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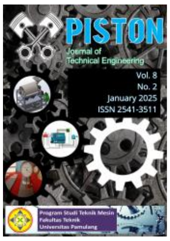

Analysis of Current Variations on Mechanical Properties and Microstructure of ASS 316L Welded Joints by TIG Welding

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Abstract: Stainless steel 316L pipe welding joints are widely used in industry, especially in the Bio-Medical field. In order to develop research on this field, the Gas Tungsten Arc Welding (GTAW) process was carried out on the butt joint of ASS 316L. In this study, the ASS 316L pipe of 89 mm (3.5 inches), a thickness of 2.6 mm, and a length of 100 mm was investigated. The effect of current variations of 30, 40, and 50A with shielding gas and Argon backing gas were analyzed. ER316L have been selected as filler metal for GTAW process. The results of microstructural observations for all currents showed the formation of dendritic and widmanstanten structures in the weld metal and austenitic phases in the base metal. The mechanical tests has been conducted to find out the ultimate tensile strength and and hardness as well as observations of the macro structure in the weld metal (WM), heat affected zone (HAZ), and base metal (BM) areas. Visual observation of the 40A current showed more stable surface and penetration results compared to the 30 and 50A currents. Observations of the macro structure were correlated with the results of visual observations of the 40A current, indicating good fusion and no defects exceeding the standard. The highest tensile strength test results were obtained in specimens with a current of 50A of 659 MPa, followed by a current of 40A of 651 MPa, and a current of 30A of 649.3 MPa. However, the highest elongation was found in specimens with a current of 40A, which was 45.3%, while specimens with currents of 30A and 50A had the same elongation value of 39.3%. The general distribution of hardness in the weld metal area was greater than in the heat affected zone and base metal areas.

Keywords: SS 316L, GTAW, Microstructures, Mechanical Properties.

Abstrak: *Sambungan las pipa stainless steel 316L banyak diaplikasikan dalam industri, khususnya di bidang biomedis. Untuk mendukung pengembangan riset di bidang ini, dilakukan proses pengelasan Gas Tungsten Arc Welding (GTAW) pada sambungan butt joint pipa ASS 316L. Penelitian ini menggunakan pipa ASS 316L berdiameter 89 mm (3,5 inci), ketebalan 2,6 mm, dan panjang 100 mm. Variasi arus pengelasan yang digunakan adalah 30, 40, dan 50 A, dengan gas pelindung dan backing gas berupa Argon. Filler metal yang digunakan adalah ER316L. Hasil pengamatan mikrostruktur menunjukkan adanya pembentukan struktur dendritik dan widmanstätten pada logam las, serta fasa austenitik pada logam induk. Pengujian mekanik meliputi uji tarik, uji kekerasan, serta pengamatan makrostruktur pada daerah logam las (WM), daerah terpengaruh panas (HAZ), dan logam induk (BM). Hasil pengamatan visual pada arus 40 A menunjukkan kualitas permukaan dan penetrasi yang lebih stabil dibandingkan arus 30 A dan 50 A. Hasil ini diperkuat oleh pengamatan makrostruktur yang menunjukkan fusi logam yang baik dan tidak terdapat cacat melebihi batas standar. Nilai kekuatan tarik tertinggi diperoleh pada arus 50 A sebesar 659 MPa, diikuti oleh arus 40 A sebesar 651 MPa, dan arus 30 A sebesar 649,3 MPa. Namun demikian, nilai elongasi tertinggi dicapai pada arus 40 A sebesar 45,3%, sementara arus 30 A dan 50 A menunjukkan nilai elongasi yang sama, yaitu 39,3%. Distribusi kekerasan menunjukkan bahwa nilai kekerasan tertinggi terdapat pada daerah logam las dibandingkan dengan HAZ dan BM.*

Kata kunci: *SS 316L, GTAW, Mikrostruktur, Sifat Mekanik.*

INTRODUCTION

Welding applications are still the main choice in the industrial world, especially in the Biomedical field. Welding joints with 316L type stainless steel are widely used, including at PT. BIOFARMA. The welding process is the connection of two or more materials by melting them using heat energy simultaneously with the characteristics of the same parent metal material or different parent metal materials. Welding parameters and welder capabilities are some of the many things to consider when planning a weld joint. The quality of the weld joint made can be influenced by these elements. The welding process, parameters must be carefully studied to obtain high-quality weld joints. This is done to prevent weld failure, which will ultimately reduce the strength of the weld joint itself.

Austenitic stainless steel (ASS) 316L is a type of material consisting of the main elements nickel (Ni), molybdenum (Mo) and chromium (Cr) which has corrosion-resistant properties so it is often used for metal joints using the welding process. ASS 316L series is a stainless steel that contains molybdenum (Mo). ASS 316L has better anti-corrosion properties compared to other alloy steels because it contains high chronium (16 to 18% Cr). Austenitic stainless steel 316L has a lower carbon content, compared to ASS 316. Welding parameters play an important role in the quality of the desired results [1].

Promud Kumar et al. studied the effect of welding current in TIG welding of 304L steel on microstructure, mechanical characteristic and temperature distribution. They discovered of TIG welded samples at different welding currents (20–120A) with constant voltage and welding speed have been investigated. The tensile fracture characteristics vary with the increase in current, showing brittle fracture at lower currents and ductile fracture at higher currents [2].

Subodh Kumar and A.S. Shahi investigated the effect of heat input on the microstructure and mechanical characteristics of gas tungsten arc welded 304 stainless steel (SS) joints. They discovered three combinations of heat input categorized as low heat (2.563 kJ/mm), medium heat (2.784 kJ/mm), and high heat (3.017 kJ/mm) [3]. Zhao et al. examined how driving forces affect weld pool flow and their effects utilizing the finite difference method. They discovered that as the peak current varies, the base current generates a periodic oscillation in the weld pool and weld ripples. They noted that the space between neighboring weld ripples is positively correlated with welding speed and the width of the weld pool, which diminishes as speed increases [4]. Fujii et al. investigated a novel GTAW method featuring ultra-depth of penetration, utilizing helium as an inert gas along with a minimal amount of oxidizing gas to manage the surface tension created by Marangoni convection. They studied the impact of O_2 and CO_2 levels in shielding gas on the shape of the weld pool in GTAW of 304L [5].

Based on the literature review conducted so far, it is believed that only a few efforts have been made in TIG welding of 316L stainless steel pipe to investigate the effects of GTAW current on macrostructure, microstructural, and mechanical properties.

METHODS

The chemical composition test of the specimen was carried out using the optical emission spectroscopy method of the Hitaci FM Expert machine with the aim of ensuring the conformity between the chemical composition content of the specimen and the reference. Table 1 shows the chemical composition of the test results from the specimen.

Table 1. Chemical compositions of ASS 316L

	Chemical Composition (%)							
	C	**Cr**	**Ni**	**Mo**	**Si**	**P**	**Mn**	**Cu**
ASS 316L (Test Result)	0.0309	17.0	12.9	3.14	0.408	0.0452	1.62	0.174
ASS 316L (AISI Standard)	0.03	16-18	10-14	2-3	1	0.04	2	1

Fig. 1 shows the welded specimen pattern of ASS 316 L pipe with dimensions of Ø3.5inch x 100mm and thickness of 2.6mm was made with a butt weld angle referring to the ISO 2553 standard [6]. The welding process using current variations of 30, 40, and 50A begins with the tack weld process on the specimen as shown in Fig 2. Tack welds are carried out to create temporary joints in the form of welding points so that they can hold the specimen from changing position during the welding process. The welding parameters used are listed in Table 2 for each specimen. The welded low carbon steel and stainless steel plates were then cut into several pieces to make test specimens. The plates were cut for each test specimen. The tensile test specimens were made according to ASTM E8M standard [7]. The tensile test specimens were made using a scrap machine. The manufacture of macro and micro photo hardness test specimens was carried out through a sanding and polishing process.

Table 2. Welding parameters

Parameters	Specimen 1	Specimen 2	Specimen 3
Current (A)	30	40	50
Tungsten	EWTH-2 Ø 2mm		
Shielding Gas	Argon 15 l/min		
Type of wire	ER 316 L		
Diameter of wire	1,6 mm		
Backing gas	Argon 10 l/min		
Dimension of specimen	Ø3,5inch x 100mm		
Welding position	1G		

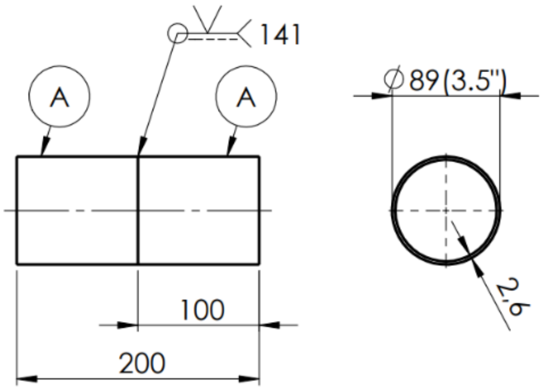

Figure 1. Test sample dimension

Figure 2. Test sample for tack weld

RESULT AND DISCUSSION

Table 3 shows the results of the welding process on the weld bead face and penetration (root). Visual analysis shows the differences in the shape and condition of the face and root of each current parameter. The results of the 30A current weld have a face that tends to be raised, and an unstable root, there are parts that do not penetrate, and the weld beads are not neatly arranged because the current is too small. The 40A current produces more stable and neat weld beads, and the penetration looks stable, indicating that the fusion has reached adequate depth and is continuous along the weld joint. The 50A current, the face tends to be concave and the penetration is too deep (excesses occur) listed in ISO 5817:2014 quality level B, excesses more than 3mm [8]. This indicates that the determination of the current is too large.

Table 3. Face and root at varying welding current 30, 40 and 50 A

Current	***Face***	***Root***
30A		

Current	***Face***	***Root***
40A		
50A		

Observation of the macro structure in fig. 3a, 30A current specimen, shows the presence of faces that arise and root penetration does not occur optimally, this indicates that the current used is too small. Fig. 3b. Macro structure of welding specimen with 40A current, it can be seen that the weld surface (face) shows results close to the standard. Penetration is quite good and not excessive, indicating sufficient fusion without over-penetration. Based on observations, the specimen with a current of 40A shows the results closest to the standard when compared to specimens welded with currents of 30A and 50A. Fig. 3c show macro structure of welding specimen with a current of 50A, it can be seen that the face is lower than the base metal and the penetration or root is too deep, this indicates that the current used is too large.

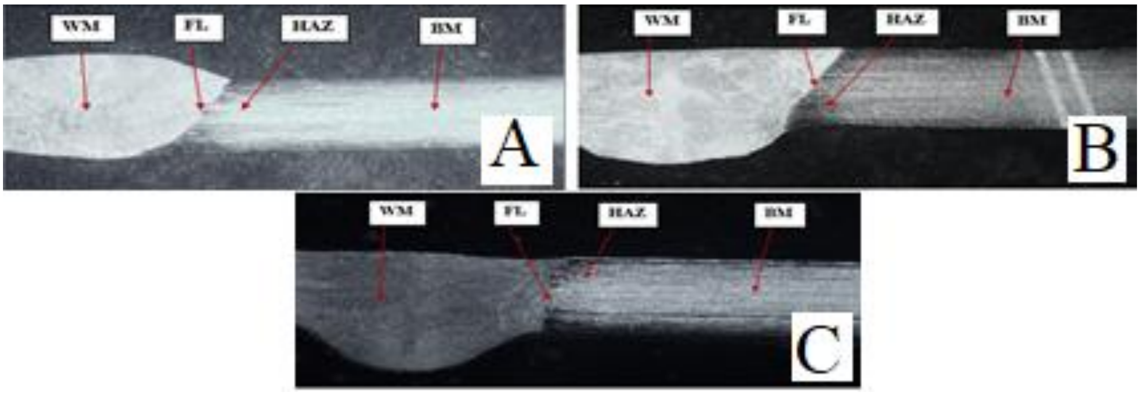

Figure 3. Macrostructures image of welding specimen at varying welding current a. 30 A, b. 40 A, and c. 50 A

Observation of the microstructure specimen at each current shows insignificant changes in the welding area. Observation of the microstructure of the welding results with currents of 30, 40 and 50A, Fig. 4 shows that there is a dendritic structure in the weld metal (WM) section. The dendritic structure in stainless steel is formed during the solidification process of the liquid metal. When the liquid stainless steel metal is cooled, small crystals are formed which become the center of crystallization. These crystals then grow to form a tree-like or dendritic structure [9] in the weld metal (WM) there is also a widmanstanten structure formed due to rapid cooling after welding, which causes the growth of long and slender grains in the filler metal [10]. In the Heat Affected Zone (HAZ), it can be seen that the fusion line (FL) in Fig. 4 welding with a current of 40A is better than welding with a current of 30 and 50A. This is due to finer grains, which indicate more optimal heat control during the welding process. The fine grain structure in the HAZ indicates that the temperature and cooling rate are in the right range, reducing the risk of cracking and improving the mechanical properties of the welded joint. In the base metal (BM) section, there is no change in the microstructure of the structure found in (BM), namely the Austenite matrix. This is because the base metal does not experience heating at temperatures above the transformation temperature, so that its structure remains stable and does not experience phase changes or grain enlargement. The base metal maintains its original mechanical properties because it is not affected by the welding heat directly.

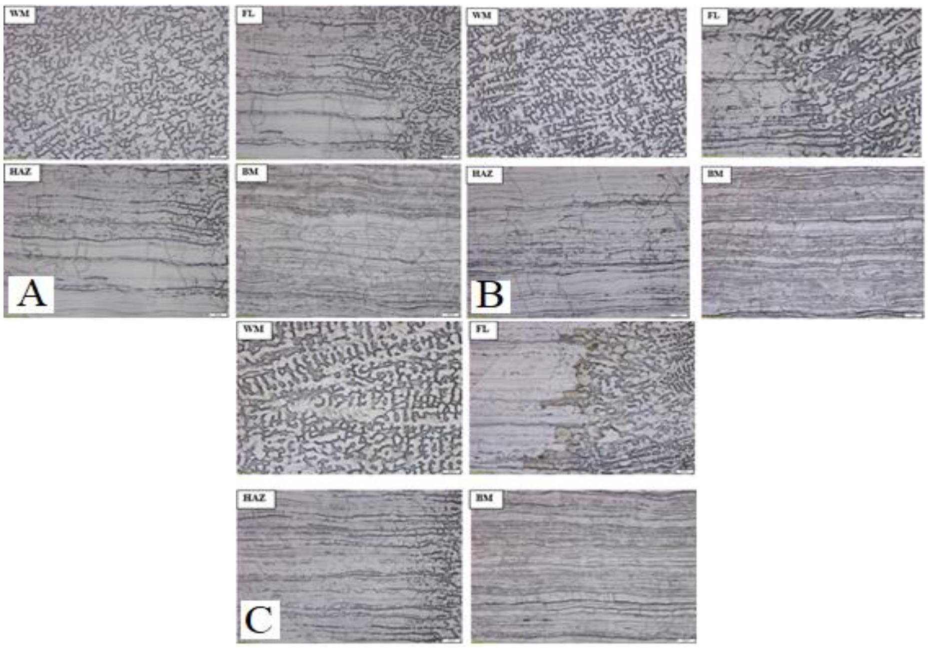

Figure 4. Microstructure of welding speciemn on base metal (BM), weld metal (WM), fussion line (FL) and heat affected zone (HAZ) for a. 30 A b. 40 A, and c. 50 A

Tensile testing was carried out for each specimen at each current variation with the test standard used, namely ASTM E8M. Figure 5 shows the chart of tensile strength and yield strength of welding specimen which is an increase in tensile and yield strength for each increase in current. It shows the lowest tensile strength at a current of 30A of 649.3 MPa and a yield strength of 447.4 MPa. The tensile strength at 40A current is 651.6 MPa and the yield strength is 458 MPa, while the highest tensile strength is at 50A current of 659 MPa and the yield strength is 484 MPa. However, the highest elongation is found in the specimen with a current of 40A, which is 45.3%, while the specimens with a current of 30A and 50A have the same elongation value of 39.3%. Overall, the fault position is indicated to be in an area of weldmetal as shown in Fig. 6. The test results also indicated that the all specimens failed in weldment region. The failure that occurred in all specimens was britlle, indicating that the material was still capable of withstanding continuous loads before experiencing significant due to rapid cooling after welding [10].

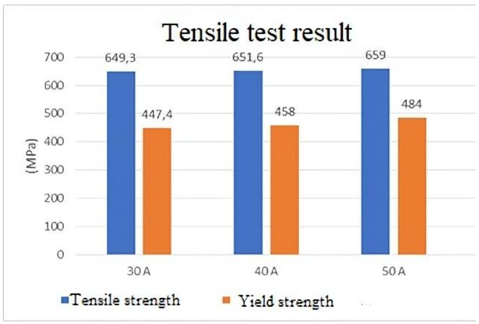

Figure 5. Tensile and yield strength of the welding specimen at varying welding current 30, 40 and 50 A

Figure 6. Tensile test result at varying welding current 30, 40 and 50 A

The hardness test data in Fig. 7 shows that the highest average hardness value was obtained in the WM (weld metal) area of the 40A welding specimen of 200.17 HV, while the lowest average hardness was obtained in the base metal area of the 50A welding specimen of 148.35 HV. The weld metal area has a larger hardness distribution compared to the HAZ and base metal (BM) areas. The hardness of the weld metal (WM) is higher than the heat affected zone (HAZ) and base metal (BM). This is due to the rapid solidification process of the liquid phase during the welding process.

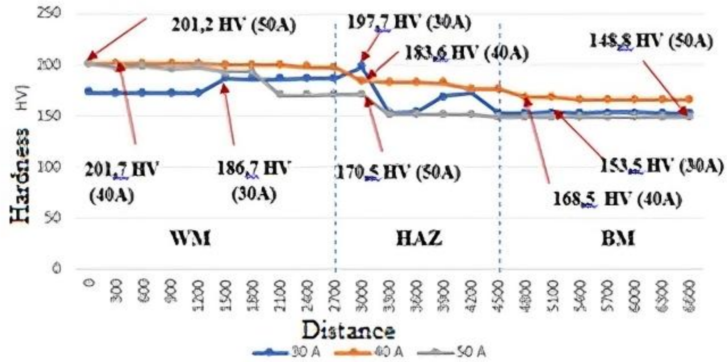

Figure 7. Tensile test result at varying welding current 30, 40 and 50 A

CONCLUSIONS

Based on the research data, it can be concluded that:

1. The results of visual observation of 40A current show more stable surface and penetration results compared to 30 and 50A currents, and there are minimal welding defects. The results of macro structure observations also correlate with the results of visual observations, including 40A current, showing good fusion and no minimal defects.
2. The results of microstructure observations for all currents did not show any significant differences, namely the formation of dendritic and widmanstanten structures in the weld metal due to the cooling rate when the welding process was stopped and the austenitic phase in the base metal.
3. The highest tensile strength test results were obtained in specimens with a 50A current of 659 MPa, followed by a 40A current of 651 MPa, and a 30A current of 649.3 MPa. However, the highest elongation was found in specimens with a 40A current of 45.3%, while specimens with 30A and 50A currents had the same elongation value of 39.3%.
4. The highest average hardness test results were obtained in the WM (weld metal) area of the 40A welding specimen of 200.17 HV, while the smallest average hardness was obtained in the base metal area of the 50A welding specimen of 148.35 HV. The general distribution of hardness in the WM (weld metal) area is greater than the heat affected zone (HAZ) and base metal (BM) areas.

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REFERENCES

[1] Riswanda, A. D. Saragih, H. Kadir, and W. A. Irawan, "The Effect of GTAW Process Parameters for Dissimilar Metals Steel Armour and ASS 304L Using ER316L Filler on Mechanical Properties," in *Proceedings of the 4th International Conference on Experimental and Computational Mechanics in Engineering*, Springer Nature Singapore, 2024. doi: 10.1007/978-981-99-7495-5_64.

[2] P. Kumar, M. Murugan, A. Saravanan, A. K. Singh, A. N. Sinha, and C. K. Hirwani, "Effect of welding current in TIG welding 304L steel on temperature distribution, microstructure and mechanical properties," *J. Brazilian Soc. Mech. Sci. Eng.*, vol. 43, no. 7, p. 1p, Dec. 2024, doi: 10.1007/s40430-021-03082-6.

[3] S. Kumar and A. S. Shahi, “Effect of heat input on the microstructure and mechanical properties of gas tungsten arc welded AISI 304 stainless steel joints,” *Mater. Des.*, vol. 32, no. 6, pp. 3617–3623, 2011, doi: 10.1016/j.matdes.2011.02.017.

[4] G. Zhao, J. Du, Z. Wei, R. Geng, and S. Xu, “Numerical analysis of arc driving forces and temperature distribution in pulsed TIG welding,” *J. Brazilian Soc. Mech. Sci. Eng.*, vol. 41, no. 1, p. 60, 2019, doi: 10.1007/s40430-018-1563-0.

[5] H. Fujii, T. Sato, S. Lu, and K. Nogi, “Development of an advanced A-TIG (AA-TIG) welding method by control of Marangoni convection,” *Mater. Sci. Eng. A*, vol. 495, no. 1, pp. 296–303, 2008, doi: 10.1016/j.msea.2007.10.116.

[6] International Organization for Standardization, “ISO 2553:2024 – Welding and allied processes -- Symbolic representation on drawings -- Welded joints.” International Organization for Standardization, 2024.

[7] ASTM International, *Annual Book of ASTM Standards: Material Test Methods and Analytical Procedures*, vol. ASTM E8. West Conshohocken, PA: ASTM International, 1998.

[8] International Organization for Standardization, “ISO 5817:2014 – Welding — Fusion-Welded Joints in Steel, Nickel, Titanium and Their Alloys (Beam Welding Excluded) — Quality Levels for Imperfections.” International Organization for Standardization, Geneva, Switzerland, pp. 5–12, 2014.

[9] S. Dépinoy, “Influence of solidification conditions on chemical heterogeneities and dislocations patterning in additively manufactured 316L stainless steel,” *Materialia*, vol. 24, p. 101472, 2022, doi: https://doi.org/10.1016/j.mtla.2022.101472.

[10] T. Lyman and H. E. Boyer, Eds., *Metals Handbook, Volume 7: Atlas of Microstructures of Industrial Alloys*, 8th ed. Metals Park, OH: American Society for Metals, 1972.