



Analysis of the Mechanical Properties of SMAW Welded Joints on ST 37 Plate Material after PWHT as a Case Study in Welding Engineering Education

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ABSTRACT

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One of the techniques in improving the mechanical properties of a welding result is the Post Weld Heat Treatment (PWHT) process. Attempts to improve these properties are the main goal of users so that the construction they build can last a long time from the influence of natural phenomena. This research aims to analyze the mechanical properties of SMAW welded joints on ST37 plate material that undergoes the PWHT process, as well as contribute as a practicum teaching material or case study in learning welding techniques in the technical education environment. In this study, welding was carried out with E7016 electrodes, and then three variations of the PWHT process were carried out, namely at temperatures of 400, 500, and 600°C with a holding time of 30, 60, and 90 minutes, respectively. The joints were tested using a penetrant test and a hardness test. The results showed that PWHT at 600°C with a holding time of 90 minutes produced the highest average hardness value compared to 400°C and 500°C with 30 and 60 minutes. This finding reinforces the understanding that temperature and holding time in the PWHT process significantly affect the hardness value of the weld. Therefore, the results of this study are not only useful in the development of manufacturing technology but also utilized as an applicable learning medium. By knowing the effect of PWHT on the mechanical properties of welded joints, welding instructors can design a more effective practicum in teaching the principles of welding.

1. Introduction

The metal industry is currently experiencing significant growth. In the welding sector, various techniques have been developed to enhance the physical and mechanical characteristics of welded metal products. One important method is the post-weld heat treatment (PWHT), which plays a vital role in determining the durability and performance of welded materials. PWHT is a thermal process applied to welded joints to obtain desired structural properties such as improved strength, ductility, hardness, and toughness. This treatment involves heating the material to a temperature below its

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transformation point at a controlled rate, maintaining it at that temperature for a certain period, and then allowing it to cool in a regulated manner (Putra Nugraha et al., 2017).

In the evaluation of welded joints, several measures can be implemented to enhance the material's strength and toughness during the welding process. These include regulating the heat input, modifying the composition of alloying elements, and performing heat treatments either before or after welding. Moreover, it is important to account for environmental factors present during welding, as these can significantly influence the final weld quality. The effects of localized heating or varying ambient conditions during high-temperature welding cause the metal to expand and contract upon cooling, leading to the formation of residual stress and elevated hardness in the heat-affected zone (HAZ). Residual stress is a permanent condition that arises from non-uniform thermal and cooling cycles.

Based on research and hardness testing on ST 37 steel subjected to annealing temperatures of 450°C, 550°C, and 650°C on SMAW welded joints, with holding times of 30 minutes, 60 minutes, and 90 minutes, it was observed that increases in both annealing temperature and holding duration influence the hardness values at the test points, especially in the weld area (Abdillah Windratama et al., 2019). Higher annealing temperatures and longer holding times tend to decrease hardness, resulting in weld joints that exhibit lower hardness levels compared to surrounding regions (Safriwardy et al., 2023).

Shielded Metal Arc Welding (SMAW) is a welding process that uses an electric arc as the heat source to melt the metal (Figure 1). Due to the heat from the electric arc, the base metal and the electrode tip melt and solidify together. The transfer of electrode metal occurs when the electrode tip melts and forms droplets carried by the electric arc current (Aljufri et al., 2024). When a high electric current is used, the droplets of molten metal carried become fine, and conversely, when a low current is used, the droplets become larger. Filler is a reinforcing or filling material that typically has strong and rigid properties. In the production of reinforcing composites, the reinforcing material is usually in the form of fibers or powders. The fibers used in composite production typically include E-glass fibers, boron fibers, carbon fibers, and natural fibers such as bamboo fibers, pineapple leaf fibers, kenaf fibers, ramie fibers, and others.

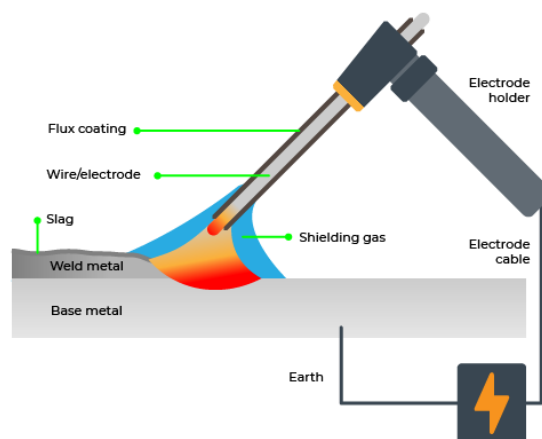


Fig. 1. SMAW welding components and working principles

ST 37 steel is categorized as a low-carbon steel, containing less than 0.30% carbon (see Table 1). This relatively low carbon content makes it a soft material, well-suited for both hot and cold forming processes. Although its strength is lower compared to medium- and high-carbon steels, ST 37 offers excellent ductility and toughness. It is commonly used in applications such as bolts, screws, and similar components. The designation "ST 37" follows the standard classification from the German

National Standards Organization (DIN – Deutsches Institut für Normung), which denotes a tensile strength of 37 kg/mm² (refer to Table 2).

Table 1. Chemical composition of ST37 steel

No.	Element	Value
1	Carbon (C)	0.20%
2	Silikon (Si)	0.15 – 0.35%
3	Mangan (Mn)	0.35 – 0.75%
4	Fosfor (P)	0.05%
5	Sulfur (S)	0.05%
6	Nitrogen (N)	0.01%

Table 2. Mechanical properties of ST37 steel

No.	Element	Value
1	Tensile Strength (σ_t)	360-460 Mpa
2	Yield Strength (σ_y)	235 Mpa
3	Elongation (ϵ) at break	25%

Hardness is an important mechanical property of materials that must be considered, particularly for components exposed to friction. It refers to a material's ability to resist compressive deformation, which can manifest as either elastic or plastic behavior. When two surfaces interact or slide against each other, both types of deformation may take place—elastic deformation tends to occur on harder surfaces, while plastic deformation is more likely on softer ones. The extent of this deformation is influenced by the relative hardness of the materials involved. Additionally, hardness is closely linked to a metal's yield strength or tensile strength, as deformation involves strain developing over time during loading.



Fig. 2. Components of the Rockwell hardness tester

Rockwell testing (Figure 2) is carried out by pressing the surface of the test specimen with an indenter. The indenter is pressed into the test specimen by applying a minor preliminary load, then adding a major main load, then releasing the main load while maintaining the minor load. Below is the formula used to determine hardness using the Rockwell method.

$$HR = E - e$$

Where:

HR = The magnitude of hardness

E = Distance between indentors

e = Distance between conditions 1 and 3 divided by 0.002 mm

2. Methodology

2.1 Research Variables

All variables used in this study were grouped into three categories: independent, fixed, and dependent variables. The independent variables consist of PWHT time (30, 60, 90 minutes) and PWHT

temperature (400, 500, 600°C). In this process, nine test specimens of the same size (length 200 mm) were cut from the test material. Constant variables include welding type (SMAW), electrode used (E7016), current strength (120 A), material (ST 37), and bevel (60°). Hardness value is the only dependent variable in this study.

2.2 Preparation of test specimens

In this process, nine test specimens were cut to the same size, namely 200 mm in length and 50 mm in width, in accordance with the respective testing standards, using a grinding machine, and welding grooves were made with a scrap machine at a 60° angle. Then, in the welding stage, the steel plate was welded lengthwise for all test specimens.

After the test specimens are welded, the next step is the PWHT process. PWHT is performed in a heating furnace with a capacity of 3000°C. The test material is heated to varying temperatures of 400, 500, and 600°C, with holding times of 30, 60, and 90 minutes. The material is then cooled to room temperature inside the furnace.

2.3 Rockwell hardness testing

The test piece is taken, and the deformation marks are observed under a microscope or magnifying glass, and the diameter of the indenter marks is measured at two intersecting points. Rockwell testing is performed with a cone indenter.

3. Results

3.1 Welding results

The welding results obtained after the welding process and welding with an E7016 electrode with a welding current of 120 A. After the welding process was carried out, the welded material was checked for defects so that hardness testing could be performed. The weld defect inspection results were obtained using a penetrant test on the welded material produced by the E7016 electrode with a diameter of 3.2 mm.

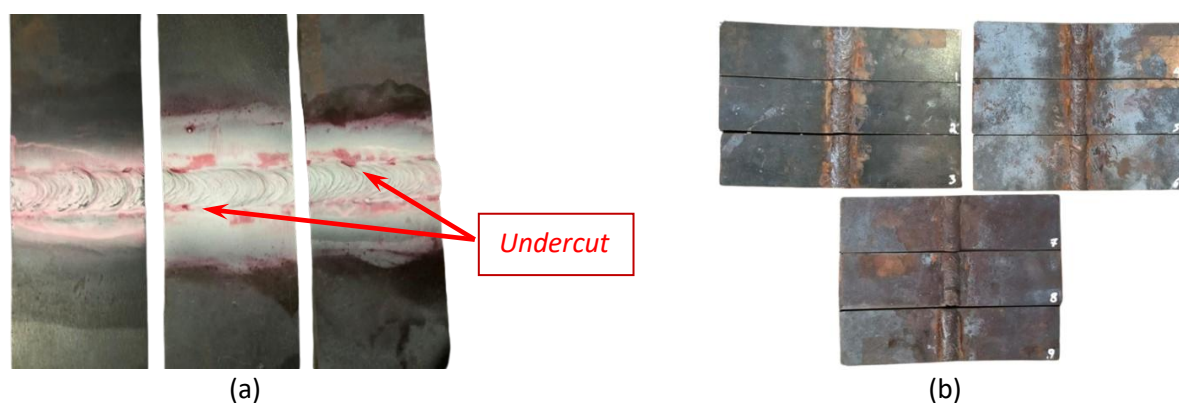


Fig. 4. (a) Penetrant test results, (b) PWHT process results

From the results of the penetrant test on the weld area, we can see that there are several undercut weld defects (Figure 4(a)) caused by uneven hand movements during welding so that the sides of the weld groove were not completely covered by the electrode during welding.

Then, the PWHT process was carried out on the welded material at temperatures of 400, 500, and 600°C with holding times of 30, 60, and 90 minutes, resulting in differences in the surface of the test material, as shown in Figure 4(b).

3.2 Hardness test results

The results of the Rockwell hardness test conducted with a 120° diamond cone indenter on the weld using an E7016 electrode with a current strength of 120 amperes can be seen in Table 3.

Table 3. Rockwell hardness test results

Test Point	Specimen number	Hardness value (HRC) Weld area		
		At a temperature of 400 °C with a holding time of 30 minutes	At a temperature of 500 °C with a holding time of 60 minutes	At a temperature of 600 °C with a holding time of 90 minutes
1	1	29	41	25
2		15	25	25
3		33	18	18
1	2	38	27	24
2		20	24	31
3		30	20	36
1	3	14	26	29
2		29	22	31
3		18	20	23
Mean		25.1	24.7	26.8

The results of the weld hardness test after undergoing a PWHT process at a temperature of 400°C for 30 minutes at three test points showed the hardness values shown in Figure 5.

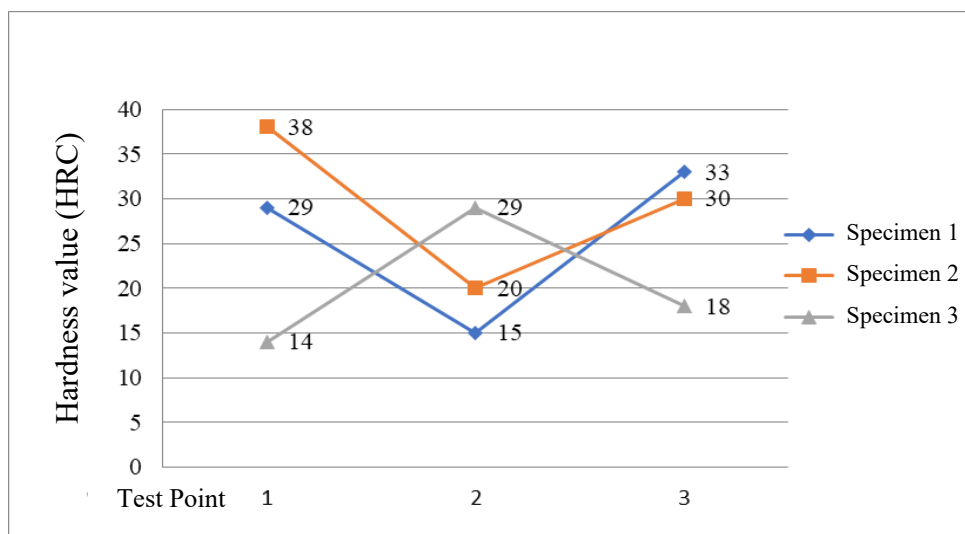


Fig. 5. Hardness value of PWHT at a temperature of 400°C with a holding time of 30 minutes

Figure 5 shows that the highest value was found in the second specimen, with the first test point having a hardness value of 38 HRC. The lowest hardness value was shown in the third specimen with the first test point with a hardness value of 14 HRC, and the average hardness value obtained from the weld area hardness test with PWHT Temperature 400°C Holding Time 30 minutes was 25.1 HRC.

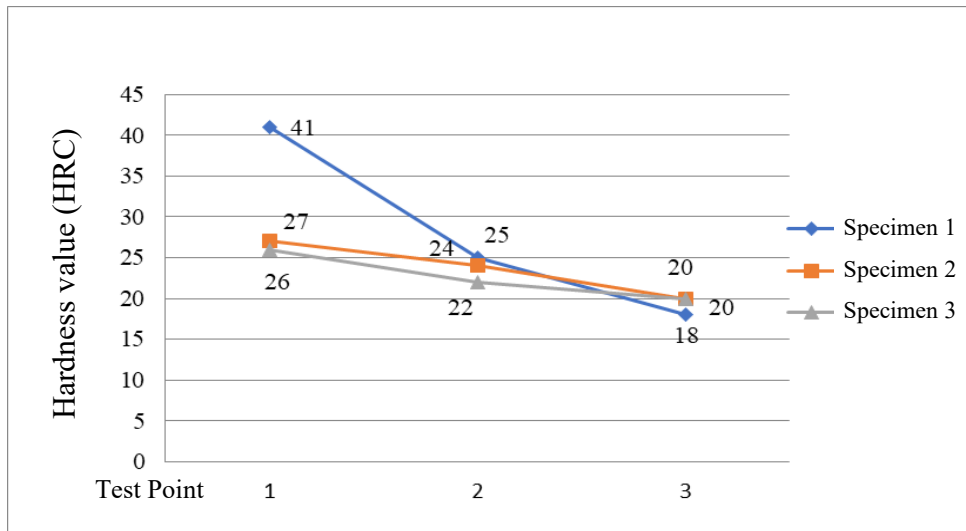


Fig. 6. Hardness value of PWHT at a temperature of 500°C with a holding time of 60 minutes

Figure 6 illustrates the results of the weld area hardness test conducted at a PWHT temperature of 500°C with a holding time of 60 minutes. The highest hardness value was recorded in the first specimen at the first test point, reaching 41 HRC. Conversely, the lowest value was observed in the third specimen at the third test point, with a hardness of 18 HRC. The average hardness across all measurements under these conditions was 24.7 HRC.

For the weld area hardness test performed at a PWHT temperature of 600°C with a 90-minute holding time, the highest hardness was observed in the second specimen at the third test point, with a value of 36 HRC. The lowest reading, 18 HRC, occurred in the first specimen at the third test point. Under these conditions, the average hardness value was calculated to be 26.8 HRC, as shown in Figure 7.

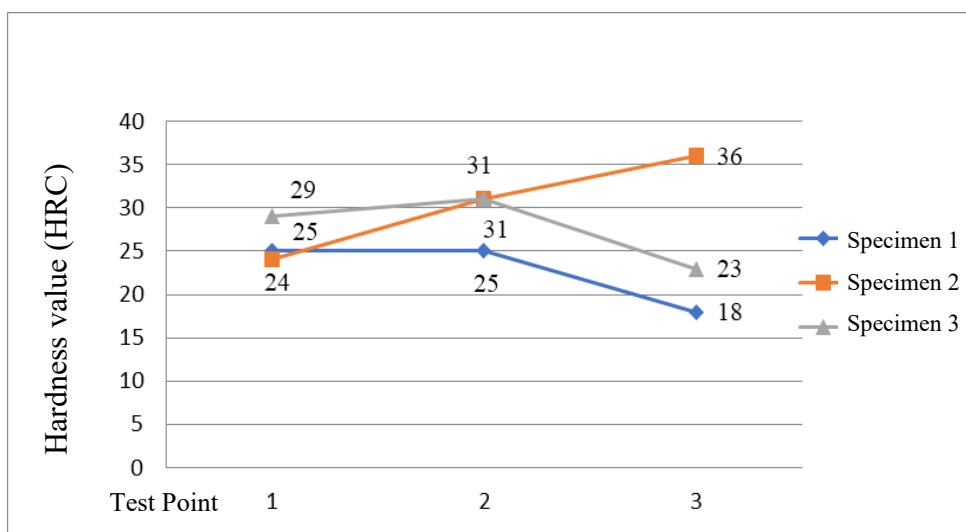


Fig. 7. Hardness value of PWHT at a temperature of 600°C with a holding time of 90 minutes

Based on the results of hardness testing on the weld area using E7016 electrodes by performing PWHT processes at different temperatures and holding times, we obtained a comparison of average hardness values as shown in Figure 8.

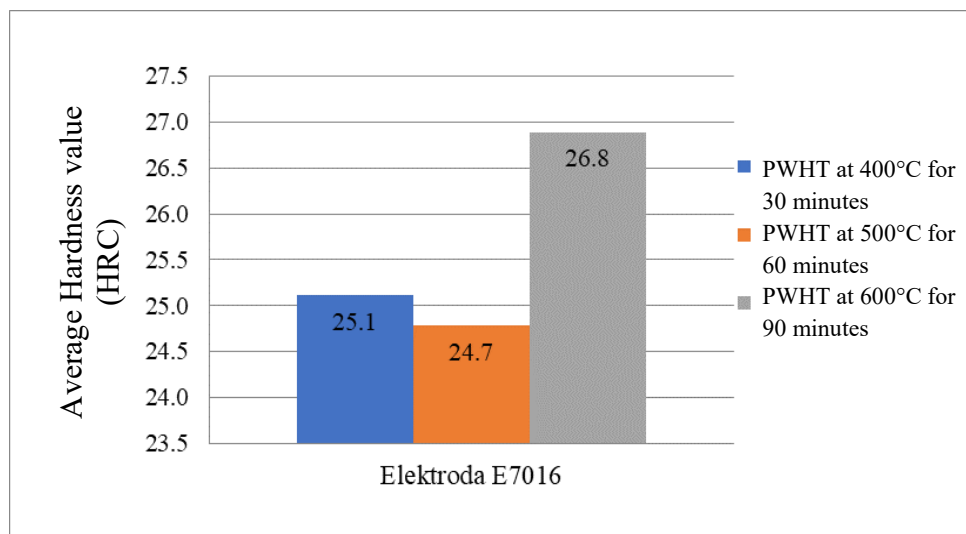


Fig. 8. Comparison of hardness values with different PWHT process variations

From Figure 8, we can see that every increase in PWHT temperature and time will always have an impact on the hardness value obtained in the hardness test conducted on the welded area, causing it to increase.

However, if we look at the bar graph comparing the average hardness value of PWHT at a temperature of 400°C with a holding time of 30 minutes with the average hardness value of PWHT at 500°C with a holding time of 60 minutes, this shows that the longer the holding time and the higher the temperature given during PWHT, the lower the hardness of the weld area. This study aligns with the research conducted by (Arifah & Ruswanto, 2020), which found that the highest microhardness was observed in the welded sample that did not undergo PWHT in the welded area, at 500.5 HV, while the lowest hardness was observed in the welded area that underwent PWHT for 3 hours, at 302 HV. This shows that the longer the holding time, the lower the hardness of the weld area. The decrease in hardness value is directly proportional to the length of the holding time.

Helianto's (2018) research states that when welding without heat treatment, the process causes a decrease in hardness value when compared to raw materials (raw 51.4 HRB, weld metal 46.8 HRB). Furthermore, with an increase in heat treatment temperature, the hardness value of the weld metal increases and even exceeds the hardness value of the raw material. This indicates that at the lowest heat treatment, the strain that occurs in the metal is neutralized, while at higher temperatures, strain hardening forms due to the difference in heat treatment temperature increase compared to cooling (48.2 HRB, 52.6 HRB, 54.3 HRB). This also shows that this study is in line with the PWHT at a temperature of 600°C with a holding time of 90 minutes; the average hardness value increases compared to PWHT 400°C and PWHT 500°C. Both studies used ST37 material, but this study used the Brinell hardness test to measure hardness.

Good welding results, as seen from the higher hardness values in the weld metal and HAZ areas, indicate that both the welding process and the strength of the welded joint are improving. The higher hardness value in the weld metal area than in the base metal area also indicates that the tensile strength of the material, especially at the welded joint, has increased.

4. Conclusions

The results of the Rockwell hardness test on the welded area of the ST 37 plate show that the higher the temperature and holding time in the PWHT process, the higher the hardness value of the welded area. PWHT at a temperature of 600°C for 90 minutes produced the highest hardness value compared to treatments at temperatures of 400°C and 500°C. This shows that PWHT greatly affects the hardness of the weld. Variations in the PWHT process also affect the distribution of hardness at several test points in the weld area. The hardness values at each point tend to be consistent in one specimen; for example, at PWHT 500°C for 60 minutes, the hardness values are 26 HRC, 22 HRC, and 20 HRC, respectively.

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References

- [1] Abdillah Windratama, F., dan Sidiq Ruswanto, dan. (2019). Analisis pengaruh parameter suhu annealing terhadap sifat mekanik hasil pengelasan smaw dissimilar metal. Prosiding seminar nasional Teknik Mesin Politeknik Negeri Jakarta, 743–750. <http://semnas.mesin.pnj.ac.id>
- [2] Aljufri, A., Sofyan, S., Rizki, M. N., Putra, R., & Mawardi, I. (2024). Influence of shielding gas flow on the TIG welding process using stainless steel 304 material. *Journal of Welding Technology*, 6(1), 38. <https://doi.org/10.30811/jowt.v6i1.5322>
- [3] Putra Nugraha, Y. D., Suharno, S., & Estriyanto, Y. (2017). Pengaruh Proses Post Weld Heat Treatment (PWHT) Pada Pengelasan Material Paduan Super Berbasis Nikel Dengan Metode Tungsten Inert Gas (TIG) Terhadap Kekerasan Dan Struktur Mikro. *Jurnal Ilmiah Pendidikan Teknik Dan Kejuruan*, 10(2), 75. <https://doi.org/10.20961/jiptek.v10i2.16916>
- [4] Anggaretno, G. (2012). Analisa pengaruh jenis elektroda terhadap laju korosi pada pengelasan pipa API 5L Grade X65. *Jurnal Teknik ITS*, 1(Corrosion), 3–7. <https://doi.org/10.12962/j23373539.v1i1.1619>
- [5] Arifah, A., & Ruswanto, S. (2020). Efek Post Weld Heat Treatment terhadap Sifat Mekanik AISI 316 Hasil Pengelasan GTAW. *Jurnal Mekanik Terapan*, 1(2), 81–87. <https://doi.org/10.32722/jmt.v1i2.3354>
- [6] Azwinur, A., Jalil, S. A., dan Husna, A. (2017). Pengaruh variasi arus pengelasan terhadap sifat mekanik pada proses pengelasan smaw. *Jurnal POLIMESIN*, 15(2), 36. <https://doi.org/10.30811/jpl.v15i2.372>
- [7] Bakhori, A. (2017). Perbaikan metode pengelasan smaw (shield metal arc welding) pada industri kecil di kota medan. *Buletin utama teknik*, 13(1), 14–21.
- [8] Bakhori, A. (2021). Analisa cacat hasil pengelasan pada baja krbon rendah terhadap pengaruh masukan panas las. *Semnastek uisu*, 0–5.
- [9] Hariyanto, I. A., Setiyono, Y., dan Sugito, B. (2012). Baja Karbonisasi Arang Kayu Sengon.
- [10] Hasil, J., Ilmiah, K., Lubis, P. C., Budiarto, U., dan Jokosisworo, S. (2022). Jurnal teknik perkapalan analisa pengaruh variasi waktu post weld heat treatment pada pengelasan smaw baja a36 terhadap kekuatan uji tarik, uji impak dan struktur mikro. *Jurnal teknik perkapalan*, 10(3), 48. <https://ejournal3.undip.ac.id/index.php/naval>
- [11] Helanianto, H. (2018). Pengaruh perlakuan temperatur pemanasan pada hasil pengelasan metode smaw terhadap hardness logam induk dan logam las. *Jurnal sistem teknik industri*, 19(1), 30–33.
- [12] Jarot Wijayanto, Murdjani, A. K. (2016). Pengaruh perlakuan panas diawal dan diakhir terhadap sifat fisis dan mekanis pada penelasan baja karbon sedang. *Jurnal intekna*, 16(1), 94–100.
- [13] Material, J. R., Energi, M., Pengaruh, A., Kayu, A., Tempurung, A., dan Dan, K. (2020). *Ft-umsu ft-umsu*. 3(2), 128–137.
- [14] Mizhar, S. (2016). Pengaruh heat treatment terhadap struktur mikro dan kekerasan aluminium paduan al-si-cu pada cylinder head sepeda motor. *jurnal ilmiah "MEKANIK" Teknik Mesin ITM*, 3(1), 9–15.

- [15] Nafi, M., Sulistyono, D., Mufti, M., dan Ruseno, D. (2022). Analisa kekerasan rockwell dan metalografi hasil pwht pada pengelasan smaw baja ST 41 dengan variasi temperatur dan waktu tahan. *MEKANIKA : jurnal teknik mesin* 8(1).
- [16] Purwaningrum, S. T. Y. (2021). Pengaruh temperatur post weld heat treatment (PWHT) terhadap sifat fisik dan mekanik pada sambungan las mig baja aisi 1000 SS. <https://dspace.uji.ac.id/handle/123456789/29848>
- [17] Ristyanto, A., Dwi Haryadi, G., Dan Umardani, Y. (2014). Pengaruh proses normalizing terhadap nilai kekerasan dan struktur mikro pada sambungan las thermite simillar baja uic-54 (union internationale des chemins de fer-54). *Jurnal Teknik Mesin S-1*, 2(2), 36–45.
- [18] Safriwardy, F., Rizki, M. N., Masrullita, M., & Daniel, M. (2023). Analysis of the influence of temperature and hold time in the solid carburization process on the hardness and microstructure of AISI 1020 and 1045 using Oil Cooling. *International Journal for Educational and Vocational Studies*, 5(1), 1. <https://doi.org/10.29103/ijevs.v5i1.12486>
- [19] Sawaldi, A., Fathier, A., dan Ibrahim, A. (2019). Pengaruh pwht terhadap struktur mikro pada lasan pipa baja astm a106 grade b. *Journal of welding technology*, 1(2), 31–35.
- [20] Sukarno, Asiri, M.H., dan M. (2022). Analisis kekuatan tarik dan bending dari beberapa jenis kampuh v,x,i pada pengelasan smaw terhadap baja karbon medium. *Journal of technology process*, 2(1), 22–32.
- [21] Supriyanto, N. S. W., Widi, I. K. A., dan Putra, D. R. (2023). Penggunaan las gesek (friction welding) guna penyambungan dua buah logam baja karbon st 42 pada pengujian tarik dan struktur mikro untuk spring pin pada mobil. *Jurnal flywheel*, 14(2), 59–65. <https://doi.org/10.36040/flywheel.v14i2.7731>
- [22] Wahyudi, R., Nurdin., dan S. (2019). Analisa pengaruh jenis elektroda pada pengelasan smaw penyambungan baja karbon rendah dengan baja karbon sedang terhadap tyensile strenght. *Journal of welding technology*, 1(2), 43–47. <http://dx.doi.org/10.30811/jowt.v1i2.1645>
- [23] Wibowo, T. N. (2019). Iteks analisis variasi arus las tungsten inert gas terhadap kekuatan mekanik pada baja st 37. 1, 1–8.