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The influence of welding speed conditions of GMAW on mechanical properties of 316L austenitic stainless steel

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Abstract. In this study, the influence of welding speed conditions of gas metal arc welding (GMAW) on mechanical properties of 316L austenitic stainless steel (SS) was investigated. The welding speed was applied with three different variations at 175 mm/minute, 190 mm/minute, and 205 mm/minute. The GMAW was equipped by solid electrode wire ER308L with 0.8 mm in diameter. The Vickers micro-hardness and tensile tests were conducted for each GMAW joint, and the results were discussed. It was found that the Vickers micro-hardness showed a dependence on welding speed conditions in weld metal (WM) and heat affected zone (HAZ) areas. A systematic increase in hardness was shown with an increase in welding speed. The ultimate tensile strength and yield strength of GMAW joints were found to decrease systematically with an increase in welding speed. From this investigation, it was found that GMAW joint with the welding speed at 175 mm/minute was suitable to be applied for 316L SS.

1 Introduction

The 316L austenitic stainless steel (SS) is widely used in a lot of applications due to its good mechanical properties at high temperatures, superior corrosion resistance, weldability, and easy of fabrication [1-2]. The major chemical compositions such as *Chromium* (Cr), *Molybdenum* (Mo), and *Nickel* (Ni) make the 316L SS suitable to be applied at elevated temperatures and corrosive environment. The "L" sign following the 316L indicates the low carbon content (<0.03 wt. %) which may responsible to avoid the potential stress corrosion cracking in heat affected zone (HAZ) area [3]. The 316L SS can be found as the components in nuclear reactor, pumps, valves, marine fittings, fasteners, paper and pulp machinery, petro chemical, etc.

Recently, most of the mechanical structures are composed of welded components. The use of welded components cannot be avoided since the construction of designs is becoming more complicated time by time.

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In the welded area, the microstructures will have different characteristics with the base area. It has been reported that the weakest links were normally found in welded area and might have an original defect [4]. Hence, the welding work must be one of the important considerations in engineering design since the defects will cause stress concentration.

The general welding problems found for the 316L SS are the risk of hot cracking appearance and the appearance of carbide chrome and oxide chrome during the welding process [4]. A smooth precipitation of carbide chrome will be formed among the grain boundaries in the fusion area, while the oxide chrome may appear on the metal surface. Both of the carbide and oxide chrome will reduce the chrome contents cause of reducing in corrosion resistance. In this study, a gas metal arc welding (GMAW) also called as metal inert gas (MIG) is applied to the 316L SS since the process is versatile, rapid and economical, and good in quality. The GMAW is one of the arc welding processes where a continuous electric arc is generated from the filler (wire electrode) supplied by a roll of wire. The GMAW is able to perform the welding process without concerning about the use of electrode for the limited length [6]. The GMAW can be performed automatically by means of welding robot or semi automatically in various welding speed. Furthermore, the contamination between the oxygen and nitrogen is prevented by Argon gas or active gas, CO_2 as plasma during the welding process [4-6].

It has been reported that the variations of welding parameters in GMAW such as welding speed, torch angle, free wire length, arc welding current, arc voltage, nozzle distance, welding position and direction, and the flow rate gas will have a significant effect to the result of welded material performance [6-9]. A further investigation is still conducted until now to find out the most suitable combination of input process parameters for a desired output in GMAW. Izzatul et al. investigated the effect of variations of input parameters such as arc voltage, welding current and welding speed to the welding penetration, microstructural and hardness measurement in mild steel [6]. Biswajit et al. investigated the characteristics of depth penetration of welded joint due to variations of welding current, arc voltage, and welding speed.

In the present study, the most suitable welding speed of GMAW to the 316L SS was investigated. The welding speed is chosen with three different variations at 175 mm/minute, 190 mm/minute, and 205 mm/minute. The Vickers micro-hardness and uniaxial tensile tests are performed and the results are discussed.

2 Experimental procedures

2.1 Specimen preparation

The complete chemical compositions of the base metal austenitic 316L SS and electrode wire of AWS 5.9/ ASME SFA 5.9 ER 308L are given in tables 1 and 2, respectively. Two plates of base metal were stuck together at the two ends along the width to make a butt joint. The welded plate had a dimension of 300 mm × 125 mm × 3 mm with a V-shaped groove of 60^o as shown in figure 1. Prior manufacturing the testing specimens, a non-destructive testing of dye penetrant was applied to the welded plate to identify the possible defects on the specimen surface. The specimens were cut from the welded plate by a power hacksaw and formed into a rectangular shape with the dimensions of 120 mm × 57 mm × 3 mm for tension specimen and 50 mm × 5 mm × 3 mm for the Vickers micro-hardness specimens. A fixed arm of a portable gas cutting machine was applied to the welding torch to control the welding speed.

2.2 Experimental apparatus

MIG/MAG 350 G-KR WELDING MACHINE, manufactured by MULTIPRO is applied to produce the welding specimens. The wire electrode is inserted automatically into the welding gun by a roller drive system. An austenitic stainless steel with the maximum carbon content of 0.02% is used as the electrode wire. An ultra high purity (UHP) of 99.99 % *Argon* (Ar) is used as shielding gas and supplied in regulated manner at a constant flow rate and at constant pressure. The GMAW conditions are given as follows:
- Polarity: DCEP
- Current: 135 A
- Voltage: 20.1 V
- Welding speed: 175 mm/min, 190 mm/min, 205 mm/min
- Pre-heating temperature: minimum of 20 ^{o}C

The hardness test was performed using a Vickers micro-hardness machine (model: Mitutoyo HM 122) with 100 gr of load and 15 second of penetration time. The hardness was determined every 500 µm along the base metal (BM), heat affected zone (HAZ), and weld metal (WM) as shown in figure 2. The tension tests were performed by universal testing machine and following the ASTM E8/E8M-13A [10]. A screw-driven load frame at constant crosshead velocity of 100 mm/min was actuated by AC servomotor type.

Table 1. The chemical composition of AISI 316L (wt. %).

Fe	C	Si	Mn	P	S	Cr	Ni	Mo	Fe
bal.	0.022	0.470	1.899	0.046	0.008	17.501	10.018	2.096	67.290

Table 2. The chemical composition of wire ER308L (wt. %).

Fe	C	Si	Mn	P	S	Cr	Ni	Mo	Fe
bal.	0.050	0.400	1.632	0.006	0.006	19.294	9.717	0.481	68.039

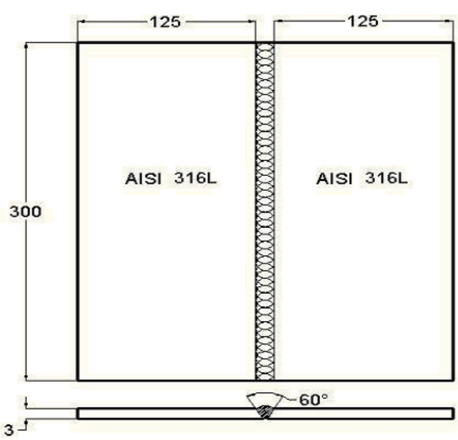

Fig. 1. The welded plate of 316L SS.

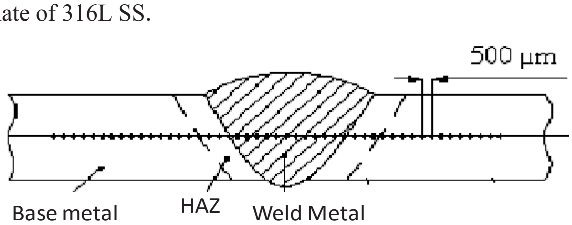

Fig. 2. The Vickers micro-hardness measurement.

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3 Results and discussion

3.1 Hardness properties

Figure 3 shows the hardness results of Vickers micro-hardness measurement for GMAW joints of 316L SS under different welding speed conditions. The BM, WM, and HAZ areas are divided by the vertical lines along the sample distance. The BM has the lowest hardness which is approximately from 162 to 168. The hardness starts to increase sharply in HAZ and continues to decrease slightly in the WM. A significant difference in hardness is observed in the HAZ and WM areas among the three different welding speeds. The hardness increases with an increase in welding speed. At the lower welding speed, the grains and grain boundaries restoration may be formed. On the other hand, a precipitation amount will increase following with an increase in welding speed. The precipitation appears from the dissolution or growth of strengthening precipitates during the welding thermal cycle [11]. Chaudari et al reported that an increase in hardness in HAZ and WM is due to over precipitation and increased carbon precipitation amount [12]. As shown in figure 3, it can be seen that the HAZ and WM hardness are nearly close to the BM at 175 mm/min, while the hardness increases significantly at the welding speed above 175 mm/min.

3.2 Tensile properties

The tensile property measurements between BM and GMAW joints are shown in figure 4. Figures 4(a)-4(b) show the ultimate tensile strength (UTS) and yield strength (YS) of BM and GMAW joints for three different welding speeds. It is shown that the UTS and YS in GMAW joints decrease with an increase in welding speed. The YS and UTS of BM are 614 MPa and 414 MPa, respectively. However, the YS and UTS of GMAW joints at 175 mm/min are 498 MPa and 264 MPa, respectively where the strength reduces about 20%. A significant decrease in UTS and YS are observed for the GMAW joints with the welding speed above 175 mm/min. The YS and UTS of GMAW joints at 190 mm/min are 302 MPa and 189 MPa, respectively which are about 50% reduction in strength. With a further increase in welding speed at 205 mm/min, the UTS and YS are about 283 MPa and 196 MPa, respectively which are about 55% reduction in strength.

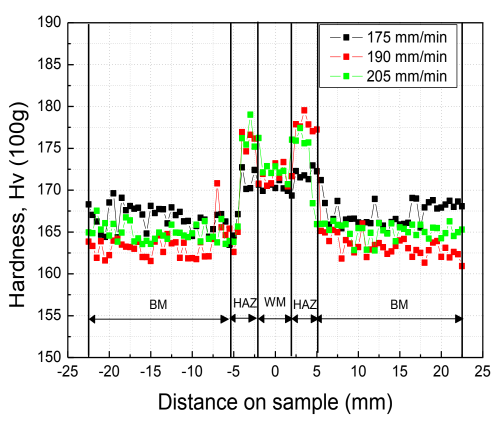
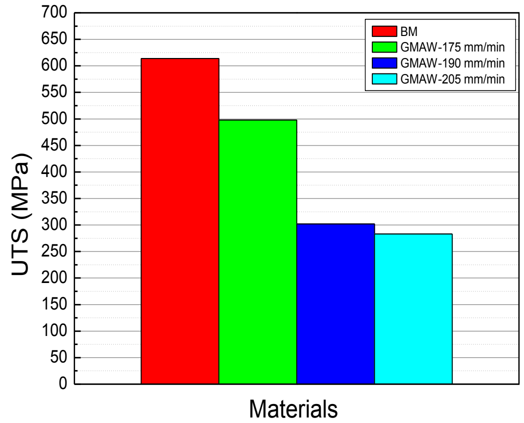
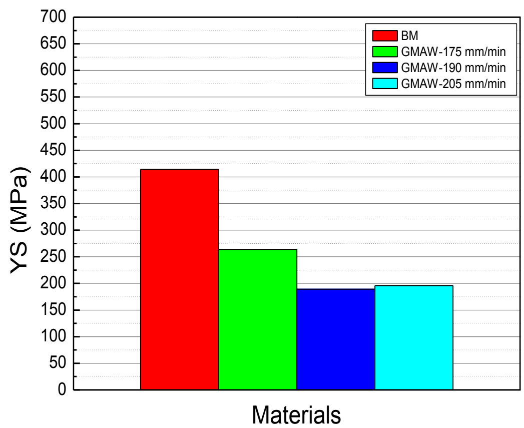


Fig. 3. Vickers micro-hardness result for different welding speed conditions.



(a)



(b)

Fig. 4. Tension test result for different welding speed conditions; (a) ultimate tensile strength, (b) yield strength.

4 Conclusions

In this paper, the influence of welding speed parameter in GMAW for 316L SS has been investigated. The recommended welding speed was proposed based on the following results.

The Vickers micro-hardness results showed that the hardness did not change significantly at the welding speed of 175 mm/min due to the occurrence of restoration process during the welding process. The tensile test results also showed that the UTS and YS did not decrease significantly at 175 mm/min comparing with 190 mm/min and 205 mm/min. According to these results, we therefore have decided to propose the welding speed at 175 mm/min as an optimal value in GMAW operation to be applied to 316L SS. Further investigation is still required to determine the specific parameters of GMAW by varying the parameters such as torch angle, free wire length, arc welding current, arc voltage, nozzle distance, welding position and direction, and the flow rate gas.

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