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The Parameters Effect on the Microstructures and Mechanical Properties of Gas-Metal-Arc Welded SKD 61 Hot Work Tool Steel

Teerayut Kanchanasangtong* and Supachai Surapunt

Department of Industrial Engineering, Faculty of Engineering,

Thammasat University, Klongluang Pathumthani 12120, Thailand.

**Corresponding Author*

**Orcid ID: 0000-0003-4676-3380*

Abstract

This research focuses on the effects of various parameters on the microstructures and mechanical properties of gas-metal-arc welded SKD 61 hot work tool steel. The experimental parameters, such as heat input and the spray and pulse welding techniques were carried out in this study. The experiment result including mechanical properties, hardness, tensile strength and impact test were investigated. The specimen was prepared following the standard AWS, which each plate has the dimension of 50 mm width, 120 mm length and 10 mm thickness and with 60 degree V groove shape at the connected edge. The specimens were welded under the current conditions of 150, 170 and 190 A, 16-25 V of arc voltages and 1.5 mm/s of welding speed. A consumable copper-coated solid wire electrode was used in this welding process. The spray and pulse welding techniques were applied to optimise the best condition of this welding technique. The results showed that the best conditions of the gas-metal-arc welding process with the molten metal spray and pulse transfers were the welding current of 150 A and 190 A, respectively. The microstructures of the welded specimens in all conditions showed martensite phase in the retained austenite. The dendrite structures were found in the welded zones for all conditions. The hardness in the welded zone of all conditions were increased with increasing heat input**,** and higher than that of the base metal, which resulted from martensite microstructure transformation. The tensile strength of the welded specimen was decreased at the area of heat the affected zone (HAZ). The large grain size and high dispersion result in better elongation and less hardness. The impact values were ascribed the heat input had a large effects on the impact strength all of the spray and pulse welding techniques.

Keywords: GMAW Process, SKD 61 Steel, Heat Input, Spray Current, Pulse Current

INTRODUCTION

The gas metal arc welding process (GMAW) can be widely used for many types of metals, such as alloy steels, stainless steels, as well as aluminum alloys [1-4]. However, welding parameter are very important factor that affect to quality, and reliability of parts because an improper welding can cause decreased tool life [5-7]. The vast majority of the information available in the literature about the repair of these steels focuses on the aspects of weld techniques, but without considering metallurgical aspects [8-9]. Despite, its wide application and advantages, the technique of pulsed current is also interesting to be applied in the gas metal arc welding process (GMAW-P) for providing more precisely controlled spray droplet transfer at low welding current [10-12]. By using this technique, a smaller and more precisely controlled welding pool can be obtained along the welding area. The major information of GMAW of these alloys concerning welding technique are available in the literature [13-17], but it still lacks of the information of metallurgical aspects for mold and die repairing. Especially for low weldability materials, such as SKD 61 hot work tool steel, undesirable microstructures, such as martensite, influenced by thermal distribution in the welded area and the heat affected zone **(**HAZ**)** are very essential factors which have effects on the material properties and increase the susceptibility to crack the steel [18]. The effect of heat input on the microstructure and hardness of the SKD 61 was investigated [19]. In this study, a detailed experimental investigation of the parameters effect on the microstructure and mechanical properties during gas-metal-arc welded SKD 61 hot work tool steel was carried out in order to evaluate mold and die repairing.

MATERIALS AND METHOD

The material used in this experiment was SKD 61, which in the form of a hot work tool steel plate. The chemical compositions of the base metal and filler material were shown in Table 1. Two steel plates with dimensions of 50 mm width, 120 mm length and 10 mm thickness with groove shape at the connected edge based on the welding specification was shown in Fig.1. The experimental welding parameters were listed in Table 2. A consumable copper coated-solid wire electrode (MSG 6 GZ-60) was used for filler material. The specimens were preheated at 400°C before welding and post heated at 300°C after welding. The sample was cut by an EDM wire-cut machine along the transverse welded bead which covered the three zones of welded zone, heat affected zone (HAZ) and base metal for microstructure investigation, hardness measurement, and tensile and impact testing. American Society for Testing of Materials (ASTM) guidelines were followed for preparing the test specimens.

The heat input (kJ/mm) at the welded area was estimated by using Eq. (1):

$$\text{Energy Input} = \frac{\mathbf{V\ x\ A}}{\mathbf{Speed}(mm/s)\ \mathbf{x\ 1000}}, \quad (1)$$

where V is the voltages (V)

and A is the electric currents (A)

Table 1: Chemical compositions of SKD 61 base metal and filler material.

Element%	C	Si	Mn	P	S	Cu	Cr	Mo	V
Base metal	**0.38**	**0.10**	**0.40**	**0.01**	**0.01**	**0.08**	**4.97**	**1.25**	**0.97**
Filler material	**0.42**	**2.80**	**0.40**	**-**	**-**	**-**	**8.50**	**-**	**-**

Table 2: Welding parameters utilized in this experiment.

Parameter	Value
Specimen	**SKD 61**
Electrode type	**MSG6 GZ-60**
Vertex angle	**90°**
Shield gas	**82% Ar – 18%CO_2**
Gas flow rate	**13 L/min**
Arc voltage	**16-25 V**
Welding current	**150, 170, 190A**
Welding speed	**1.5 mm/s**

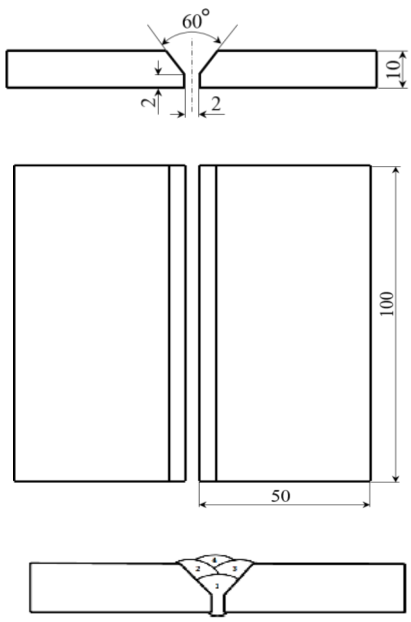


Figure 1: Schematic illustration of the workpiece of this experiment.

RESULTS AND DISCUSSION

The values of the heat input were calculated from the arc current and arc voltage by using Eq. (1) and are shown in Table 3 and 4.

Table 3: Heat input values (Spray) calculated using Eq. (1)

Arc current (A)	Arc voltage (V)	Heat input (kJ/mm)
150	**16.5**	**1.65**
170	**18.7**	**2.24**
190	**19.4**	**2.46**

Table 4: Heat input values (Pulse) calculated using Eq. (1)

Arc current (A)	Arc voltage (V)	Heat input (kJ/mm)
150	**25.1**	**2.51**
170	**26.6**	**3.01**
190	**27.9**	**3.53**

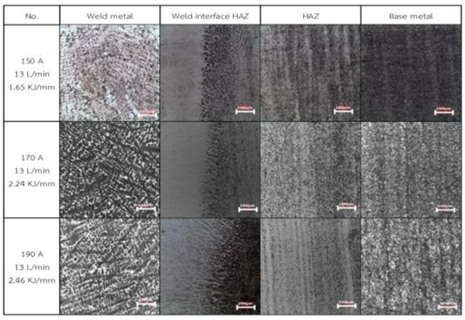
The effect of heat input on Microstructures

As the results, it was found microstructure of the welded for the spray and pulse welding techniques were investigation:

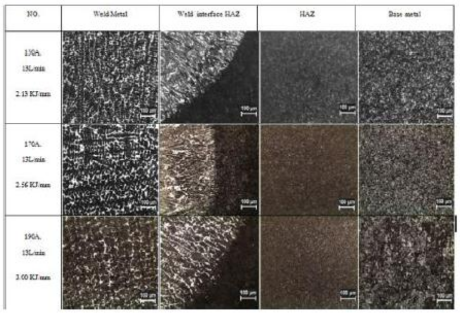
For the spray current was found of the retained austenite and martensite microstructures were found caused by the rapid cooling of molten metal from the welding temperature. And chromium carbides distributed to martensite matrix in the heat affected zone (HAZ). It shows that welding currents are an important variable in the welding and properties of specimens after welded. Using of high currents will result in hardening and brittle metal due to changes in the structure of the metal from heat was shown in Fig. 2(a).

That the pulse current provides shown of the microstructure at the weld metal transfer. Martensite is a round shape formed by the transition from austenite to martensite with a large phase. And carbide rounded appearance surrounded, as was shown in Fig. 2(b). At the higher welding current and the higher heat input, result increase of carbon from the filler material, which results in a higher ratio of the martensite and retained austenite phases. In the heat affected zone (HAZ), the mixed phases of rounded martensite and a large amount of carbide particles were founded in the retained austenite matrix phase. The remained of austenite was caused by the incomplete in the phase change from austenite to martensite during welding process.

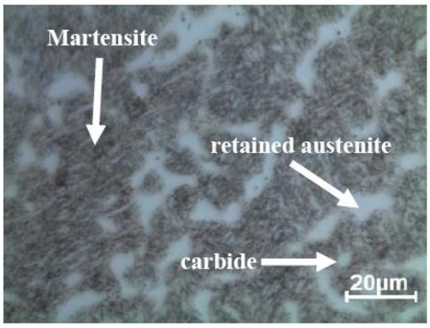
As for evaluation of MGS6 GZ-60 weld metal (WM) revealed coarse and columnar grains of martensile matrix with retained austenite austenite in the matrix of dendritic segregation pattern of martensite phase, and with some carbide particles was to be observed in all of conditions in the spray current and the pulse current as Fig. 2(c,d). This phenomenon was associated with the activation of diffusion mechanisms of alloying elements retained in the austenite. As the consequence, of carbides and transformation of austenite to martensite were produced.



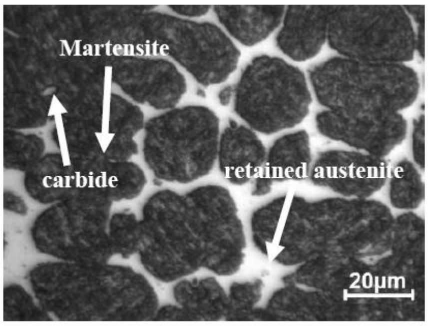
(a) Spray Current



(b) Pulse Current



(c) Spray Current (WM)



(d) Pulse Current (WM)

Figure 2: Microstructure of the welded zone reveals martensite with retained austenite in the dendritic phase.

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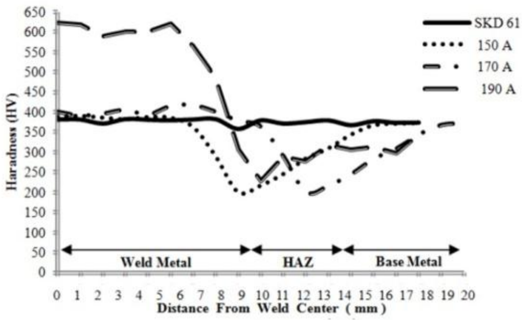
The effect of heat input on hardness properties

The hardness profiles of the welded specimens measured along the welded zone, heat affected zones and base metals are shown in Fig. 3. The average hardness values of specimens were 373.7 HV, that the welded zones for the spray currents of 150, 170 and 190 A were 402, 403 and 517 HV, respectively. It was found that the current affects the hardness profiles, when the current increased shown in Fig. 3a. Which the current was 190 A, shown the effect of heat input on hardness properties were max values from martensite transformation.

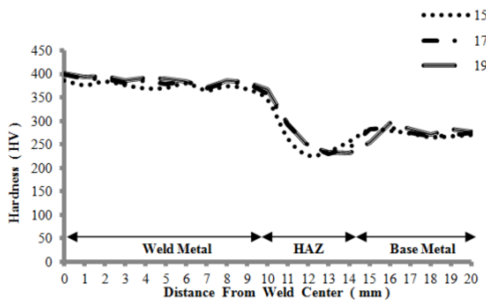
Moreover, the result were that the average hardness values at the welded zones for the pulse currents of 150, 170 and 190 A were 386, 399 and 401 HV, respectively, shown in Fig. 3b. It was found that the hardness values slightly increased with increasing heat input which resulted from martensite transformation for the pulse currents. The higher heat input results in the higher ratio of retain austenite and matensite matrix phases.

This unique microstructure causes a strong influence on hardness properties. In the welded zone, the hardness values were higher than those in the HAZ and the base metal. It can be ascribed as the difference of microstructures in the welded area and HAZ.

In the base metal, welding variables have no influence on the hardness profile.



(a) Spray Current



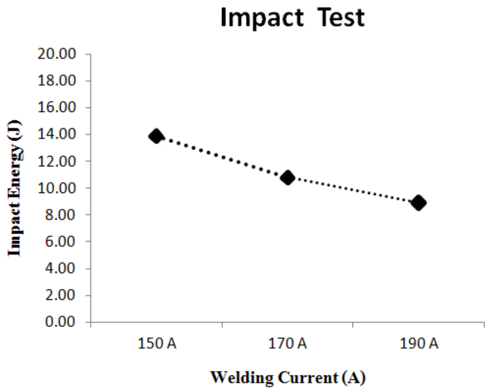
(b) Pulse Current

Figure 3: Vicker microhardness (HV) profiles of base metal and welded specimens at 150, 170 and 190 A arc welding currents.

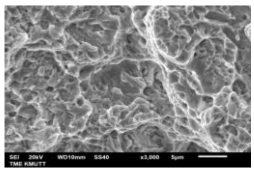
The effect of heat input on Impact properties

The impact energy was measured at the welded zone of the specimen. The relationship between impact values and welding currents is showed in Fig. 4. The energy absorption at the spray currents of 150, 170 and 190A were 13.9, 10.8 and 8.9 J, respectively showed in Fig. 4a. It can be observation inverse, when the current increases, the impact values were decreasing respectively. Consideration of characteristic specimen at 150A, the appearance of the cracked (dimples), shows the toughness of the fracture. It compares with specimen at 190A, the appearance of the cracked (brittle), shows the brittle fracture. For the area that checked was the fracture of the weld.

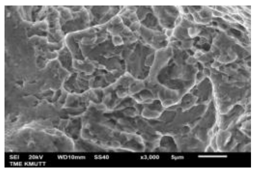
Moreover the energy absorption at the pulse currents of 150, 170 and 190A were 8.7, 10 and 14 J, respectively showed in Fig. 4b, characteristic of specimen at 190A the appearance of the cracked (dimples) shows the toughness of the fracture over the another currents, that shows the brittle fracture. It was shown that the heat input had a large effects on the impact properties. It can be ascribed as the difference of the higher ratio of retain austenite and matensite matrix phases in the welded zone [18,19].



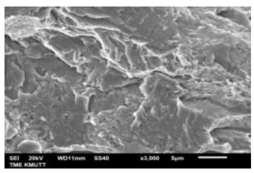
(a) Spray Current



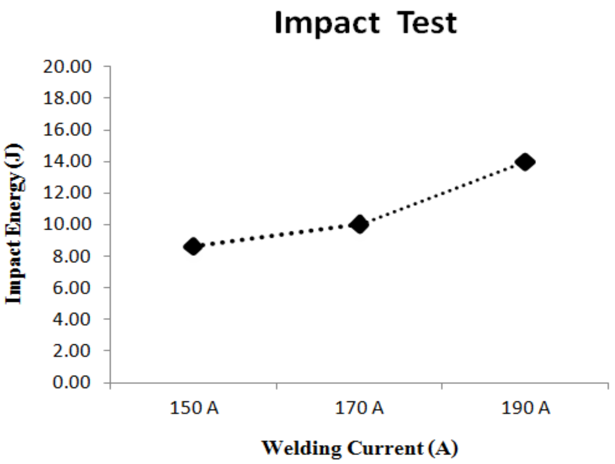
150 A



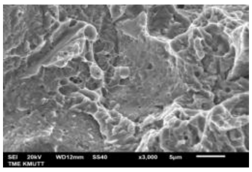
170 A



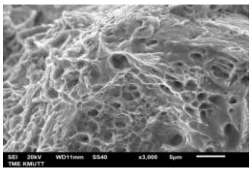
190 A



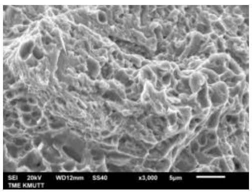
(b) Pulse Current



150 A



170 A



190 A

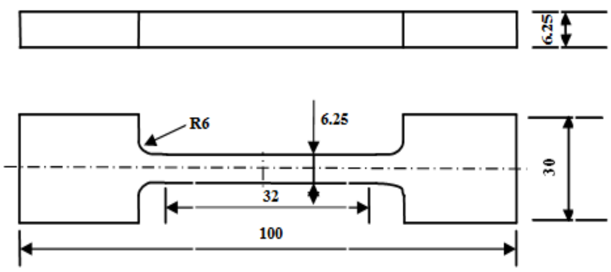
Figure 4: Relationship between impact energy and arc welding current.

The effect of heat input on Tensile Strength

Tensile strength values of the base metal was 450 MPa. Furthermore, specimens with spray currents of 150, 170 and 190 A were 447.1, 440.0, 259.0 MPa, respectively. It shows that the effects of welding currents were affected the heat input on the specimens, which resulted from martensite transformation. The ability of tensile strength was according to the currents. As the current increases, the tensile strength was decreasing which shown in Fig. 5a .

However, the pulse currents of 150, 170 and 190 A were 248.4, 251.5 and 258.0 MPa, respectively which shown in Fig. 5b. The tensile strengths of specimens were almost the same and lower than the base metal due to the mixed phases of rounded martensite, carbide and retained austenite phases in the heat affected zone (HAZ). The strength decreases at the area of heat the affected zone (HAZ), as a result of rapid heat transfer from welded. The large grain size and high dispersion result in better elongation and less hardness, resulting in higher toughness.

The fracture of specimens all of conditions were ruptured at the area of heat affected zone (HAZ).



Current (A)	Tensile Strength (MPa)	(Elongation%)
150	**447.1**	**4.58**
170	**440.0**	**4.56**
190	**259.0**	**4.51**

(a) Spray Current

Current (A)	Tensile Strength (MPa)	(Elongation%)
150	**248.4**	**3.23**
170	**251.5**	**3.28**
190	**258.0**	**3.38**

(b) Pulse Current

Figure 5: Tensile load for tensile strength values (MPa) of base metal and welded alloys at 150, 170 and 190 A arc currents.

CONCLUSION

The effect of various parameters on the microstructure and mechanical properties of SKD 61 hot work tool steel using gas metal arc welding spray and pulse current was investigated. The following conclusions are summarized in this experimental study:

1) The results showed that the best conditions of the gas metal arc welding process with the molten metal spray and pulse transfers were the welding current of 150 A and 190 A, respectively.

2) All of the spray and pulse current welding techniques. The microstructures in the welded zone are composed mainly of martensite matrix phases with retained austenite in the dendritic segregation pattern. In the welded zone, the heat input resulted in an increased transformation of martensite, which can cause higher hardness in the weld metal than the base metal.

3) The results of mechanical tests include: hardness tests, impact tests and tensile tests have shown that welding,

with the spray welding techniques. Has a higher strength than pulse transfers are the result of weldability of SKD 61 hot work tool steel. Found that the spray welding techniques have completely fusion more than that pulsed transfer.

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