Mechanical Properties and Microstructural Analysis of 304 Stainless Steel by TIG Welding

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Abstract

Gas tungsten arc welding is the process repairing and widely used in heavy engineering for joining metal. It can be uses for various type of metal and application. The aim of this project is to study the effects of 304 stainless steel with 3 mm thickness on mechanical properties and its microstructure analysis towards gas tungsten arc welding method. The variables set up in this project were current, gas flow rate and welding direction upon rolling direction of stainless steel sheet. Three current setup were used which is 60 A, 80 A and 100 A Type of filler metal used in this project was ER 308L with 1.6 diameter. Two set up for gas flow rate were used which is 8 l/m and 12 l/m. Testing that carried out were tensile test, Vickers macro hardness test with 10 kgf load and microstructure analysis by using optical microscope. The effects of microstructure in austenitic stainless steel welds is discussed. From the mechanical properties procedures, the strength of the weld metal was obtain. For hardness testing, the most important zone to be focused were heat-affected zone (HAZ) and weld metal (WM). The integrity of the welding tested by using tensile test and hardness test with different amount of current and gas flow rate.

Keywords: Mechanical properties, microstructural analysis, 304 stainless steel, TIG welding.

1. Introduction

Gas tungsten arc welding (GTAW) were widely used in steel fabrication and joining metal process [1]. Commonly, the application were applied in heavy engineering field such as aircraft frames, automobile parts, railway wagon and many more [2]. The product from welding application exhibit good mechanical properties and manufacturing characteristic. This allowed the welding process done in different environment including in open air and under water. Furthermore, there were also joining of welding by dissimilar metal such as steel and aluminium to increase the strength of the joining metal [3]. The underwater welding normally associated by using stainless steel as it's good in corrosion viewpoint relatively and has extensive lifetime due its composition. The usage of stainless steel is small compared to carbon steels but exhibits a steady growth. The important thing about welding a stainless steel were the quantity of ferrite in the welds must be minimized or controlled to avoid degradation during its lifetime service [2]. However, there are several factors that will change the behavior of the welding strength when some welding parameters were being altered. Hence, this study were cope for several parameters such as current, welding towards rolling direction of stainless steel plate and gas flow rate for argon. Suit with the objectives of this study to determine the welding joint integrity by altering the welding parameters. The different setup in each parameters will produce a different result and the optimum or the best result was analyzed. The objectives of this paper is to study mechanical properties and microstructure of 304 stainless steel by TIG welding.

2. Materials and Method

There were many types of stainless steel used in GTAW by depending on the application suit. The main reason why stainless steel were used because it highly corrosion resistance and have high strength. In this study, 304 stainless steel or also known as austenitic stainless steel were used. The existence of chromium in the composition of typical austenitic stainless steel make it as a good corrosion resistance agent. The composition of 304 stainless steel were shown in Table 1. Meanwhile in Table 2 show the physical properties of 304 stainless steel.

Table 1. Chemical composition of 304 stainless steel [4].

Stainless steel type	**UNS designation**	**Carbon (wt %)**	**Manganese (wt %)**	**Silicon (wt %)**	**Chromium (wt %)**	**Nickel (wt %)**
304	S30400	0.00-0.008	0.00-2.00	0.00-1.00	18.00-20.00	8.00-10.50

Table 2. Physical properties of 304 stainless steel [5].

Aspect	Density of liquid (kg/m^3)	Effective viscosity, (kg/ms)	Solidus temperature, (K)	Liquidus temperature, (K)	Coefficient of surface tension, (K)	Coefficient of thermal expansion, (K^{-1})
Value	$7.2x10^3$	0.1	1697	1727	-0.43×10^{-3}	1.96×10^{-5}

In GTAW, others element that important were shielding gas (argon) used. The main purpose of the shielding gas was to prevent contamination during the welding process from any others impurities exist in the atmosphere. This study were using a pure argon gas as a shielding gas. Instead of argon used as a shielding gas, there also other element were used such as hydrogen, helium, nitrogen and many more. The effectiveness of each shielding gas were depend on the materials used and type of application or fabrication. Gas flow rate is important and the setup need to be suitable with the type of welding joint and materials used. If the gas flow rate too slow the welding penetration is not good as the weld pool will become shallow and will lead to low strength. Meanwhile, if the gas flow rate too much the weld pool will disperse and no molten metal left at the weld pool. The characteristic of every different shielding gas were tabulated in Table 3.

Table 3. Welding shielding gas characteristics [6].

Type of gas	**Content in air (%)**	**Density at 15°C, 1 bar (kg/m^3)**	**Relative density with regard to air at 15°C**	**Chemical activity**
Hydrogen	0.5×10^{-6}	0.085	0.06	Reducing
Argon	0.934	1.669	1.38	Inert
Helium	5.2×10^{-6}	0.167	0.14	Inert
Nitrogen	78.084	1.170	0.91	Reactive
Carbon dioxide	0.033	1.849	1.44	Oxidizing
Oxygen	20.946	1.337	1.04	Oxidizing

Argon were widely used as a shielding gas when welding a stainless steel as it provide low levels of an oxidant. There were also some addition to the argon gas composition was made to enhance the weld quality. For example, addition of carbon dioxide can improve the wettability of the weld bead and improve the weld quality. Meanwhile, addition of hydrogen increased the volume of melted materials and welding speed but it can lead into hydrogen cracking if the current apply is too high. Addition of helium were to increase weld penetration and weld puddle fluidity and leads to higher travel speed and less distortion [5]. In other research, it was found that by using the pure argon as a shielding gas will provide the best result for micro hardness profile across the welded section [7].

3. Result and Discussion

The results and discussion are based on the three type of testing carried out on the sample. The three test are tensile test, Vickers macro hardness test and microstructure analysis with different parameters. The parameters set are welding current, gas flow rate for shielding gas and welding direction. The welding current were varying from 60 A, 80 A and 100 A. Meanwhile, gas flow rate for argon used were 8 l/m and 12 l/m. Filler metal used was ER 308L with 1.6 mm diameter. Each one of these parameters will be applied on both welding direction either transverse or longitudinal. For Vickers macro hardness testing, load applied use were 10 kgf for all samples. Table 3 show the summarized of tensile strength for all samples. Meanwhile in Figure 1, clearly shows that a decreasing pattern of tensile strength as the welding current is increasing for longitudinal welding direction. In the other hand, the tensile strength increasing for transverse welding direction when the current increase whenever using 8 l/m gas flow rate. The highest tensile strength achieved for 8 l/m gas flow rate are 738 MPa at longitudinal sample. Meanwhile the highest tensile strength for 12 l/m gas flow rate are 820 MPa also exhibit at longitudinal sample. This is shown that welding process either using 8 l/m or 12 l/m gas flow rate, longitudinal welding direction will have higher strength. This support with previous researcher by where specimens welded transverse to the rolling direction exhibit more cracking and resulted in less strength compare to longitudinal direction [8]. Result shown that the specimens welded transverse to the rolling direction exhibit less strength compare to longitudinal direction.

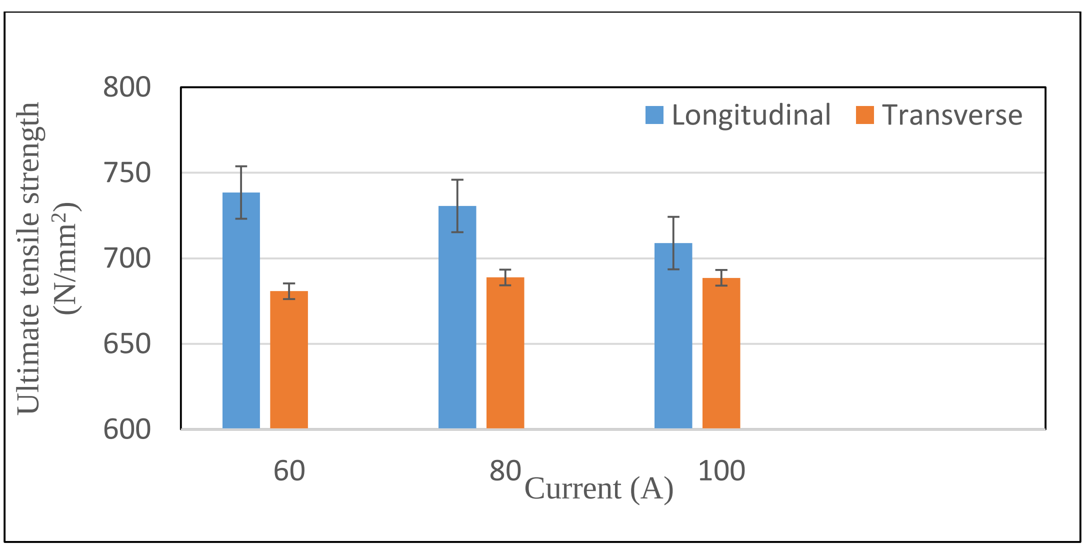

Fig. 1. Current against UTS for 8 l/m gas flow rate.

Table 4. Tensile strength obtained from tensile test.

Current (A)	Gas flow rate (l/m)	Welding direction	Ultimate tensile strength (MPa)
60	8	Transverse	681
		Longitudinal	738
	12	Transverse	710
		Longitudinal	689
80	8	Transverse	688
		Longitudinal	731
	12	Transverse	712
		Longitudinal	820
100	8	Transverse	689
		Longitudinal	709
	12	Transverse	704
		Longitudinal	592

In Figure 2, grain boundary in the HAZ can be relate with the solidification grain boundary in the fusion zone. A typical grain size structure at the regions near the fusion line or also known as heat affected zone. The grain size was changed significantly depending on the temperature and current input. As the current increases, the grain structure at HAZ will become coarser [5]. The coarse structure was form when the temperature is above the austenite formation temperature for a certain time which the grains grow dramatically. In addition, the heat affected zone widened with the increasing of the welding current. Specimen from weld metal showing dendritically cored structure containing some delta ferrite and precipitated carbide in an austenite matrix [9]. Dendritic coring is known as a characteristic of rapidly frozen austenitic weld metal. Meanwhile for the fusion zone area which interface of weld metal and heat affected zone, the heat affected zone fully recrystallized because the heat is directly upon that area during welding [9].

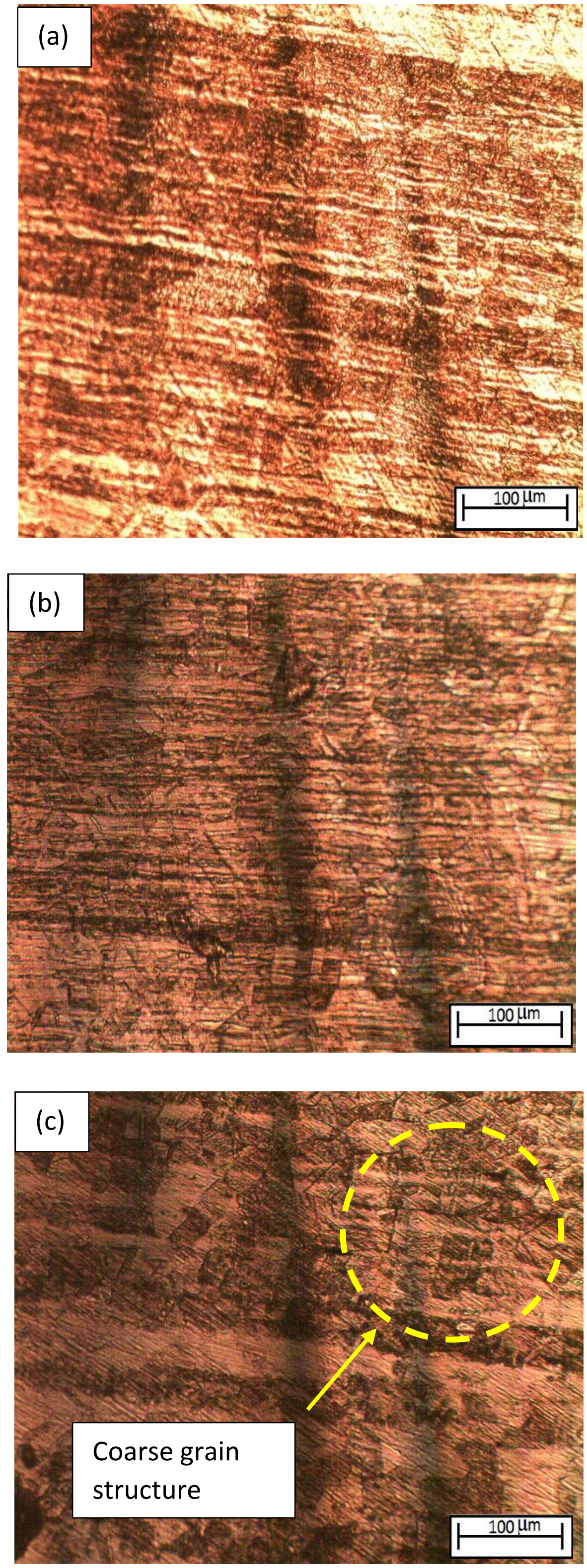

Fig. 2. Microstructure of heat affected zone (HAZ) under optical microscope at 50x magnification (a) Current 60 A; (b) Current 80 A; (c) Current 100 A for longitudinal welding direction.

Figure 3 shows that base metal has the highest hardness profile which is 215 HV. However, the most significant profile hardness need to be highlighted was at weld metal since the stress focused at weld metal during the tensile test. The hardness of weld metal was lower than heat HAZ and base metal [10]. By comparing the hardness of weld metal for transverse and longitudinal welding direction. The highest hardness result for longitudinal welding was 185 HV by using 80 A. Meanwhile the highest hardness at weld metal for transverse welding only 163 HV. This hardness result can be correlated with tensile result. The highest tensile strength was 820 MPa by using 80 A and longitudinal welding. It is clearly shown that longitudinal welding direction have higher strength compare to transverse welding direction from this both hardness and tensile result. As a conclusion, the hardness will increase as the tensile strength increases. For a typical austenitic stainless steel, the variation of HAZ hardness was more likely increase up until 200 HV. It is worth to mention that this occurs because of the recrystallization carbide precipitation and formation of the ferrite at the grain boundaries during the welding process [9].

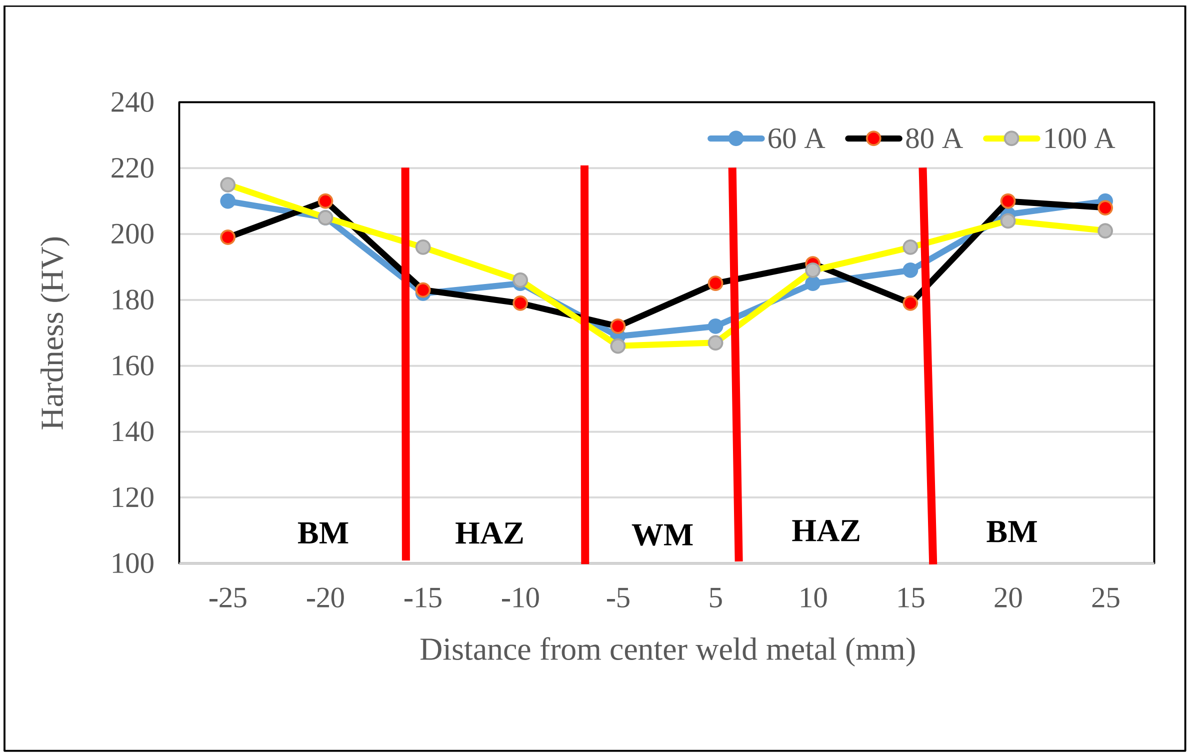

Fig. 3. Hardness profile against various current on longitudinal welding.

4. Conclusion

Based on the overview and findings, the following conclusions are drawn:

i. Welding in longitudinal direction was found to have the highest strength in tensile test and hardness test by using 80 A and 12 l/m gas flow rate. The strength was recorded was 820 MPa and 182 HV respectively.
ii. The variation of microstructure were observed in each of welding zone. The grain were getting coarser when the zone was approaching weld metal zone.

5. Acknowledgement

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