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Effect of Temperature Variation PWHT Dissimilar Welding Low Carbon Steel ASTM A36 with ASTM A240 Type 316L

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Abstract

ASTM A36 low carbon steel is steel commonly used in construction, and the austenitic stainless steel 316L series is stainless steel with good corrosion resistance. Joining two dissimilar metals is unavoidable because it can provide good mechanical properties and resist corrosion at a low cost. This study studied the effect of variations in post-welding heating process temperature (PWHT) on mechanical properties and microstructure by shield metal arc welding (SMAW) low carbon steel ASTM A36 with ASTM A240 type 316L with a thickness of 6 mm with a single V connection and using an E308L-electrode. 16. The PWHT process was carried out to improve the weld results with variations in heating temperatures of 400, 600, and 900˚C with a holding time of 1 hour with 15% dromos quenching media. Testing mechanical properties includes hardness test using micro Vickers method on low carbon steel base metal, HAZ, weld metal, HAZ, and stainless steel base metal and impact test using Charpy method. Optical microscopes were used to study the microstructure of the area of the base metal, HAZ, and weld metal viewed using a laser scanning microscope. The test results show that the highest average hardness value in the weld metal area is in the specimen without PWHT with a value of 124.96 HV and samples with a PWHT temperature of 400˚C on the weld metal 121.63 HV and the lowest in the PWHT specimen 900˚C 76.17 HV. in the HAZ 316L area. The hardness value of the weld metal without PWHT and PWHT indicates that the hardness value is higher than the two-parent metals. While the impact test with PWHT specimens at 400˚C had higher impact energy than specimens without PWHT by 6.50%, and the lowest was 16.26% at the optimum temperature of 900˚C, the shape of the samples showed ductile cracks.

Keywords: Welding of dissimilar metals, post-welding heat treatment, SMAW welding, impact test

1. Introduction

The connection of materials with the welding method is a method of joining similar or different metals that has been widely applied. One of the challenges in the field of welding is the welding of different metals. This challenge is more difficult than similar welding due to differences in hardness, toughness, and physical and chemical composition of the parent metal [1, 2]. In today's industrial world, welding applications for dissimilar metals have been widely used, such as in marine, automotive, and power plants. Changes in microstructure and compositional gradients can affect changes in the physical properties and chemical compositions of welded joints of dissimilar metals [3]. Accordingly, large industries are now maximizing the properties of materials and compositions to obtain high-quality products at low operating costs by using dissimilar metal joint to obtain high-quality products [3, 4, 5].

Post-welding heating (PWHT) aims to eliminate residual stresses, make the grains finer, increase corrosion resistance, and reduce hardness to obtain plastic and tensile mechanical properties [3, 6]. Residual stress in the weld is affected by heat input, and this can lead to embrittlement, decreased weld strength, and low corrosion resistance [6, 7]. Heat treatment to remove residual stresses is mostly carried out below the critical temperature and n in the crucial temperature [6]. In recent years, several experiments have been carried out on the effect of PWHT on welds [3, 6, 7]. Variation of holding time 1 hour, 2 hours, and 3 hours temperature 550˚C PWHT process welding different metals ST 37 and AISI 304, the value of hardness without PWHT was higher after PWHT 168.22 HVN and 157.03 [8]. Another study describes variations in temperature of 450˚C and 1100˚C with different holding times. The highest hardness value of 238.5 HV was obtained from PWHT welding specimens of 450˚C for 4 hours having good weld quality [9].

Setiawan et al. studied the effect of temperature variations of 450, 550, and 650˚C for 3 hours of PWHT process on toughness and corrosion resistance of ASTM 252 material. That the optimum value of toughness is achieved at a temperature of 550˚C [10]. Sadeghi et al. observed the effect of temperature variations at 480, 560, 620˚C, and 680˚C PWHT of different metal joints of A537CL1 pressure vessel steel and A321 austenite steel,

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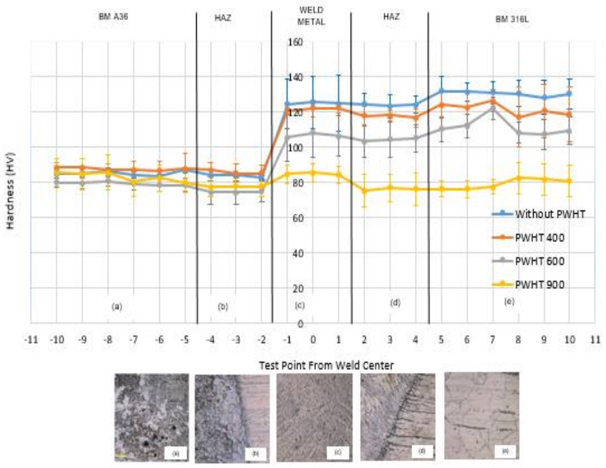
Table 1. Chemical composition of weld metal and electrode (%wt)

Element	C	Ni	Cr	Mo	Mn	Si	P	S	Cu	Fe
316L	0.03	10-14	16-18	2-3	2	0.75	0.045	0.03	-	Bal.
A36	0.26	-	-	-	-	0.04	0.04	0.05	-	Bal.
E308L-16	0.04	9-11	18-21	0.75	0.5-2.5	-	-	-	-	Bal.

they found that PWHT had no significant effect on the microstructure at other joint areas and the value of hardness and tensile strength decreased [6]. Based on those research, this paper aims to evaluate the effect of temperature variations of PWHT 400, 600, and 900˚C on the mechanical properties of hardness, impact, and microstructure tests of welded metal joints of different metals ASTM A36 and ASTM A240 type 316L using filler metal.

2. Research Method

This study uses an experimental method, A36 low carbon steel plate material with 316L stainless steel plate with a thickness of 6 mm, single V connection. SMAW welding current 70 A with reverse polarity with a 0.59 kJ/mm heat input. Electrodes E308L-16 and 2.6 mm in diameter. The chemical composition of the base metal and electrodes is shown in Table 1. After welding the specimen in the Non-Destructive Test, the next step is to make a specimen size 6 mm x 11 mm x 55mm. Mechanical properties are tested in two parts of the specimen, namely, without PWHT and PWHT. PWHT samples with temperatures of 400˚C, 600˚C, and 900˚C using a Thermo Scientific furnace, holding time of 1 hour, and quenching media of 15% dromus. The specimens were then prepared for hardness and impact tests. Samples for microstructure were first sanded with grit 400, 800, 1000, 1500, 2000, and 5000. Then, carbon steel parts were etched with 2% nital, and weld metal parts and stainless steel parent metal were etched with glycergia etching reagent. (10 ml HNO3, 20 ml HCL, and 30 ml glycerin). Hardness test on the second part of the base metal, HAZ, and weld metal using the Vickers method Mitec type 402MVDS-Y, load 0.5 Kgf and dwell time 10 seconds. The impact test specimen with a standard sub-size size of 55 mm x 10 mm x 55 mm refers to the ASTM E23 standard with the Charpy impact test method, and the machine used Impact Testing type MJB-W300B with a load of 300J.



(a) BM A36,(b) HAZ A36, (c) Weld Metal, (d) HAZ 316L, (d) BM 316L

Figure 1. The distribution of hardness of the weld metal E308L-16 and the microstructure without treatment

3. Results and Discussion

3.1. Hardness

This study aims to analyze the hardness profile and microstructural changes in welded joints between austenitic stainless steel and low carbon steel after post-weld heat treatment (PWHT). The hardness test profile looks like Fig. 1. The results indicate that the hardness profile distribution of the welding metal differs from that of the filler metal E308L-16. Hardness tests using the Vickers microhardness method show an increase in hardness from the base metal to the weld metal for both specimens without PWHT and with PWHT. The highest weld metal hardness in the sample without PWHT was 124.96 HV, while the lowest weld metal hardness in the 900˚C PWHT specimen was 85.01 HV.

The distribution of hardness values in each treatment shows that the average hardness value of the weld specimen without PWHT is higher than that of the treated samples in all test areas. Changes in PWHT temperature resulted in hardness degradation in the base metal, heat-affected zone (HAZ), and weld metal. Based on the hardness profile graph, the weld metal shows a higher hardness value than the base metal and HAZ. The increase in weld metal hardness is associated with a smoother microstructure and the absence of chromium carbide formation. Research conducted by [12, 13] also indicates that PWHT affects the hardness distribution and microstructure in welded joints between austenitic stainless steel and low-carbon steel. The findings are consistent with our results, where PWHT at high temperatures (900˚C) results in a decrease in hardness due to grain enlargement and carbide dissolution. Additionally, another study by [15] found that PWHT on low-carbon steel and stainless steel welded joints results in significant hardness variation. High-temperature PWHT increases strength but decreases hardness due to microstructural changes, including grain enlargement.

Further, the research by [11] on the effect of delta ferrite on the mechanical properties of dissimilar ferritic-austenitic stainless steel welds supports our findings. Delta ferrite in the weld metal can influence hardness and mechanical properties. The presence of delta ferrite is beneficial in preventing hot cracking during welding, but excessive delta ferrite can lead to brittleness and decreased toughness. Our study found no chromium carbide formation, which aligns with the beneficial effects of delta ferrite in maintaining weld metal integrity.

3.2. Impact

Figure 2 shows the average results of the Charpy V-notch impact test with welding metal E308L-16, and Figure 3 shows the impact test fracture. The test was carried out on the weld metal area at room temperature. This figure shows that the highest impact after the post-welding heating process on the 400˚C PWHT specimen was 1.31 joules/mm^2, or an increase of 6.5% from the specimen without PWHT. The lowest impact values were in the 600 Cand 900˚C PWHT specimens by 6.5% and 16.26% of the samples without PWHT. In general, the purpose of the post-welding heating process is to expect the value of toughness, flexibility, and impact energy to increase with the increase in post-welding heating temperature. The amount of ferrite phase in the weld metal can affect the decrease in the impact energy value. This is because the temperature and time of the post-welding heating process will jeopardize the ferrite delta phase transformation [7]. The fracture shape of the specimen was without heat treatment, and after PWHT, it showed a ductile fracture. The decrease in the toughness of the weld metal can be influenced by inclusions [14].

3.3 Microstructure

Macro-observation of the welding of different metals with *filler metal* E308L-16 after etching with glysergia aims to reveal some differences between carbon steel and stainless steel with weld metal. The difference between the weld metal, A36 low carbon steel base metal, and 316L base metal, the HAZ area adjacent to the weld metal, is visible. In addition to this area, there is still a hot area between the weld metal and the HAZ area, called the welding boundary (*fusion line*), as shown in Fig. 4.

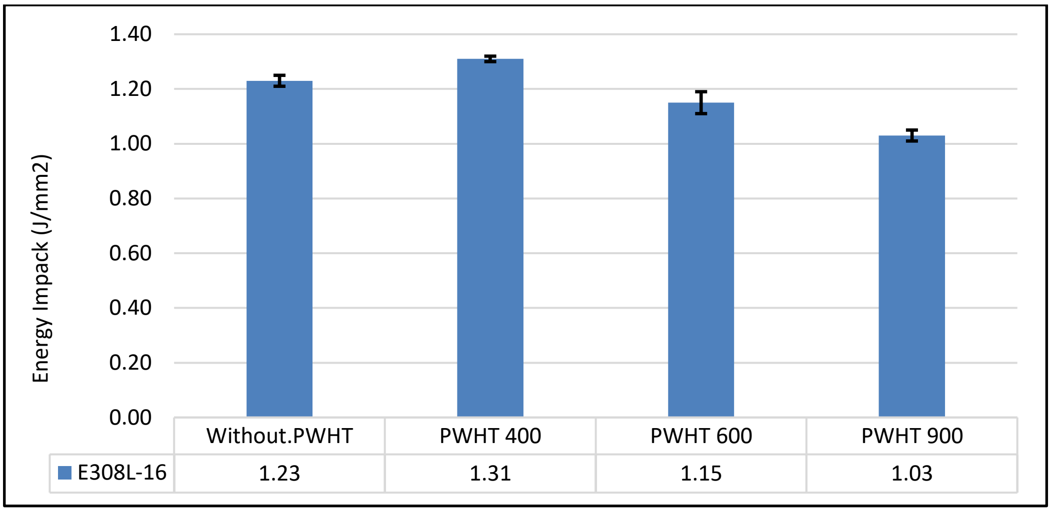
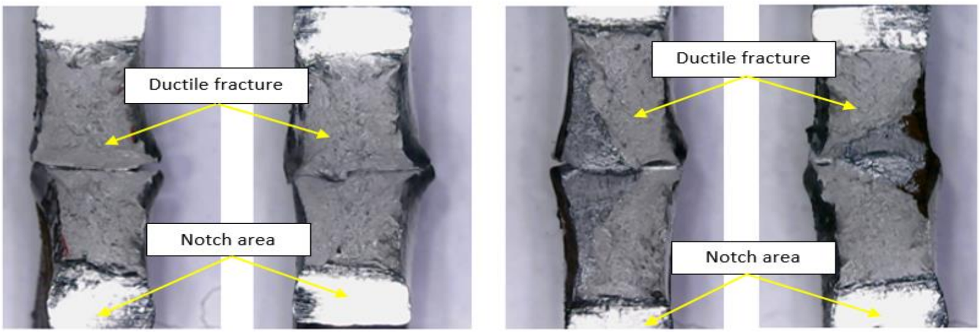


Figure 2. Impact Strength of weld metal E308L-16



(a) (b) (c) (d)

Figure 3. Impact test fracture (a) without PWHT, (b) PWHT 400˚C, (c) PWHT 600˚C and (d) PWHT 900˚C

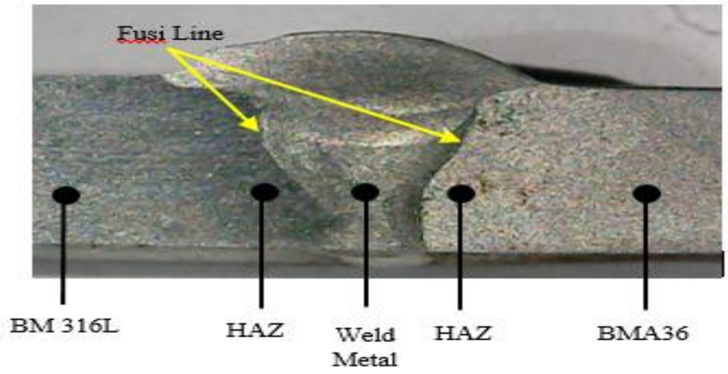
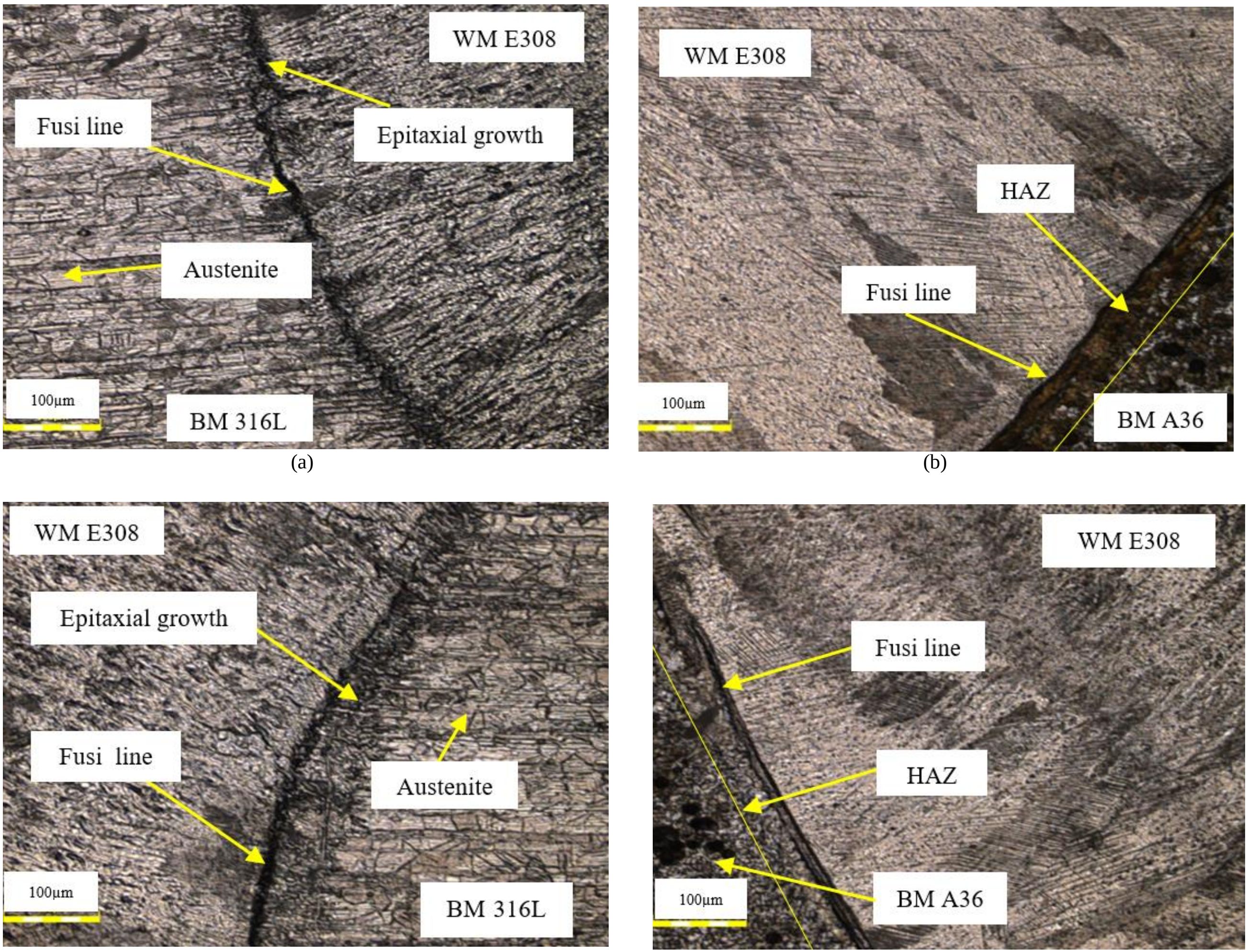


Figure 4. Dissimilar metal welding macrostructure



(a) (b) (c) (d)

Figure 5. Microstructure of the weld metal surface of stainless steel and low carbon steel, (a) HAZ area 316 and WM E308L-16 without PWHT, (b) area HAZ A36 and WM E308L-16 without PWHT, (c) area HAZ 316 and WM E308L-16 PWHT 400 and (d) HAZ area A36 and WM E308L-16 PW

The results of observing the microstructure of the welding of different metals are shown in Fig. 5. The difference between the parent metals for carbon steel is visible. Low-grade, stainless steel, and weld metal. Figures 5 (a) and 5 (c) show the welding surface between the weld metal and 316L stainless steel base metal. The surfaces of these two parts show similarities because the chemical composition of chromium and nickel contains a small ratio, and epitaxial growth of the weld metal fuses with the parent metal is also visible. While Fig.s 5 (b) and (d) show the weld surface of the weld metal with A36 low carbon steel, showing significant differences due to the different chemical compositions. The results of metallographic observations in Fig. 5 show that the heat treatment sample with a temperature of 400˚C does not show any influence on the joint weld zone. This is because the post-weld heat treatment temperature is below the critical temperature, so there is no phase change [7]. The phase changes that occur during the welding process and post-weld heat treatment (PWHT) significantly influence the mechanical properties of welded joints. In the welding of austenitic stainless steel and low-carbon steel, the primary phase transformations that may occur include the martensitic transformation in the heat-affected zone (HAZ) of the carbon steel and the formation of delta ferrite and austenite in the stainless steel.

For carbon steel, the transformation from austenite to martensite can increase hardness but reduce toughness. In contrast, the formation of delta ferrite in stainless steel can provide stability against hot cracking but may lead to brittleness if the delta ferrite content is excessive. When PWHT is conducted at temperatures lower than the critical temperature (e.g., 400˚C), there are no significant phase changes in the microstructure, and thus, the mechanical properties remain relatively unchanged. However, higher PWHT temperatures, such as 900˚C, can cause microstructural alterations, including carbide dissolution and grain growth, leading to a decrease in hardness, as observed in your research findings. Relevant studies, such as the [15], reveal that high-temperature PWHT can decrease hardness and strength due to the phase changes and microstructural transformations that occur. Additionally, the study on the [11] highlights that the delta ferrite formed during dissimilar welding can impact mechanical properties, particularly in maintaining joint integrity against hot cracking. However, it must be carefully controlled to avoid reducing toughness.

4. Conclusion

Conclusions obtained in this research are as follows:

- The hardness decreases with increasing heat treatment temperature. The hardness value decreased in the PWHT 900˚C specimen by 31.97% of the untreated sample, and the hardness of the weld metal was higher than the two-parent metals.
- The highest impact test value was on specimens with PWHT 400˚C at 6.5 %, and the lowest was on samples of PWHT 900˚C with a reduction in the value of 16.26% from samples without PWHT.
- The macrostructure shows the difference between the metal parts of the two-parent metals, haz area, weld metal, and fusion line. The chemical composition ratio of chromium and nickel is the same, showing the similarity between the base metal and the parent metal.
- Researchers suggest researching corrosion resistance in the HAZ area of A36 base metal with welded metal.

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References

[1] M. J. Marques, A. Ramasamy, A. C. Batista, J. P. Nobre, and A. Loureiro, “Effect of heat treatment on microstructure and residual stress fields of a weld multilayer austenitic steel clad,” *J. Mater. Process. Technol.*, vol. 222, pp. 52–60, 2015, doi: 10.1016/j.jmatprotec.2015.03.004.

[2] M. Sadeghian, M. Shamanian, and A. Shafyei, “Effect of heat input on microstructure and mechanical properties of dissimilar joints between super duplex stainless steel and high strength low alloy steel,” *Mater. Des.*, vol. 60, pp. 678–684, 2014, doi: 10.1016/j.matdes.2014.03.057.

[3] M. P. Prabakaran and G. R. Kannan, “Optimization of laser welding process parameters in dissimilar joint of stainless steel AISI316/AISI1018 low carbon steel to attain the maximum level of mechanical properties through PWHT,” *(Optics Laser Technol. , 2019)*, pp. 314–322.

[4] M. M. A. Khan, L. Romoli, M. Fiaschi, G. Dini, and F. Sarri, “Laser beam welding of dissimilar stainless steels in a fillet joint configuration,” *J. Mater. Process. Technol.*, vol. 212, no. 4, pp. 856–867, 2012, doi: 10.1016/j.jmatprotec.2011.11.011.

[5] S. Ghorbani, R. Ghasemi, R. Ebrahimi-Kahrizsangi, and A. Hojjati-Najafabadi, “Effect of post weld heat treatment (PWHT) on the microstructure, mechanical properties, and corrosion resistance of dissimilar stainless steels,” *Mater. Sci. Eng. A*, vol. 688, pp. 470–479, 2017, doi: 10.1016/j.msea.2017.02.020.

[6] B. Sadeghi, H. Sharifi, M. Rafiei, and M. Tayebi, “Effects of post weld heat treatment on residual stress and mechanical properties of GTAW: The case of joining A537CL1 pressure vessel steel and A321 austenitic stainless steel,” *Eng. Fail. Anal.*, vol. 94, no. July 2017, pp. 396–406, 2018, doi: 10.1016/j.engfailanal.2018.08.007.

[7] C. C. Huang and T. H. Chuang, “Effects of post-weld heat treatments on the residual stress and mechanical properties of laser beam welded SAE 4130 steel plates,” *Mater. Manuf. Process.*, vol. 12, no. 5, pp. 779–797, 1997, doi: 10.1080/10426919708935184.

[8] F. A. Windratama *et al.*, “Analisis Pengaruh Parameter Suhu Annealing Terhadap Sifat Mekanik Hasil Pengelasan SMAW Dissimilar Metal,” pp. 743–750, 2019.

[9] M. Nurbanasari, D. Hadiprayitno, and Y. E. Tandiayu, “Pengaruh Parameter Post Weld Heat Treatment terhadap Sifat Mekanik Lasan Dissimilar Metal AISI 1045 dan AISI 304,” vol. 1, pp. 1–5, 2014.

[10] I. Setiawan and M. N. Ilman, “Pengaruh Post Weld Heat TreatmentTerhadap Sifat Mekanis dan Korosi Sambungan Las Spiral Saw pada Pipa Baja ASTM A252,” *J. Energi Dan Manufaktur*, vol. 5, no. 1, pp. 67–75, 2013.

[11] R. Ghasemi, B. Beidokhti, and M. Fazel-Najafabadi, “Effect of delta ferrite on the mechanical properties of dissimilar ferritic-austenitic stainless steel welds,” *Arch. Metall. Mater.*, vol. 63, no. 1, pp. 437–443, 2018, doi: 10.24425/11895

[12] W. Chuaiphan, S. Chandra-Ambhorn, S. Niltawach, and B. Sornil, “Dissimilar welding between AISI 304 stainless steel and AISI 1020 carbon steel plates,” *(Applied Mech. Mater. Switzerland, 2013)*, pp. 283–290.

[13] L. T. Nhung, P. Mai Khanh, N. Duc Thang, and B. S. Hoang, “Microstructures in haz after heat treatment of carbon steel and austenitic stainless steel welds,” *Mater. Sci. Forum*, vol. 985 MSF, pp. 137–146, 2020, doi: 10.4028/www.scientific.net/msf.985.137.

[14] P. B. Srinivasan, V. Muthupandi, W. Dietzel, and V. Sivan, “An assessment of impact strength and corrosion behaviour of shielded metal arc welded dissimilar weldments between UNS 31803 and IS 2062 steels,” *Mater. Des.*, vol. 27, no. 3, pp. 182–191, 2006, doi: 10.1016/j.matdes.2004.10.019.

[15] M. P. Prabakaran and G. R. Kannan, “Effects of post-weld heat treatment on dissimilar laser welded joints of austenitic stainless steel to low carbon steel,” *Int. J. Press. Vessel. Pip.*, vol. 191, no. December 2020, p. 104322, 2021, doi: 10.1016/j.ijpvp.2021.104322.