld penetration with a smooth bead profile. One of other different characteristics of helium is that it is one of the lightest gases, approximately ten times lighter than argon. The higher ionization potential of helium which is approximately 25eV when compared to 16eV for argon, produces a significantly higher arc voltage. The arc formed in helium is considerably hotter than argon based gas. It can often promote higher welding speeds and improve the weld bead penetration profile. But disadvantages for pure helium employed are: difficulty in initiating the arc and the poor tolerance to cross-draughts [7]-[8] and the price of helium which is significantly higher than argon. For these reasons, argon/helium gas mixtures are more commonly used than

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Volume 5, Issue 1, ISSN: 2277 – 5668

pure gas. It is clear that precise selection of the optimal shielding gas is essential as the mechanical properties of welds are affected by the weld-bead shape. Therefore, the aim of this study was to investigate the effects of the argon/helium gas mixtures and the heat inputs as input parameters on bead geometry and tensile stress of weld metal as well as to select the appropriate gas mixtures with Al5083-O for GMA welding process. The bead geometry and tensile stress were examined and evaluated according to four different argon/helium gas mixtures (Ar100%+He0%, Ar67%+He33%, Ar50%+He50%, and Ar33%+He67%) and various test temperatures (+25℃, -30℃, -85℃, and -196℃).

II. Experimental Method

The base metal employed for this study was 12 mm thick. The specified chemical compositions and mechanical properties of the Al5083 non-heat-treatable alloy and welding wire (Al5183-WY, ø 1.2 mm) are shown in Tables 1 and 2. Welding plates with 12 mm thick, 240 mm width and 600 mm length were employed for specimen. Figure 1 illustrates the configuration of the proposed GMA welding (left) and macro-photograph and schematic diagram of the weld cross section (middle and right).

Table 1. Chemical compositions (wt. %)

Materials	Al5083-O	Ak5183-WY
Si	0.40	0.10
Fe	0.40	0.27
Cu	0.10	0.01
Mn	0.70	0.58
Mg	4.45	4.55
Cr	0.15	0.11
Zn	0.25	0.06
Ti	0.14	0.11

Table 2. Mechanical properties

Materials	Al5083-O	Ak5183-WY
Yield Strength(MPa)	19.0	18.6
Tensile Strength(MPa)	34.2	32.7
Elongation (%)	14	14
Young's Modulus(MPa)	7.0×10^{3}	7.0×10^{3}

Table 3. Conditions of shielding gas composition and welding condition

Composition	Heat Input	Travel Speed (Cm/min)	Arc Voltage (V)	Welding Current (A)
Ar100% + He0%	L	50	21	220
	M	40		
	H	30		
Ar67% + He33%	L	50	23	
	M	40		
	H	30		
Ar50% + He50%	L	50	26	
	M	40		
	H	30		
Ar33% + He67%	L	50	29	
	M	40		
	H	30		

(L : Low Heat Input, M : Middle Heat Input, H : High Heat Input)

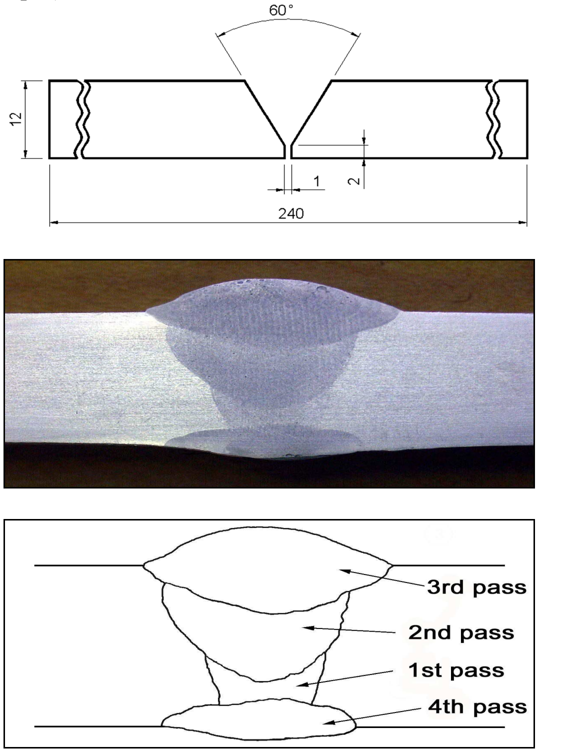


Fig. 1. Geometry of welding plate preparations

GMA welding was conducted so that the polarity and flow rate of the shielding gas were DCRP and 20 to 25 L/min, respectively. The welds were made on an inverter pulse type MIG/MAG welder (HITACH 350 CAP2), having a 350A current capacity. During welding, the aluminum plates were placed horizontally on a back plate and preheated to 100~120℃ by the end taps during the welding process. For comparison, four kinds of argon/helium mixtures (Ar100%+He0%, Ar67%+He33%, Ar50%+He50%, and Ar33%+He67%) and three kinds of heat inputs applied as shown in Table 3. The monatomic gases (99.995% pure) were premixed to the aforementioned ratios to reduce irregular mixing error. Once the welding completed, the transverse sections of each welded specimen were cut using a power hacksaw at the middle position of welds. Specimen end faces were machined polished and then etched using a 2.5% nital solution to display bead geometry. The schematic diagrams of the bead geometry were analyzed using a metallurgical microscope interfaced with an image processing system.

Tensile test specimens were prepared as shown in Figure 2. The crosshead speed of tensile test was 2 mm/min and the speed of impact test was 5 m/sec. Also, the tests were carried out at 25, -30, -85, and -196℃. Furthermore, low temperature tests were performed by mixing petroleum ether and liquid nitrogen together into an insulated container until the required temperatures were reached. To achieve a uniform temperature distribution, specimens were maintained for about 30 min at the intended temperatures before test. Simultaneously, to prevent temperature loss, liquefied nitrogen was continuously supplied and controlled by supply devices, a controller, thermocouples and a solenoid valve.

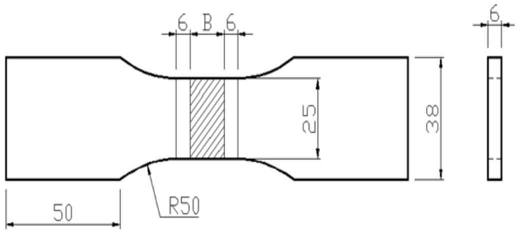
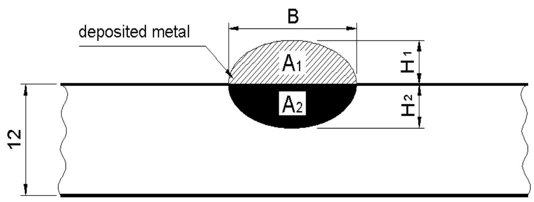


Fig. 2. Tensile Test Specimen (B: Weld Width)

III. Results and Discussion

A. *Bead Geometry*

It was found that the bead geometry is a function of the welding current, voltage, travel speed, electrode diameter, electrode polarity, electrode extension, and shielding gas [11]. The relationships between welding parameters and bead geometry are complex since a number of factors are involved. Yet, there is a need to ascertain this information for the development of welding procedure and for the understanding the mechanism of bead formation. Therefore, in this investigation, an attempt has been studied the influence of welding parameters such as heat input and shield gas mixture using the experimental results. The bead geometry was chosen bead width, bead height, penetration depth, reinforcement area, penetration area, and dilution from the cross sections of welds. A schematic diagram of the bead geometry is illustrated as shown in Figure 3.



B: Bead Width H_1: Bead Height
A_1: Reinforcement Area H_2: Penetration Depth
A_2: Penetration Area

Figures 4 and 5 presented the relationships between bead profile and the shielding gas compositions according to heat input. As shown in Figure 4, the higher the heat input, the more increase of the bead width. It indicates that the bead width increased in Ar67%+He33%, Ar50%+ He50%, Ar100%+He0%, and Ar33%+He67% in order. The increase in heat input results in a very high rate of increase in bead height as shown in Figure 5. It means that the bead height significantly increased in Ar33%+He67% mixture. Figure 6 shows not only the influence of the reinforcement area upon the heat input and shielding gas composition, but also that the higher heat input, the more increase of reinforcement area. The area increased in Ar67%+He33%, Ar100%+He0%, Ar50%+He50%, and Ar33%+He67% in order. Also, the effect of heat input on the penetration area is shown in Figure 7, which reveals that penetration area increases with an increase in heat input. In particular, the penetration area increased significantly in Ar33%+He67% mixture. The effect of heat input is not significant due to a little change on penetration depth as shown in Figure 8. As shown in Figure 9, not only the increase in heat input results in a high rate of decrease in dilution, but also the dilution was the best in the shielding gas composition. Among the weld features, the dilution is one of the most important factors because it not only affects the number of passes required to fill a joint, but also constitutes a major portion of the bead size and hence it determines the dilution [11]-[12]. Therefore, in this investigation, it was investigated that the best shielding gas composition was Ar33%+He67% mixture as given in Figure 6.

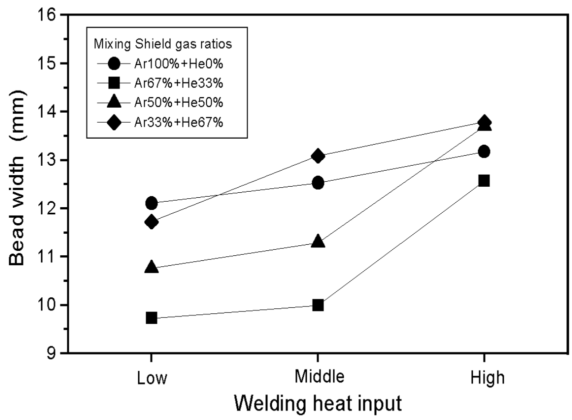


Fig. 4. Relations between Bead Width and Welding Heat Input

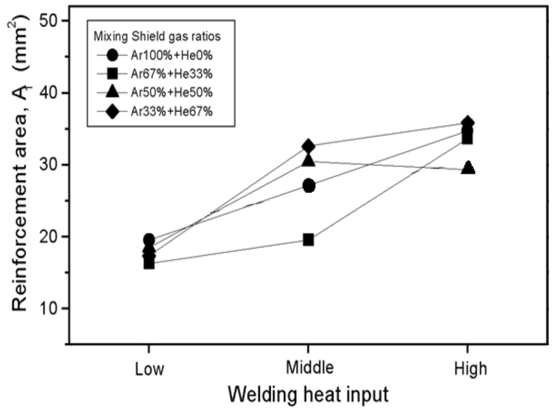


Fig. 5. Relations between Bead Height and Welding Heat Input

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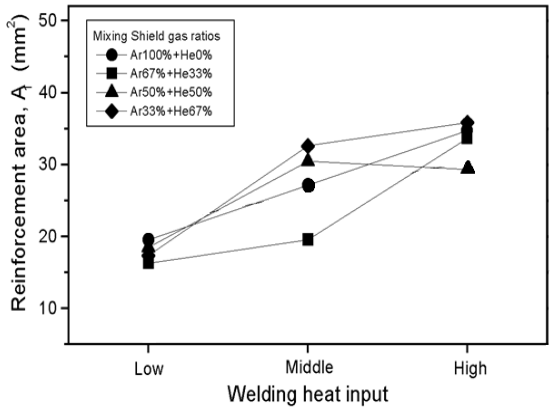


Fig. 6. Relations between Reinforcement Area and Welding Heat Input

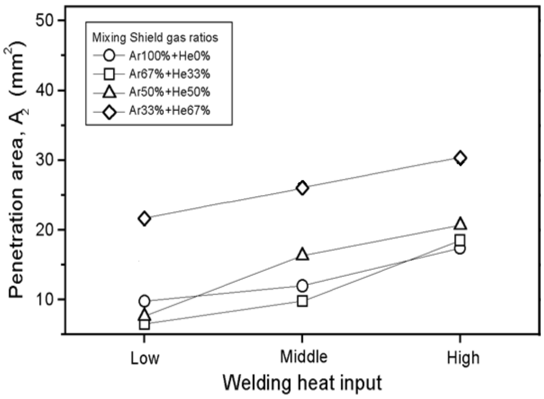


Fig. 7. Relations between Bead Height and Welding Heat Input

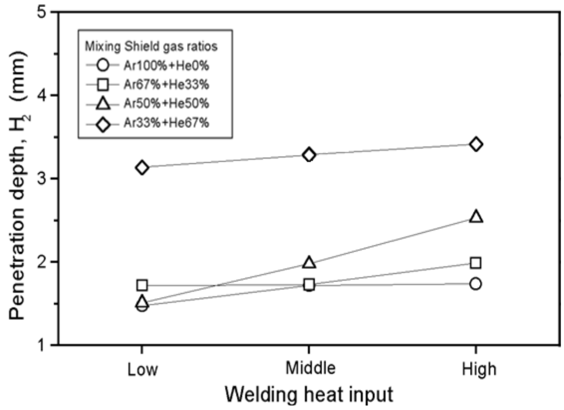


Fig. 8. Relations between Penetration Depth and Welding Heat Input

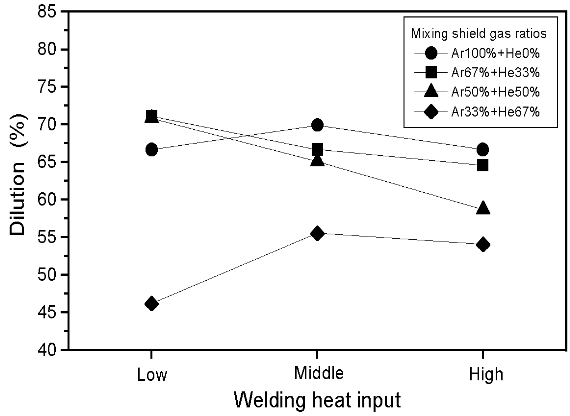
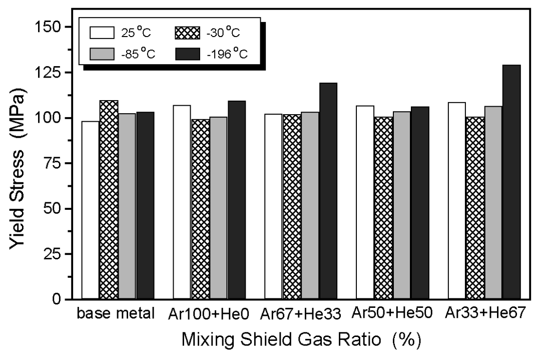


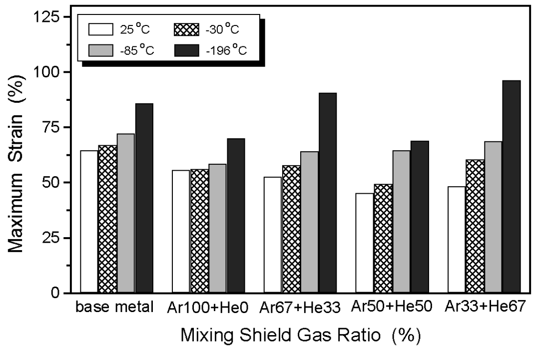
Fig. 9. Relations between Dilution and Welding Heat Input

B. *Effect on Yield and Tensile Stress*

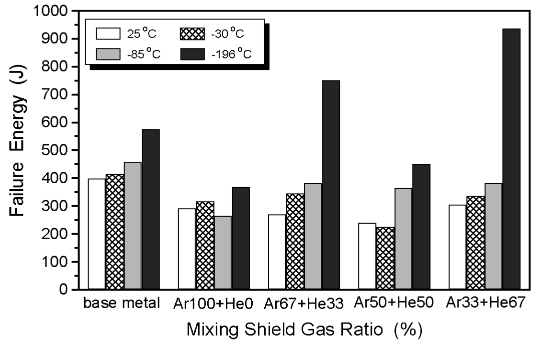
The variation of tensile strength, yield strength, and strain tested at various temperatures from +25℃ to -196℃ as shown in Figure 10 (a) to (c). The strength of the base metal was not greatly affected by test temperature in the range +25℃ to -85℃, but increased greatly at -196℃. Also the strain tended to increase as the test temperature decreased. However, it was shown that the increase of strain with decreasing test temperature was the opposite result to those generally reported in the literature [13]. It indicated that materials could be used at extremely low temperature as their strain increases at low temperature and a similar phenomenon was observed in the Al5083-O used in the present study. It was described that since an aluminum alloy has a face centred cubic (FCC) crystal lattice, there was no low temperature toughness effect as observed in alloy. And this result could be analyzed through an examination of deformation behavior based on strain hardening rate [14]. Varying the shielding gas composition does not have a great influence on the mechanical properties, unlike test temperature, but in general, the best strength and strain were shown for the 33%Ar+67%He mixture. From the tensile test result, as there was no shielding gas composition that caused a pronounced decrease of strength and strain, it was considered that no decrease of mechanical properties could be attributed to the generation of porosity.



(a) Yield Stress



(b) Maximum Strain



(c) Failure Energy

Fig. 10. Effect of Test Temperature and Shield Gas Mixture on Tensile Test Result

IV. Conclusions

This study was to evaluate the bead geometry and the welding strength of 5083-O aluminum alloy according to the shielding gas composition and temperature change. The bead width was greatest in Ar100%+He0% mixture. However, the penetration depth and area were greatest in Ar33%+He67% mixture showing that the lower argon gas ratio, the higher bead width. The higher heat input, the more increase of the deposit area. Also, it particularly increased significantly in Ar33%+He67% mixture and dilution was also the best in the shielding gas composition. Tensile and yield strengths did not show a great variation with test temperature at +25℃ to -85℃, but increased greatly at -196℃. Also, shielding gas composition does not have a great influence on the strength and elongation. Future work needs to focus on the application of these modeling and optimization techniques to find out the optimal welding combinations for a certain welding process at which the process could be considered safe, environment friendly and economical.

V. Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (No. 2015R1D1A3A01020246)

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Author's Profile

Ill-Soo Kim is a Professor at Department of Mechanical Engineering, Mokpo National University, Mokpo, Korea. He received his doctor degree in Mechanical Engineering from Wollongong University. He has been conducting research on the development and control of the weld bead of automated systems in the welding field, which has been recognized as the 3D industry. He has contributed more than 450 domestic conference and journal papers with additional 47 SCI-grade papers in various international academic journals.