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The Effects of GMAW Parameters on Penetration, Hardness and Microstructure of AS3678-A350 High Strength Steel

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Abstract

This research aims to study the effects of various welding parameters in gas metal arc welding (GMAW) process on welding penetration, microstructure and hardness of AS3578-A350 high strength steel with the thickness of 10 mm. The welding process parameters were a welding current of 100-200A, an arc voltage of 20-30V, a welding speed of 20-60 cm/min and a gas shielding type of Ar and Ar+CO_2. The summarized experimental results are as follows. An increase of the welding current and voltage affected to increase the penetration depth of the joint. However, when the welding speed was decreased, it increased the penetration depth of the joint. Using the Ar gas for shielding the weld area, produced the higher penetration depth and the less narrow weld bead than the joint that was shielded by the mix gas of Ar+CO_2. The variation of the welding process parameters affected to produce the various microstructures of weld metal and heat affected zone and also showed the various kind of hardness along the weld joint.

Keywords*: gas metal arc welding, high strength steel, depth penetration, Microstructure.*

1. Introduction

The Gas Metal Arc Welding process is an important procedure in industries such as shipbuilding, aircraft, aerospace,building construction, pipeline system and automotive industry because of it's joint strength, high productivity and useful automatic process like the robotics welding which makes it low cost as compared to the other joints processes [1]. Gas Metal Arc Welding or GMAW as defined by American Welding Society is also called Metal Inert Gas (MIG), the principle of the process is that the melting occurs by a continuous electric arc and Joule effect mechanism. The weld is made by successive melt metal transfer to the weld pool. The shielding gas is always used for the protection of the weld pool from atmosphere between oxygen and nitrogen which are the contamination cause of the porosity in weld metal. The shielding gas used in GMAW are argon and helium. But many industries use argon, another popular shielding gas in industry are CO_2 or

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oxygen mix with argon. They are known as Metal Active Gas(MAG) and the shielding gas generally used for weld carbon steel is CO_2, it's called CO_2 welding. In the gas metal arc welding the molten metal is transferred from a consumable electrode wire. The solid wire called electrode is continuously fed into the weld pool, it has unlimited advantage of using long length electrode for welding position. In gas metal arc welding, the variation of power supplies, shielding gas, electrode, welding current and voltage have significant effects, resulting in different process variations. All important metal used in different applications such as aluminium, copper, stainless steel, carbon steel and high strength low alloy steel can be joined by GMAW process by choosing appropriate electrode, shielding gas and different welding condition [2,13]. Currently the manufacturing technology is growing exponentially due to the advent of high speed microcomputers based on fully automated fabrication processes. Welding technology also needs upgrading due to the use of wide applications. In order to constantly produce high quality of weld, arc welding requires experienced welding personnel at the same time. One reason for this is the need of properly selecting the welding parameters for a given task to provide the best weld quality which can be identified by its micro structure, the amount of spatter and the correct bead geometry size [3]. Furthermore, the GMA welding parameters are the most important factors affecting the quality, productivity and cost of welding joints. Weld bead size and shape are important considerations for design and manufacturing engineers in the fabrication industry. In fact, weld geometry directly affects the complexity of weld procedure and thereby the construction and manufacturing costs of steel structure and mechanical devices [4,14,16]. It has been very important to know the performance of welding process and input process parameters. It can be separated into two groups. First, adjustable welding current, arc voltage and welding speed. Second, torch angle, free wire length, nozzle distance, weld direction, weld position and flow rate of gas [5, 6]. For enough penetration and right welding profile occurrence, the quality of welding joints are affected by welding current, arc voltage, welding speed and gas shielding parameters [2,4-5]. A lot of research work has been done to find out the most suitable input parameters for desired out put of the best weld quality. Izzatul et al. investigated the effects of gas metal arc welding process on different welding parameters by studying input parameters such as arc voltage, welding current and welding speed effected the microstructure penetration and hardness [7]. Mohanty et al. investigated the neural modelling of the influence of welding parameters in arc welding processes to study the welding current, arc voltage and welding speed in different arc welding process which effected the bead geometry and heat affected zone [8]. Kim et al. investigated a study on the quality improvement of robotic GMA welding process and reported the top-bead width [9]. Rajkumar [10] found that the shape of fusion zone depends upon a number of parameters such as gas flow rate, voltage, travel speed and wire feed rate.In HAZ the value of hardness was found highest but the hardness at weld metal (WM) was found minimum. As well as the study of change of physical metallurgical properties of low alloy steel 16Mo3 in HAZ, MMA and MAG welding processes, Belma Fakic [11] found that micro structure, grain size, hardness and impact test in the HAZ showed some difference in the mechanical and metallographic properties of the applied welding processes.Therefore the wide researchs are done on welding parameters due to its important affect on the weld profile, weld quality, weld properties and welding cost for manufacturing fabrications [16,17].

This research aims to study the effects of various welding parameters in gas metal arc welding (GMAW) process on welding penetration, microstructure and hardness of AS3578-A350 high strength steel widely used in the heavy car equipment fabrication.

2. Experimental Procedure

For the experimental studies, the high strength low alloy steel specification AS/NZS 3678-A350 having the diamension, length 100 mm., wide 150 mm. and 10 mm.thick was used as the base metal(BM). The chemical composition of base metal and wire electrode are given in the table 1

Table 1. The chemical composition of the base metal and electrode rod, wt(%)

Element wt %	C	Si	Mn	S	P	Ni	Cr	Mo	Cu	Al	Ti	Nb	V
Base Metal	.15	.29	1.19	.011	.016	.025	.027	.002	.017	.031	.017	.001	.004
Electrode Rod	.06-.15	.80-1.15	1.40-1.85	.035	.025	.15	.15	.15	.50	-	-	-	.03

The table 1 shows the chemical composition of commercial base metal is high strength steel AS 3678-A350, amount of wt% in alloying element and ferrous balance and the composition of commercial electrode rod ER-70S-6 (AWS classification).

The power sourch for gas metal arc welding process is the fronius A-4600 welds type transplus synergic 2700 and the mechanize welding machine is wavering auto welding carriage type HK-100. The shielding gas are argon 99.95% (Industrial Grade) and mix gas Ar + 20% CO_2. The constant set up were the torch angle of 90°, nozzle work distance of 10 mm, diameter of electrode rod was 1.2 mm, flow rate of gas shielding was 15 cfm and the base metal thickness of 10 mm. The variable that are choosen in this study were welding current, arc voltage, welding speed and type of shielding gas. The welding current and arc voltage were chosen as 100, 150 and 200 A and 20, 25 and 30 V approximately. The welding speed was chosen as 20, 40 and 60 cm/min.

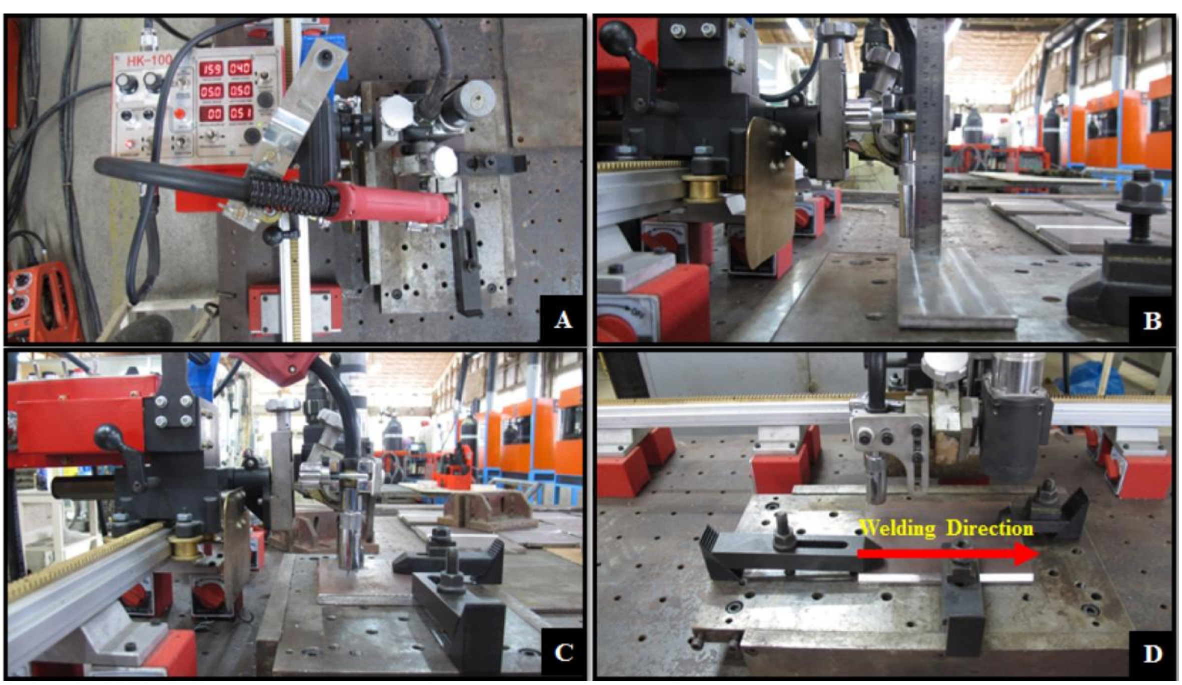


Figure 1. Shows the welding constant set up of mechanize welding machine

The welding constant set up shown in figure 1 (A) set up of variable parameters of welding current, arc voltage and welding speed (B) set up of nozzle work distance of 10 mm (C) shows the torch angle set up at 90° and (D) set up of torch angle and weld direction.

After done with the welding process, all of the welding parameters were recorded such as weld length, weld width and spatter. After that the welding specimen was prepared by cutting work pieces perpendicular to the weld direction by band saw and cut-off machine respectively. Then, grind polishing and fine polishing specimen was prepared by etching using 5% nital to clear the weld metal, heat affected zone and base metal. To measure the depth of penetration, we used the stereo macroscope with magnification less than 10x and examination of microstructure of weldment was done by optical microscope with more than 10x magnification. Finally, for micro hardness test, Vickers hardness 9.81 N load was applied up to 20 seconds on welded metal, heat affected zone and base metal.

3. Results and discussions

We may consider that the profile of welding determined by macroscopic observation and microstructure examination of the grain weld metal are best with the following parameters in Figure 2.

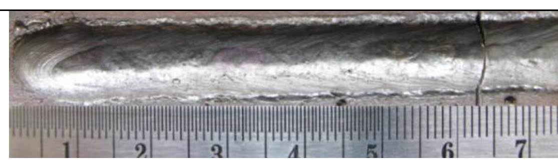
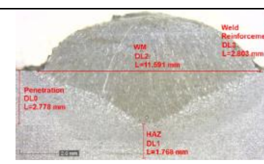
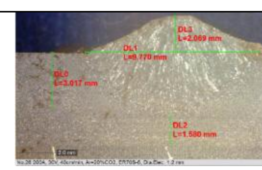
Welding parameters	Shieding gas	Bead Appearence	Cross-section
150 A 30 V 60 cm/min	Ar 100%		
200 A 30 V 40 cm/min	Ar+20%CO2		

Figure 2. Shows the bead appearance and cross-section of welding

From the figure 2, the best weld profile of gas metal arc welding has welding parameters as welding current 150A, arc voltage 30V and welding speed 60 cm/min., shielding gas-Ar 99.95%, flow rate of 15 cfm and the wire electrode ER 70S-6 with diameter of 1.2 mm. The physical properties of best welding in gas metal arc welding are smooth weld bead, the reinforcement is convex, low spatter, no slag and has the diamension penetration as 3.19 mm, bead width 11.59 mm and bead height 2.8 mm. The best weld profile in metal active gas(MAG) has welding parameters as welding current 200A, arc voltage 30 v and welding speed 40 cm/min, shielding gas-Ar+20%CO_2, flow rate of 15 cfm and the wire electrode ER70S-6 with diameter of 1.2 mm. The welding appearance are: the surface of weld bead is rough, the reinforcement is smooth at the edges and convex on the center of welding, more spatter and slightly slag at the edges of weld bead.

3.1 The effects of welding current on penetration

The effect of welding current on penetration of the high strength low alloy steel base metal with a thickness 10 mm in the different parameters. In the Fig.3(A), the welding parameters such as welding current and arc voltage were varied but the welding speed was fixed as 20 cm/min. The variation in depth of penetration depends on welding current and arc voltage. When the welding current and arc voltage for 20, 25 and 30 V increased the depth of penetration was increased. The most depth penetration was 4.10 mm in 200A and 30V condition, while the lowest penetration was 1.19 mm in 100A and 20V. From the all of three conditions, rise of the penetration is linear for 20V and 25V arc voltage, furthermore the penetration highly increased in 30V between 150A to 200A.

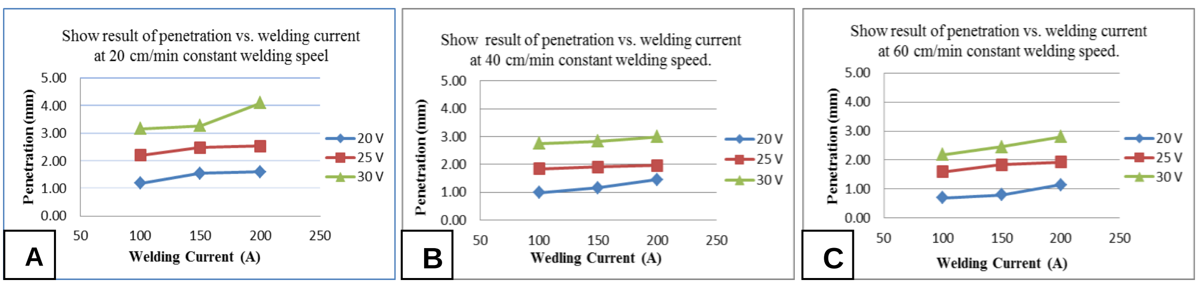


Figure 3. Show the effect of welding current on penetration

The Fig. 3(B) shows the effects of welding parameters at the fixed welding speed of 40 cm/min and the variation in depth of penetration depends on the welding current and arc voltage. When we increased the welding current as 100, 150 and 200A and arc voltage as 20, 25 and 30V, the penetration was increased. The most depth penetration was 2.99 mm in 200A and 30V condition, while the lowest penetration was 0.99 mm in 100A 20V. The change was similar to the condition compared with 20 cm/min welding speed, the depth of penetration increased when the welding current was increased. Observe the Fig.3(C), it shows the effects of welding parameters at the fixed welding speed of 60 cm/min and the change in depth of penetration depends on welding current and arc voltage as previously. The most penetration was measured as 2.81 mm in 200A and 30V which showed the linear increase in depth penetration with welding speed and arc voltage [4,5,7]. The shielding gas Ar+20%CO_2 effected the results of welding parameters between welding current on penetration which were same with Ar shielding but the penetration were lower.

3.2 The effects of arc voltage on penetration

The effects of the welding variables on the bead penetration within the ranges of welding current 100, 150 and 200A and arc voltage 20, 25 and 30V, plate thickness of 10 mm and fixed welding speed as 20, 40 and 60 cm/min are discussed in the Figure 4 which shows the effects of arc voltage on bead penetration.

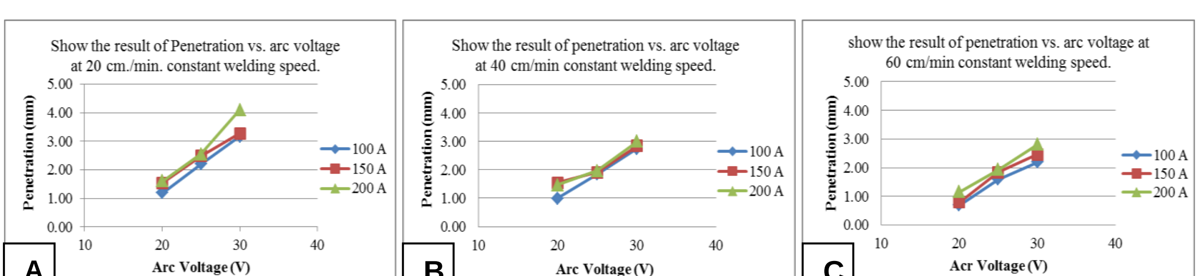


Figure 4. Show the effect of arc voltage on penetration

The relationship of welding parameters between the arc voltage with the bead penetration is shown in the figure 4(A). The welding parameters in figure 4(A) indicates arc voltage 20, 25 and 30V and welding current 100, 150 and 200A and fixed welding speed of 20 cm/min with bead penetration. The depth of penetration increased with increasing arc voltage. However, these are very low penetration values when compared with the welding current 100, 150 and 200A and arc voltage as 20, 25 and 30V. The depth of penetration increment were very low 0.42, 0.35, 0.93 mm respectively which showed the low effect of welding current on depth penetration when the arc voltage were constant [4], while the depth of penetration was stronger between 25-30V in 200A due to low welding speed. It caused increased heat input . The situation was approximately similar at 40 cm/min constant welding speed as given in Figure 4(B). It shows that the linear depth penetration increased with increasing arc voltage. However, at constant arc voltage 20, 25 and 30V and varied welding current 100, 150 and 200A the depth of penetration were increased to 0.47, 0.11 and 0.24 mm respectively which showed the low effect of welding current on penetration when the arc voltage was constant. In the Figure 4(C), the linear depth penetration increased when the arc voltage was increased in comparison to the penetration with constant arc voltage 20, 25 and 30V with varied welding current 100, 150 and 200A which had penetration as 0.46, 0.33 and 0.62 mm respectively.

From all the condition of arc voltage with depth penetration of weld bead are related as linearly when increase arc voltage the penetration are increase but the depth penetration value were very low comparing to welding current. In the Ar+20%CO_2 shielding gas get the result effected of arc voltage with depth of penetration like the Ar shielding but the depth of penetration are lower.

3.3 The effect of welding speed on penetration

The effects of welding speed on depth penetration are shown in the Figure 5. It indicate the result of welding speed and depth penetration in constant voltage 20, 25 and 30V.

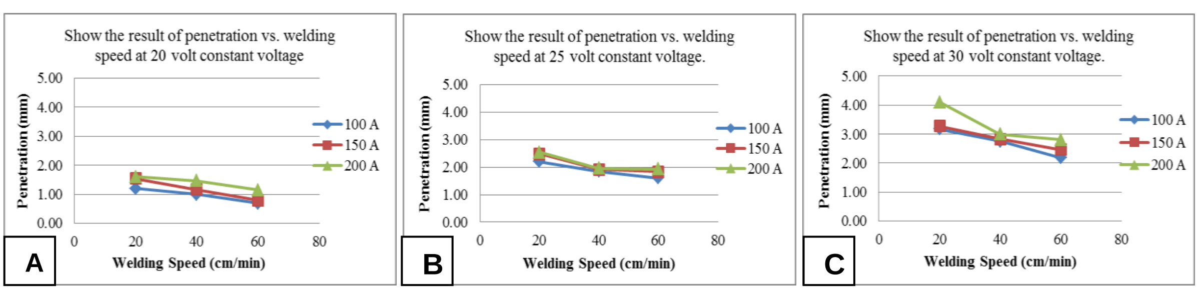
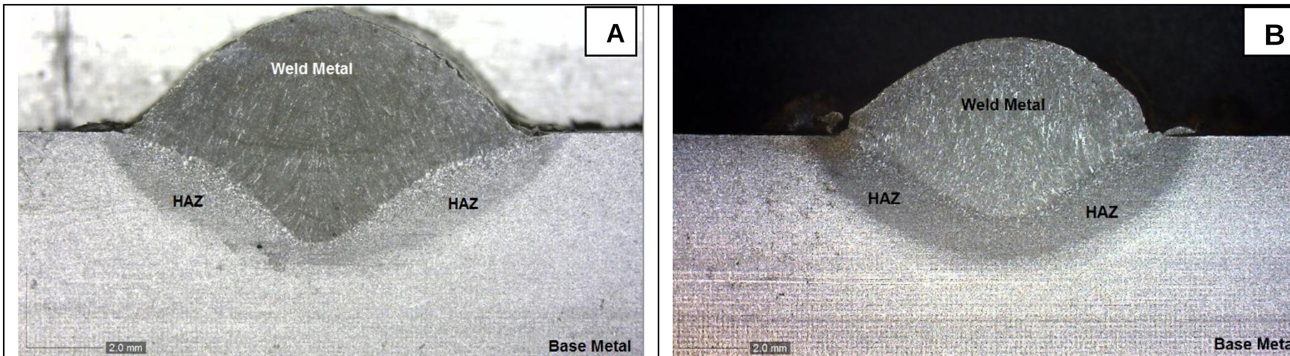


Figure 5. Show the effect of welding speed on depth penetration

In the Figure 5(A) indicated the effect of welding speed with depth penetration at constant 20 Volt. The depth of penetration decreased in liner aspect when the welding speed was increased. However, considering the welding current, the effect of penetration at constant voltage was low. The Figure 5(B) shows the depth of penetration decreased when the welding speed was increased at 25 Volt and the penetration reduced slightly when welding speed was 40 to 60 cm/min. The Figure 5(C) shows penetration while welding speed was constant at 30V. The depth of penetration decreased linearly when the welding speed was increased. From all the three observations about the effects of arc voltage, we found that the increase in arc voltage increased the depth of penetration with the same welding speed and welding current. In case of Ar+20CO_2, the result of welding speed penetration were same as the Ar shielding but the depth of penetration was lower.

3.4 The macro and microstructure examination

The Figure 6 shows the marcostructure of welding that has the best weld profile of gas metal arc welding with welding current 150A, arc voltage 30V, welding speed 60 cm/min, shielding gas Ar 99.95% and the electrode rod ER70S-6 diameter 1.2 mm. And the best weld profile of metal active gas has the weld parameters as welding current 150A, arc voltage 25V, welding speed 40 cm/min., shielding gas Ar+20%CO2 and the electrode rod ER70S-6 diameter 1.2 mm.

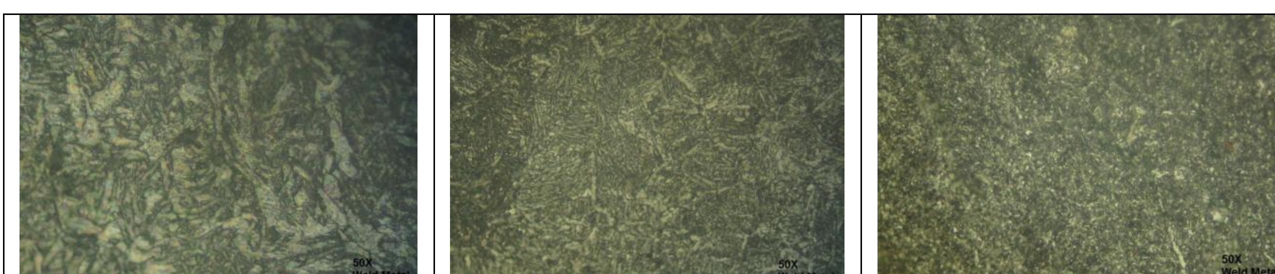


Argon 99.95% shielding gas	Ar+CO2 shielding gas

Figure 6. Shows the marcrostructure of welding in Ar and Ar+CO_2 shielding gas

The figure 6 of the macroscopic structure shows the cross-section of welding using gas metal arc welding process. It has high depth penetration, the root of weld is narrow and cape and the reinforcement is of convex shape. The figure 6(B) shows the cross-section of welding using metal active gas process which shallow penetration, the root of weld is convex and wide and the reinforcement is curved and serrated.

Figure 7 show the microstructure change in gas metal arc welding parameters. The increased welding current, arc voltage and welding speed caused the difference in the grain size of microstructure of each weld metal.



200A, 25V, 20cm/min	200A, 25V, 40cm/min	200A, 25V, 60cm/min

Figure 7. Shows the microstructure of weld metal

Figure 7 shows the microstructure of weld metal using gas metal arc welding process having welding parameters as welding current 200A, arc voltage 25V and welding speed of 20 cm/min, 40 cm/min and 60 cm/min and indicates the different sizes of grain. At the welding speed of 20 cm/min (lowest), the high heat input caused the large grain size, at the welding speed of 40 cm/min (moderate) the grain size was smaller than lowest welding speed. The higher welding speed of 60 cm/min provided the smallest grain size.

3.5 The Hardness Value

The welding specimen for microhardness test was prepared by using cut off machine to cut the specimens and grinded with sandpaper No.400 to 1500 followed by the cloth polishing. These samples were etched with nital 5% for clearing the base metal zone, heat affected zone and weld metal zone. Then hardness value was measured by Vickers microhardness test using the load 9.81N pressed on the weld bead for 10 seconds and the hardness values were recorded. Figure 8 shows the Vickers hardness values of the cross-section welding in all different welding parameters. The highest hardness value appeared on the weld metal and occurred at high welding speed of 60 cm/min. It provided high cooling rate in the weld metal that formed Bainite or martensite phase in the fused zone and increased hardness[8,15]

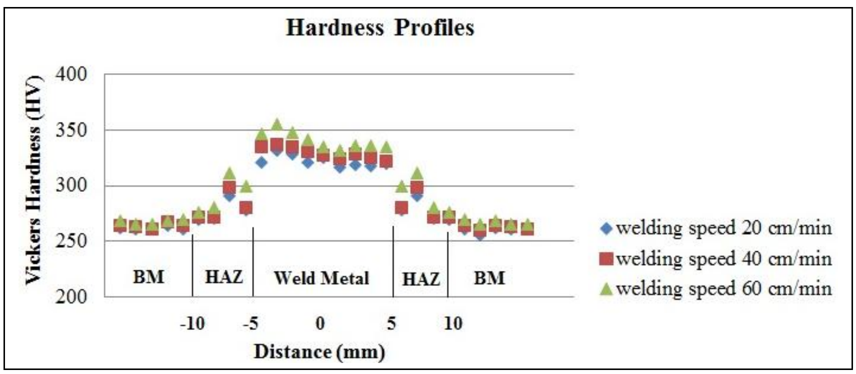


Figure 8. Show the hardness profiles of welding

The hardness values in heat affected zone(HAZ) were lower than weld metal due to the slow cooling rate in HAZ. This area as the local thermal cycle from heat input transfer produced the grain growth to become coarse grain. So the hardness value decreased [9,10,12] but some area in the HAZ had grain refinement such as aluminum, niobium, vanadium and titanium. The grains at HAZ are refined compared to grain size of base metal. The hardness value in HAZ is higher than the base metal [8,11,18]. Figure 9 shows the effects of different welding parameters on hardness value.

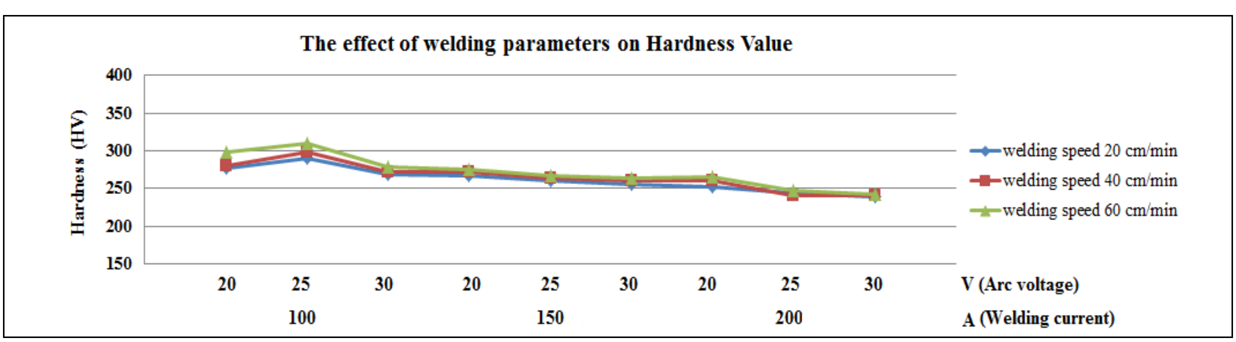


Figure 9. Show the effects of welding parameters on Vicker hardness value

The hardness values are increased at 100A and slowly decreased to 150A. The highest hardness value was at welding speed of 60 cm/min and 25 arc voltage due to the faster speed at a medium arc voltage which caused the transformation to the hard structure as bainite or martensite phase. Therefore, the hardness increased.

4. Conclusions

In this research we studied the effects of gas metal arc welding process parameters on penetration, hardness and microstructure. The variables parameters in this experiment were welding current, arc voltage, welding speed and gas shielding. The conclusions derived from this work are:

1. The value of depth penetration increased with increasing welding current 100A, 150A and 200A, arc voltage but decreased welding speed. The best value parameters to get the best weld bead profile were welding current 150A, arc voltage 30V, welding speed 60 cm/min, shielding gas Ar 99.95%. The highest value of penetration was 4.1 mm with welding current 200A, arc voltage 30V and welding speed 20 cm/min.
2. The hardness value at the weld bead was highest at the point with welding current 100A, arc voltage 25V and welding speed 60 cm/min.
3. The microstructure and phase transformation of welding changed when the variables of welding parameters were changed in the weld metal microstructure which transformed to hard structure Bainite or martensite. The HAZ produced coarse grain and grain refinement from some alloying element.
4. The shielding gas argon 99.95% provided the best weld profile and higher depth penetration than Ar+20%CO_2 but the change in microstructure and hardness value were nearly same.

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