IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Effect of welding electrode variation on dissimilar metal weld of 316l stainless steel and steel ST41

To cite this article: I A Pahlawan *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1010** 012001

Effect of welding electrode variation on dissimilar metal weld of 316l stainless steel and steel ST41

I A Pahlawan[1], A A Arifin[2], E Marliana[3], H Irawan[2]

[1]Department of Mechanical Engineering, Sapienza University of Rome, Italy
[2]Department of Mechanical Engineering, Institut Teknologi Adhi Tama Surabaya, Indonesia
[3]Department of Mechanical Engineering, Universitas 17 Agustus 1945 Surabaya, Indonesia

pahlawan.1757957@studenti.uniroma1.it

Abstract. The propeller shaft is part of the ship which transmitting rotation from engine to propeller. The shaft is also used in small-medium size of fisherman boat. In order to reduce the cost of production, dissimilar metal bases are used by joining Steel ST41 and 316L Stainless Steel in process. This research was conducted to analyze effect of welding electrode towards tensile strength, macrostructure, and microstructure of Steel ST41 and 316L Stainless Steel welded metal. Two variations of electrode that used in this paper were E309-L and E6013 with Shielded Metal Arc Welding process (SMAW). The other parameter such as current was set at 80 A and voltage was set at 20 V with 20 mm/min welding travel speed. The results of tensile test show average tensile strength max (σ_{max}) of E309-L and E6013 electrode were 581,42 MPa and 599,24 MPa respectively. These results show that welding process is increasing the maximum tensile strength from base material strength level. The microstructure test interpretation shows E309-L electrode has lower possibility to create delta ferrite in HAZ (Heat Affected Zone) rather than E6013 electrode. This means welding process with E6013 tends to have lower corrosion resistance.

1. Introduction

Sea water environment is contained NaCl as catalyst which could causes corrosion for some material, especially steel. It is important to use material with high corrosion resistance for ship components that have any direct intact to sea water. In the recent year stainless steel capable to protect the material from any corrosion because of its oxide layer. On the other hand, Stainless Steel is more expensive than carbon common steel in use. It leads to developing new dissimilar joints which has the quality of stainless steel at corrosion resistance and has low material cost [1]. In this case, small-medium size boat usually has stainless steel part at tip of shaft, due to the application of propeller inside the sea water. The quality of dissimilar joint depends on certain parameter, for example on joining configuration [2]. The other important parameter is welding position [3].

The welding parameter could leads heterogeneity in microstructure and degradation of material strength in period of time [4]. The consideration of fatigue in period of time is also important to achieve good quality of dissimilar joint [5]. The other parameter that needs to take into account is groove. Narrower groove means higher tensile strength that could be achieved [6]. In microstructure point of view, δ-Ferrite structure is important due to its contribution for preventing hot cracking after welding operation [7]. The formation of δ-Ferrite is affected by cooling rate after welding process [8].

Phase transformation also could alter the mechanical properties of material [9]. The other parameter is heat input of welding operation because it could determine the size of weld pool [10]. The type of welding technique also become a consideration for improving the quality of mechanical properties [11].

In the previous study by Hesham, the metals are CK45 and Stainless Steel 316L. On microstructure result, it showed that dissimilar joining process tend to create more δ-Ferrite structure. This condition could lead to reducing internal corrosion resistance. In comparison, this research was conducted by variating type of electrode E309-L and E6013 on Dissimilar Weld Metal (DWS) as an alternative to cut highly cost of fully austenite or clad joint in previous study comparison. The expected results of experiment are tensile strength, macrostructure, and microstructure of Steel ST41 and 316L Stainless Steel welded metal. The objective of this research is to analyze the correlation of electrode variation towards mechanical properties, macrostructure, and microstructure of material.

2. Materials and Methods

2.1 Materials

The materials used in this research were round bar of ST41 and 316L Stainless Steel with 22,225 mm (7/8 in) diameter. Welding groove was designed with 60^{o} full circle. Fabrication of specimens was done by lathe machine. Chamfer in each material was designed to be 30^{o}. The tip of chamfer was 1 mm in diameter. The weld was totally performed by certificated welder on lathe machine to perform good weld quality and to reduce deformation of bars. For detailed chemical composition and mechanical properties of base metals and weld metals (shown at Table 1).

Electrodes which used in this research were commercially by E6013 ENKA brand and NSN 309L Nikko Steel brand with same 2.6 mm diameter. Both of them were performed by same SMAW machine and same weld parameter with DCEN polarity, 80A current and 120 mm/min average travel speed to maintain heat input in range 800 J/mm. Welding process is performed until the groove was fully loaded. Then the process was continued by manufacturing it into ready test specimen. For detailed welding record are note in Table 2 and Table 3.

Table 1. The Composition of SGD 400-D (ST 41) and AISI 316L base material with E6013 and E309L weld material

Chemical Composition %									Mechanical Properties	
									Tensile Strength, MPa	
Base metals	C	Si	Mn	S	P	Cr	Ni	Mo	Ult.	Yield
ST 41	0,146	0,187	0,589	0,034	0,015	-	-	-	316-550	250
AISI 316L	0,016	0,53	1,76	0,02	0,038	16,73	10,04	2,02	515	205
Weld metals	C	Si	Mn	S	P	Cr	Ni	Mo	Ult.	Yield
E6013	<0,2	0,25	<1,2	0,016	0,012	<0,2	-	<0,3	527	458
NSN-309L	0,015	0,40	2,0	0,010	0,012	23,50	13,5	0,25	590	400

Table 2. Record parameter for E 6013 electrode specimen

Layer Level	*Welding Process*	*Filler metal*		*Current*		*Voltage*	*Travel Speed*	*Heat Input*
		Class	*Ø size*	*Type*	A	V	mm/min	J/mm
1	SMAW	E 6013	2,6	DCEN	80	20	120	800
2	SMAW	E 6013	2,6	DCEN	80	20	120	800
3	SMAW	E 6013	2,6	DCEN	80	20	120	800
4	SMAW	E 6013	2,6	DCEN	80	20	100	960
5	SMAW	E 6013	2,6	DCEN	80	20	100	960

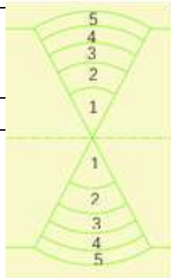
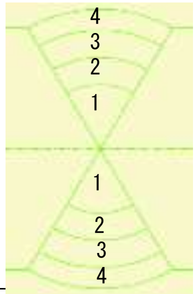


Table 3. Record parameter for of E309L electrode specimen

ayer Level	*Welding Process*	*Filler metal*		*Current*		*Voltage*	*Travel Speed*	*Heat Input*
		Class	*Ø size*	*Type*	A	V	mm/min	J/mm
1	SMAW	E309L	2,6	DCEN	80	20	120	800
2	SMAW	E309L	2,6	DCEN	80	20	120	800
3	SMAW	E309L	2,6	DCEN	80	20	120	800
4	SMAW	E309L	2,6	DCEN	80	20	100	960



2.2 Specimen Testing Methods

Tensile Test was applied for evaluating the strength of material with respect to shaft condition during applied longitudinal force. Round bar specimen test was lathed for specific dimension required (ASTM E8). The standard of Inner diameter (D) is 12.5 +- 0.2 mm, Gage length (G) is 62.5 +- 0.1 mm, radius is min 10 mm, and Length of reduced section is 75 mm are represented in **Figure 1**. Tensile test was done by using common universal hydraulic machine, with quasi static speed. Yield point can be achieved by calculating with offset method 0,2 % of L_{max}. Next thing to do was measuring overall dimension before and after specimen was tested. By using equation below, stress and strain can be calculated by assigning P with load (N), A_0 with cross section area (mm^2), L_0 with initial length (mm^2), and L_1 with final length (mm^2).

$$\sigma_{eng} = \frac{P}{A_0}\ [MPa] \tag{1}$$

$$\varepsilon_{eng} = \frac{L_1 - L_0}{L_0} \times 100\%\ [\%] \tag{2}$$

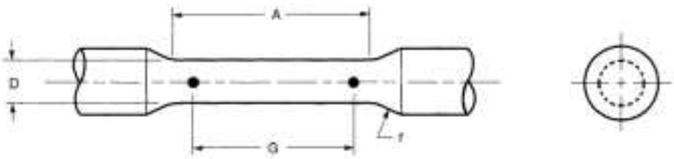


Figure 1. Round bar test specimen illustration

Metallography test were performed to analyze dilution or penetration depth and weld area of specimen. The specimen represented by 1 specimen on macro and 1 specimen on. Preparation is initiated by cutting specimen parallel to longitudinal line into two pieces. One side for macrograph and another one for micrograph. Specimen preparation were supported by mounting mold of resin to make better handgrip. The parallel surface was grinded and polished with several step grid to make surface smoothness up to 1-0,05 micron. Combination etching liquid for dissimilar material between stainless steel and carbon steel, Ethanol 95%:NHO_3:HCl with ratio 1:1:½ were applied for short duration. The etched surface was cleaned by water and ethanol then dried. The picture was taken by common proportionate camera. CAD software was used to determine the area of weld and measuring specific area, and to calculate weld dilution with Equation 3.

$$\%Dilution\ (area) = \frac{Fused\ Base\ and\ Weld\ Metal\ Area}{Weld\ Area + Fused\ Base\ and\ Weld\ Metal\ Area} \times 100\ \% \quad (3)$$

The welding process is performed to achieve minimum standard dilution percentage between 10-20 % with welding parameter current 80A and electrode rod diameter 2.6 mm, neglecting some minor perturbations from environment.

Weld dissimilar material will lead to some specific problem occur, such as altering austenite structure into ferrite structure and could degrading quality of mechanical properties and corrosion resistance of stainless steel. This phenomenon is occurred in range of temperature between 600-900°C, where Chromium element easily attracted to grain boundary and lead to brittle carbide precipitation [12]. The emergence of δ-Ferrite certainly will reduce the ductility and the potential toughness. Meanwhile, austenite/ferrite bonding will become a place that has higher possibility to form a carbide participation $M_{23}C_6$ and sigma phase where embrittlement agent arises in stainless steel.

3. Discussions

3.1 Tensile test

The requirement for tensile test is the result of welding specimen tensile strength should not in lower level than minimum tensile strength of the base metal. On other hand, the crack has to be located in the weakest base metal, which for this case was on ST41 with minimum tensile strength (σ_u) 316 MPa. The lowest tensile strength test from 4 specimens result is 524 MPa. These results were already surpassing the minimum tensile strength (σ_u) acceptance of requirement as shown in **Figure 2**. In the Stress-Strain diagram **Figure 2**, the yield strength (σ_y) minimum from 4 specimens is 423,97 MPa (*by using offset method*), which means already surpassing the minimum base metal yield strength of 205 MPa. The initiation of necking and fracture was located in base metal of ST41 closed to Heat Affected Zone as shown in **Figure 3**.

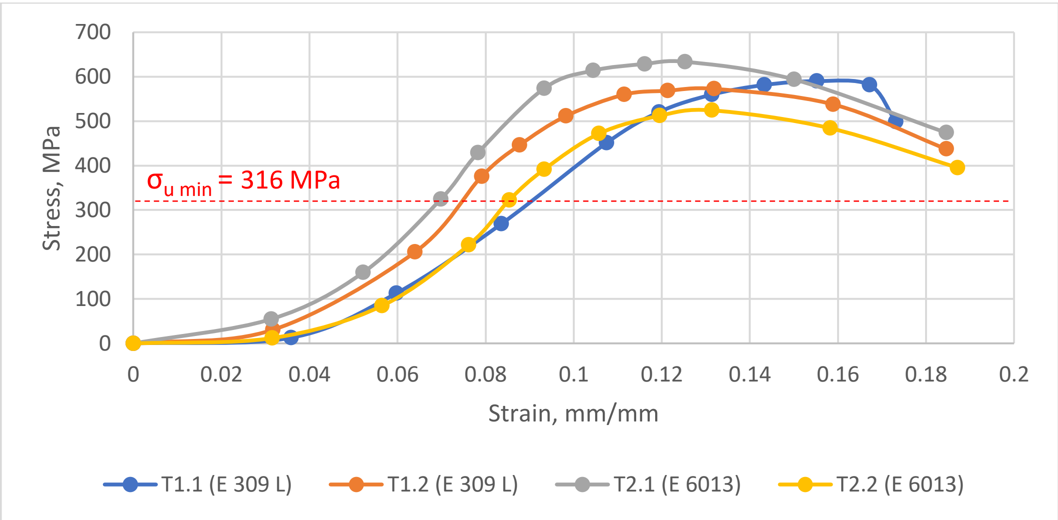


Figure 2. Stress – Strain engineering graph for each specimen tensile test result.

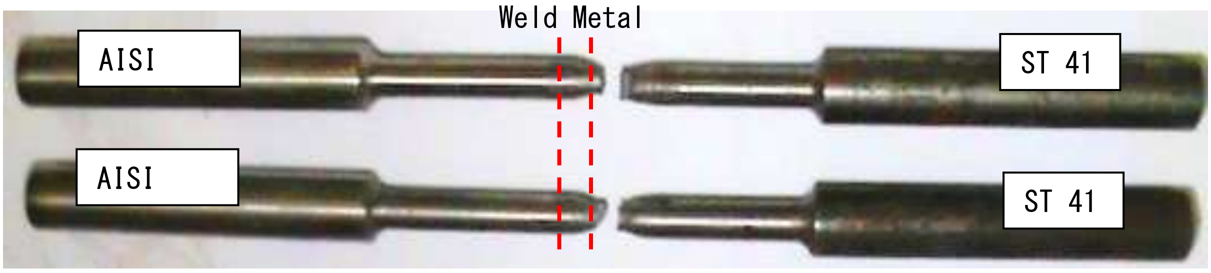


Figure 3. Tensile test specimen after tensile force applied.

3.2 Macro Test

Welded joint using E6013 electrode rod deposits more layer due to unstable puddle and it tends to create spatter spark during weld processes. It needs more weld layer and duration to fulfill complete grove. This phenomenon is affecting higher heat input and as a result is wider Heat Affected Zone (HAZ). Meanwhile, using E309L electrode rod creates more stable puddle and reduce duration of weld processes. It was filling groove faster even with the same parameter as before. It has lower heat input and followed by narrower Heat affected Zone (HAZ). Macrostructure were evaluated by calculate dilution area resulted from using E309L as shown in **Figure 4** and E6013 as shown in **Figure 5**, were up to 15,7% and 16,6% respectively. This result is fulfilling the criterion standard of dilution area 10 - 20 %. Raw results **Figure 4 (a)** and **Figure 5 (a)** were plotted to CAD software to measure the dilution distance as presented in **Figure 4 (b)** and **Figure 5 (b)**.

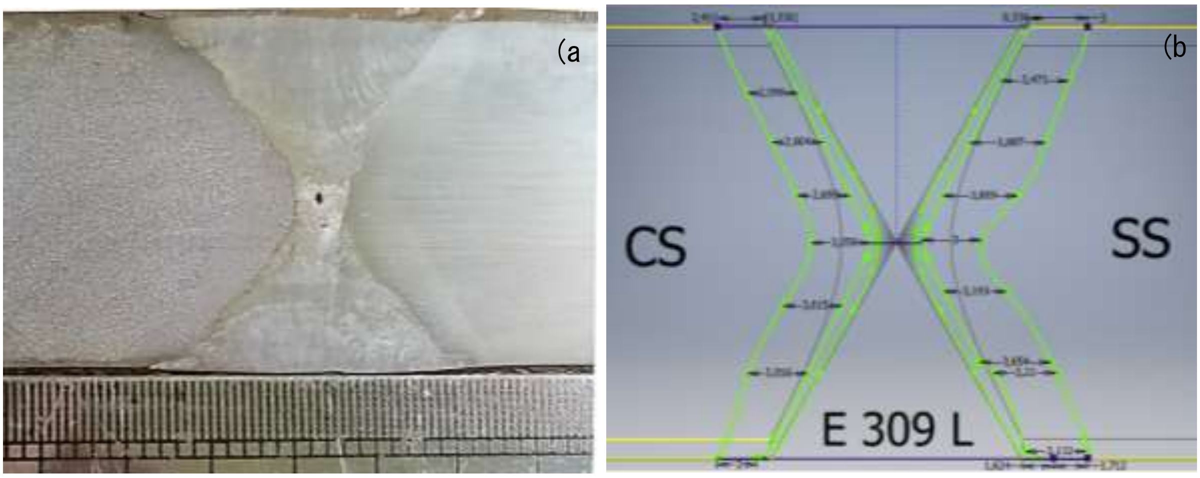


Figure 4. Macrostructure of joint ST41 and AISI 316L with 309L rod (a) raw image; (b) re-measuring groove and dilution.

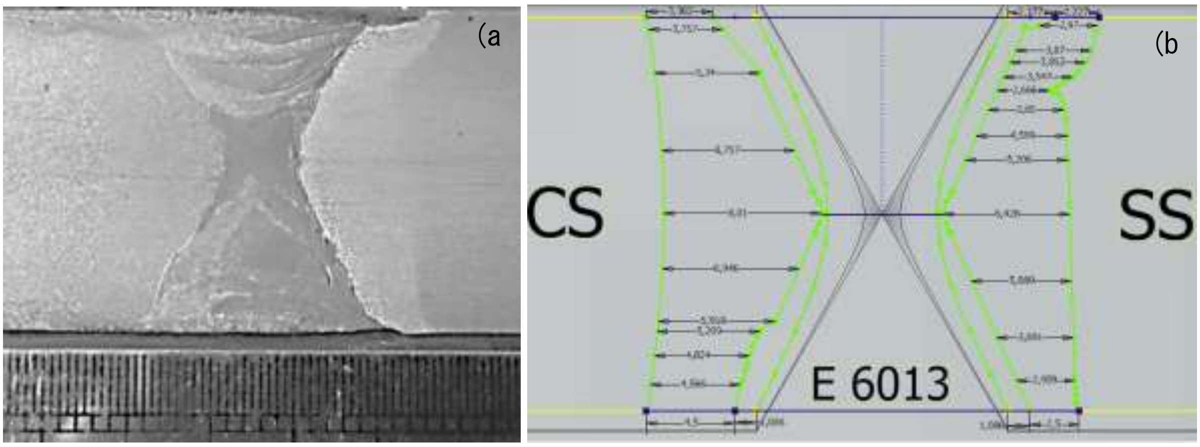


Figure 5. Macrostructure of joint ST41 and AISI 316L with E6013 rod (a) raw image; (b) re-measuring groove and dilution.

3.4 Micro Test

By using E309L electrode, could reduce the carbide participation risk and ferrite transformation in microstructure austenite base metal 316L as shown in **Figure 6(a)** and **(b)**, due to its low amount of carbon element, lower heat input and rapid deposit of weld. Relatively low amount of δ-Ferrite cluster (black sphere) were located only near the fusion line. Meanwhile by using E6013 electrode, could increase susceptible of carbide participation and ferrite transformation in HAZ of stainless steel AISI 316L. Furthermore, it could lead to high risk of carbide participation followed by intergranular corrosion, where shown in microstructure **Figure 7(a)** and **(b)**. It has higher amount of δ-Ferrite cluster. Meanwhile, microstructure in HAZ of Carbon Steel ST41 have no significantly affected by electrode used. Yet, grease or another protection are good enough to be alternative solution to give lower risk of corrosion and reduce the possibility to intergranular corrosion rise.

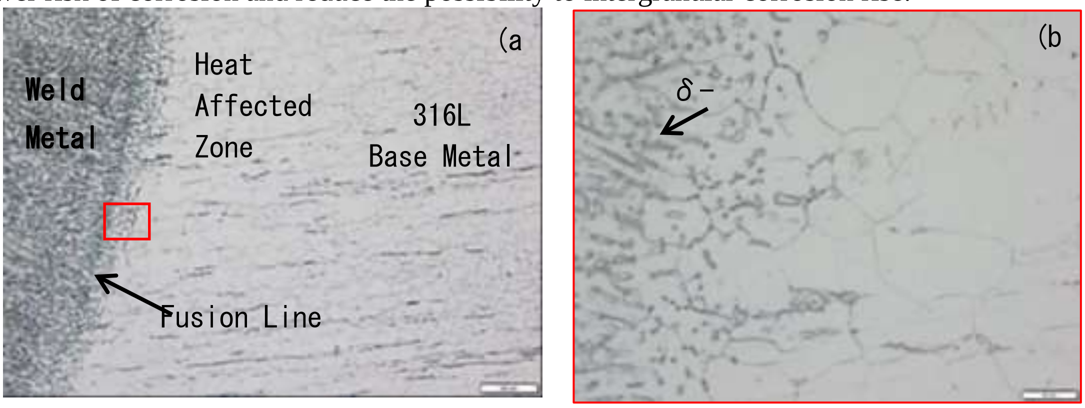


Figure 6. Microstructure of E309L weld metal to AISI 316L base metal magnification (a) 100 x (b) 500 x

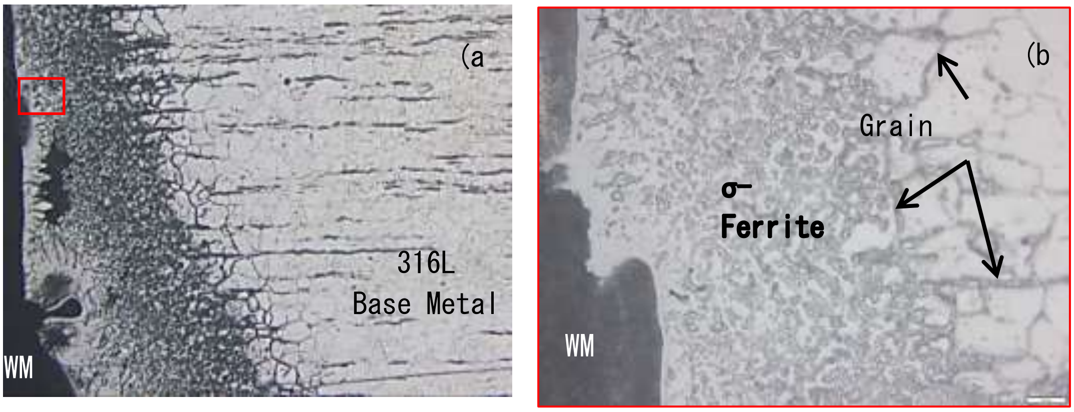


Figure 7. Microstructure of E6013 weld metal to AISI 316L base metal magnification (a) 100 x (b) 500 x

4. Conclusions

The results of tensile test for both variations of electrode are on higher level of base material ultimate tensile strength. This means by doing dissimilar joint of ST41 and 316 Stainless Steel with E6013 and E309L is increasing the quality of ultimate strength of material. Although, the disadvantage of using E6013 electrode is wide Heat Affected Zone (HAZ). It can decrease the mechanical properties of materials at some points. In term of dilution percentage, E6013 has higher result than E309L. This means welding process with E6013 has better penetration to base metal which can lead to decreasing probability of occurring defect of porosity. On microstructure result, it shows that joining process with E6013 tend to create more δ-Ferrite structure. This condition could lead to reducing internal corrosion resistance.

5. References

[1] Santoso W, Widodo EWR, Kuswanto A, et al. Analisis Kuat Arus, Jenis Logam Pengisi, dan Jenis Kampuh Las Terhadap Kekuatan Tarik dan Kekerasan Dissimilar Welding dengan Gas Tungsten Arc Welding (GTAW). *J Tek Mesin Inst Teknol padang* 2018; 8: 2–6.

[2] Rajput SK, Kumar A, Tripathi SS, et al. Investigation of microstructural behavior and mechanical properties of dissimilar weld joints of austenitic-ferritic stainless steel. *Mater Today Proc* 2020; 25: 778–784.

[3] Advaith V, Vaisikan A, Thirumalini S, et al. Comparative studies on pulsed GTAW and AGTAW on dissimilar alloy C-22 and AISI 316L weldments. *Mater Today Proc* 2020; 1–10.

[4] Awale DD, Ballal AR, Thawre MM. Dissimilar weld joints of P91 and 316LN for power plants Applications-A review. *Mater Today Proc*. Epub ahead of print 2020. DOI: 10.1016/j.matpr.2020.05.003.

[5] Wang WK, Zhang JX, Zhong J. Comparative evaluation of LCF behavior of dissimilar steels and welds in an ultra-supercritical turbine rotor at 280 °C. *Int J Fatigue* 2020; 139: 105771.

[6] Wahyu E, Widodo R, Setyowati VA, et al. PENGELASAN LOGAM TIDAK SEJENIS MATERIAL STAINLESS STEEL 304L DAN BAJA AISI 1040 DENGAN GAS TUNGSTEN ARC WELDING. 327–332.

[7] Setyowati VA. Pengaruh Pengelasan TIG pada Stainless Steel 304 dan 304L terhadap Sifat Mekanik, Karakterisasi XRD, dan EDX sebagai Material Pressure Vessel. *J Tek Mesin* 2011; 7: 2011.

[8] Wei P, Li H, Liu J, et al. The effect of water environment on microstructural characteristics, compositional heterogeneity and microhardness distribution of 16Mn/304L dissimilar welded joints. *J Manuf Process* 2020; 56: 417–427.

[9] Marliana E. Analisa Pengaruh Perubahan Fasa Terhadap Konstanta Pada Coil Spring Shape

Memory Alloy (SMA). 2020; 7: 9–16.
[10] Setyowati VA, Suheni S. Variasi Arus Dan Sudut Pengelasan Pada Material Austenitic Stainless Steel 304 Terhadap Kekuatan Tarik Dan Strukturmakro. *J IPTEK* 2016; 20: 29.
[11] Yelamasetti B, Rajyalakshmi G. Effect of TIG, pulsed TIG and Interpulse TIG welding techniques on weld strength of dissimilar joints between Monel 400 and AISI 316. *Mater Today Proc* 2019; 19: 755–760.
[12] Hesam Pouraliakbar, M. H. Designing of CK45 Carbon Steel and AISI 304 Stainless Steel Dissimilar Welds. *Materials Research* 2014; 106-114.