IOP Conf. Series: Materials Science and Engineering **316** (2018) 012051 doi:10.1088/1757-899X/316/1/012051

Microstructural and Mechanical Properties of Welded High Strength Steel Plate Using SMAW and SAW Method for LPG Storage Tanks

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Abstract. Indonesian government policy to convert energy consumption for domestic household from kerosene to liquefied petroleum gas (LPG) may lead to the increasing demand for LPG storage tank. LPG storage tank with a large capacity generally used the HSLA steel material of ASTM A516 Grade 70 joined by SMAW or combination between SMAW and SAW method. The heat input can affect the microstructure and mechanical properties of the weld area. The input heat is proportional to the welding current and the arc voltage, but inversely proportional to its welding speed. The result shows that the combination of SMAW-SAW process yield the lower hardness in the HAZ and the fusion zone compared to the singe SMAW process. PWHT mainly applied to reduce residual stress of welded joint. The result shows that PWHT can reduce the hardness in the HAZ and the fusion zone in comparing with the singe SMAW process. The microstructure of weld joint shows a coarser structure in the combined welding process (SMAW-SAW) comparing with the single welding process (SMAW).

1. Introduction

Indonesian government policy to convert energy consumption for domestic household from kerosene to liquefied petroleum gas (LPG) may lead to demand for LPG storage tank. LPG storage tank with a large capacity generally used a low-carbon steel material ASTM A516 Grade 70.

In the fabrication process, Shielded Metal Arc Welding (SMAW), Submerged Arc Welding (SAW) and combination of both can be used for joining the LPG tank as can be seen in Figure 1.

The major variables that affect the weld involve heat input and include the welding current, arc voltage, and travel speed. Welding current is the most important. The higher the current, the deeper the penetration. The welding current should be selected based on the electrode size. The higher the welding current, the greater the melt-off rate (deposition rate). [1]

In general, deposition rate of SAW process is higher that of SMAW process. Hence, in welding a low carbon steel, SAW process will produce a deeper penetration & wider HAZ compared to SMAW Process. [1,2]

(a)

(b)

Figure 1. Spherical (a) and ordinary (b) tanks for LPG storage

This paper purposed to study the effect of heat input on the microstructure and mechanical properties of the weld area. In addition, PWHT performed to the weldment is due to the plate thickness of 35 mm, in order to evaluate the effect of PWHT on the microstructure and mechanical properties of the weldment after welding.

2. Research Methodology

The research was carried out using the high strength steel plates with 35 mm thickness. The base material is specified by ASTM A516 Grade 70 having the chemical composition as shown in Table 1.

Table 1. Chemical composition of base metal – steel plate ASTM A516 Gr.70 (in weight %).

C	Si	Mn	P	S	Cr	V
0.21	0.34	1.10	0.02	0.01	0.01	0.01

The plate was prepared by V-grooved design as seen in Figure 2. The sample was then welded by SMAW and the combination of SMAW-SAW method as shown in Figure 3 with welding parameter which refers to ASME section IX are as follow:

Method	: SMAW & Combination of SMAW-SAW
Joint Design	: Butt joint with 70° V- groove.
Filler type	: E7016, E7018 & F7P8 – EH12K
Filler size	: 3.2 mm in diameter
Preheat Temp	: 65 – 95 °C (gas burner)
Interpass temp	: 250 °C max
Current	: 130 Ampere (SMAW) & 550 Ampere (SAW)
Voltage range	: 24 Volts
Travel speed	: 23 mm/min (SMAW) & 50 mm/min (SAW)
Heat Input	: 7.78 – 13.2 kJ/cm

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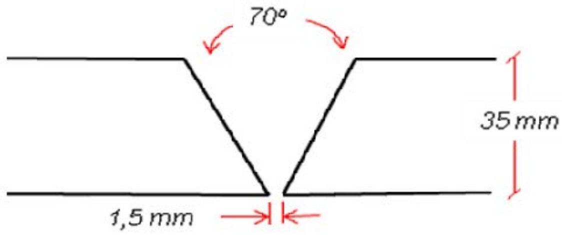


Figure 2. Welding Design with V-Goove

Figure 3. Stages of manufacturing process, from welding, testing and monitoring of joining steel plates

After welding, the specimen was post heat treated in the furnace by hating rate of 222 °C per hour and then holding at temperature of 650 °C within 1 hour 15 minutes and then cooling in furnace with the cooling speed of 280 °C per hour [3,4] as can be seen in Figure 4.

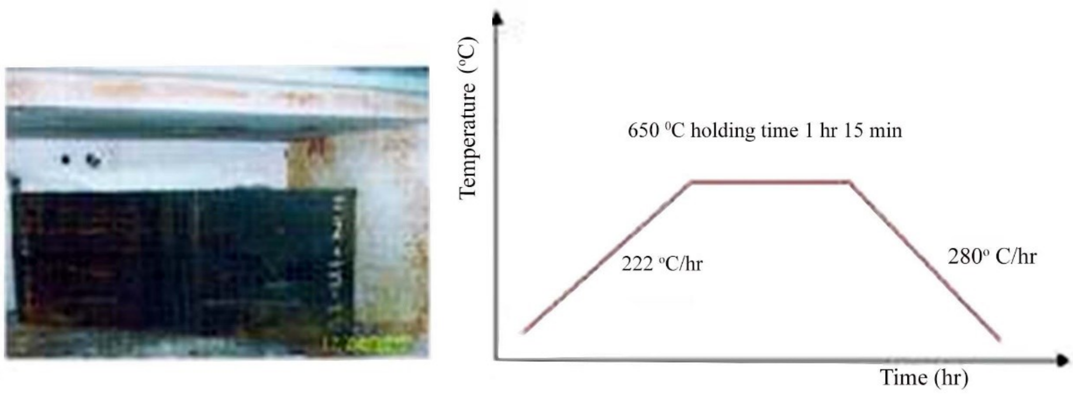
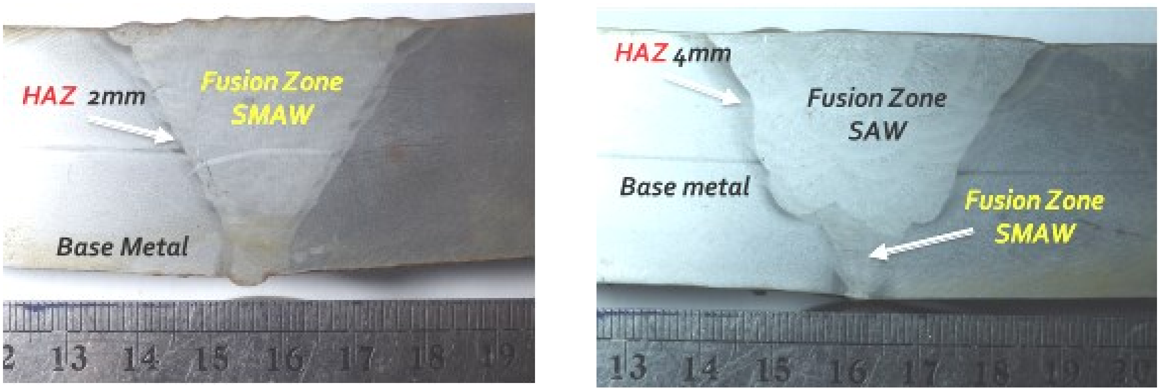


Figure 4. Stages of post weld heat treatment (PWHT).

3. Results And Discussion

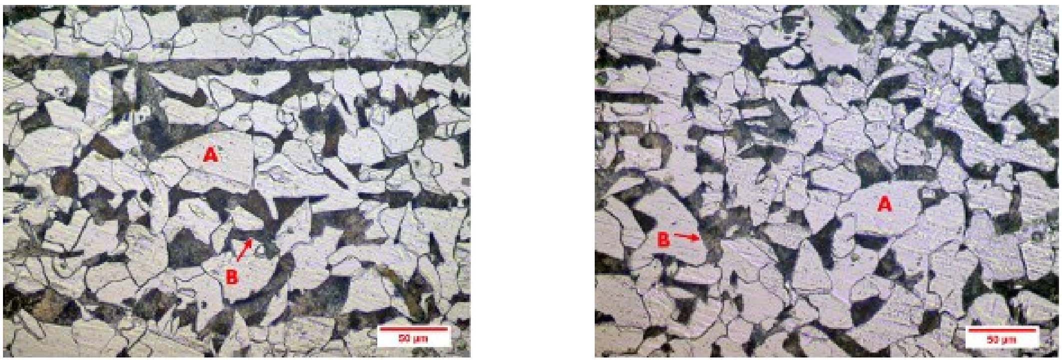
The calculation of heat input is carried out to determine the amount of heat input received by the test specimen. The amount of heat input can determine changes in the microstructure [4,5]. The average heat input on the SMAW welding test specimen (P1) is 0.77 KJ/mm, while for SAW welding is 2,30 KJ/mm. The heat input received by the test specimen is directly proportional to the magnitude of the applied arc voltage and welding current. The greater the arc voltage and the welding current, the greater the heat input received by the test specimen. The speed of welding (travel speed), inversely proportional to the amount of heat input [4,6].



(a) **(b)**

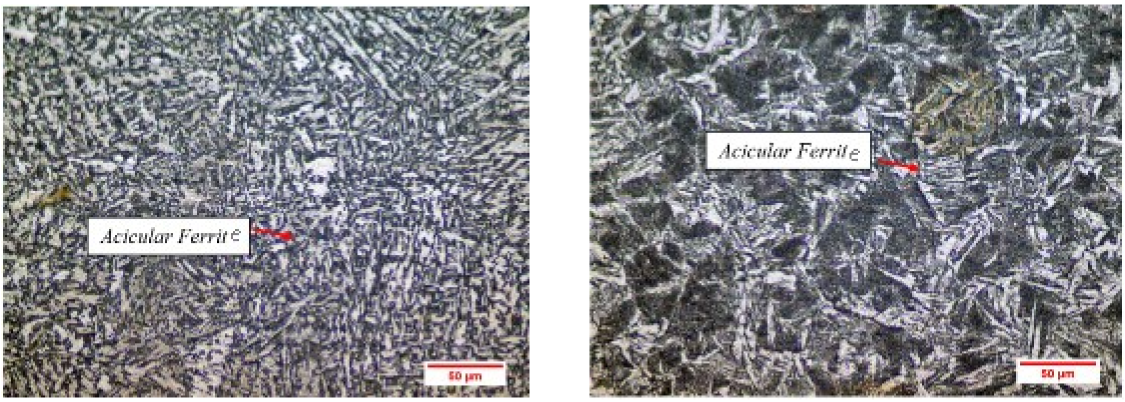
Figure 5. The macro structure of the welding of test specimens (a) welding P1 and (b) welding P2

Figure 5 is a macrostructure of the SMAW weld specimen (P1) and SMAW-SAW combination weld specimen (P2). P1 welding was done as much as 59 layers, while P2 was as much 30 layers. The previous welding area are exposed to high temperatures, so that the hardness decreases and the material's toughness increases [1,5,6]. The size of HAZ in P1 test specimen is about 2 mm wide, while the size of HAZ in P2 test specimen is about 4 mm wide. The size of HAZ depends on the amount of heat input received by the material. In another study it was also stated that the increase the heat input, the wider size of HAZ would occur [5].



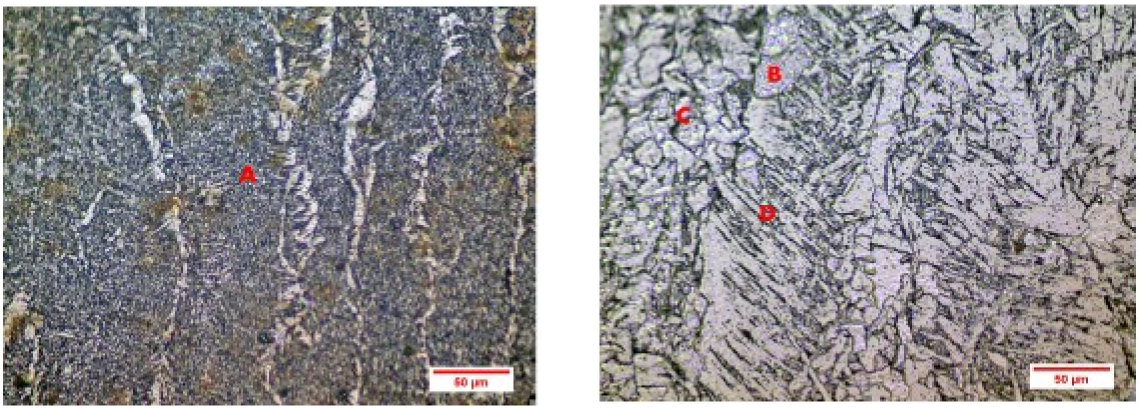
(i) **(ii)**

Figure 6. The base metal microstructures (i) before PWHT (ii) after PWHT; A = ferrite phase; B = perlite phase



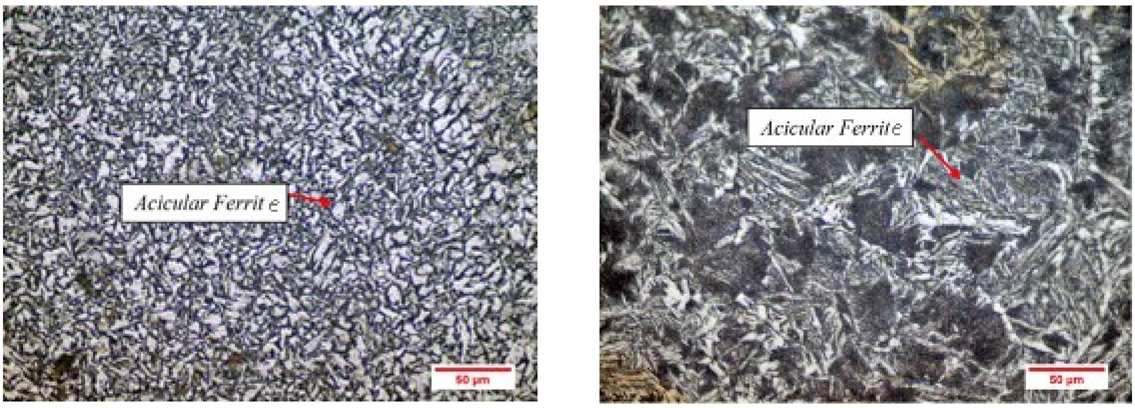
(i) **(ii)**

Figure 7. HAZ microstructure on P1 sample (i) before PWHT (ii) after PWHT; Grain growth occurs in acicular ferrite



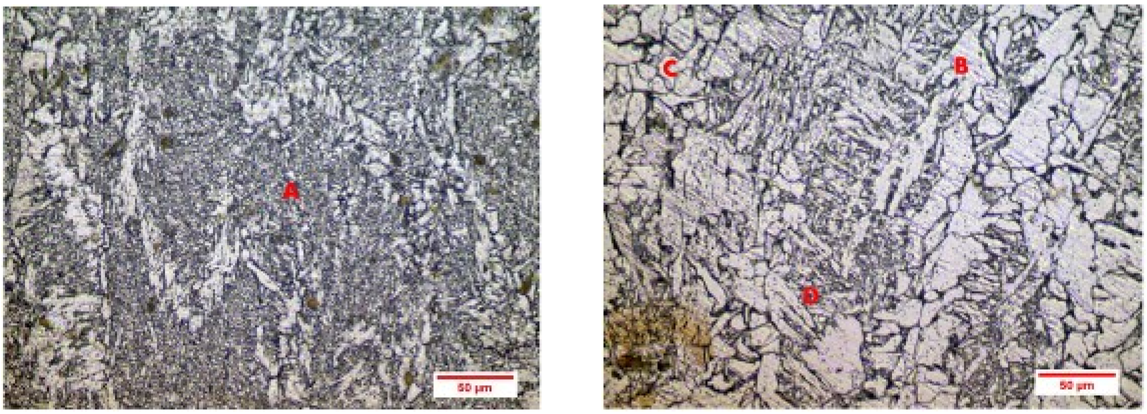
(i) **(ii)**

Figure 8. Fusion Zone microstructure on P1 sample (i) before PWHT (ii) after PWHT; A, acicular ferrite; B, grain boundary ferrite; C, polygonal ferrite; D. Widmanstaten Ferrite



(i) **(ii)**

Figure 9. HAZ microstructure in sample P2 (i) before PWHT (ii) after PWHT; Grain growth occurs in acicular ferrite



(i) **(ii)**

Figure 10. Fusion Zone microstructure in P2 sample (i) before PWHT (ii) after PWHT; A, acicular ferrite; B, grain boundary ferrite; C, polygonal ferrite; D, Widmanstaten Ferrite

In Figure 6 to Figure 10 shows the differences in the microstructure between P1 and P2 (before and after PWHT), respectively, ranging from HAZ P1, fusion zone P1, HAZ P2 and fusion zone P2. In each of these differences of microstructures can be seen the growth of ferrite grains. In another study mentioned that the existence of this ferrite growth will cause material hardness decreased and material toughness increased [5,6].

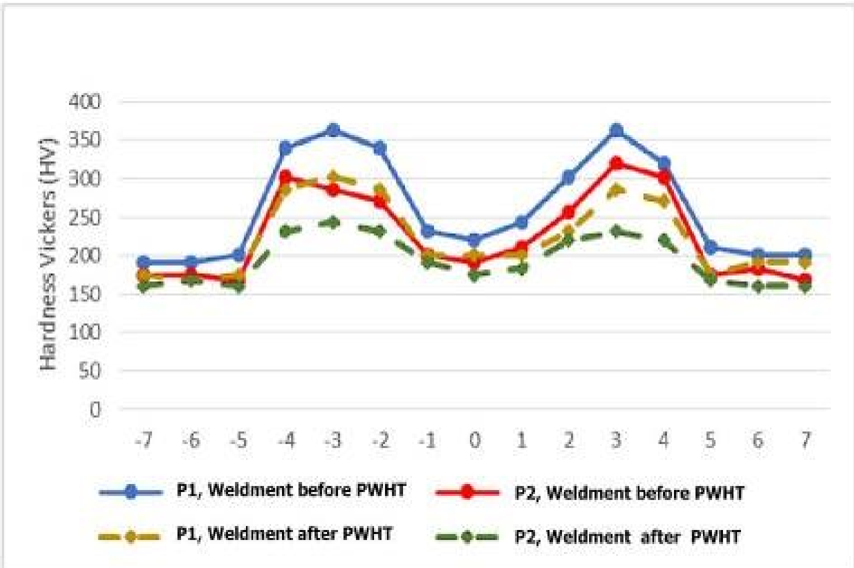


Figure 11. Graph of hardness distribution testing on P1 and P2 specimens before and after PWHT; 0 indicates the centre line of fusion zone

Figure 11 shows the hardness distribution of the test specimens on P1 and P2 either with before PWHT or after PWHT. In both specimen tests, there was a decrease in hardness after PWHT. According to research by Markku Pirinen and Bin Hu, the decrease of hardness in the material after welding can increase the toughness [7]. The high hardness in the HAZ area is due to the residual stresses occurring in the weld area. This residual stress is due to by tensile and compressive stress resulting the melting zone and solidifying zone of the filler material. At the time the filler metal is still in the liquid phase, it will be compressive force in HAZ and it will change the microstructure of the HAZ. While at the time of solidifying of filler metal, there will be tensile force in HAZ. The residual stress caused by the welding process can be reduced by reheating treatment after welding (PWHT).

4. Conclusion

The following conclusions are as follows:

1. Weldment produced by the combination process (SMAW and SAW) gives the lower hardness in both of HAZ and weld metal compared with weldment produced by the single SMAW process.
2. The purpose of PWHT are to reduce residual stress of welded joint and it shows that PWHT can reduce the hardness of weldment in both either in single SMAW process or in combination process (SMAW and SAW).
3. The microstructure for all area of weld joint (HAZ and weld metal) produced by the combination processes is seems a bit coarser comparing with weld produced by the single SMAW process.

5. Acknowledgement

The authors would like to acknowledge the Directorate of Research and Public Services, Universitas Indonesia for the financial support as part of PITTA Research Grant in 2017.

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