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Analysis of the Effect of Shielding Gas Composition and FCAW Parameters on Shipbuilding Steel Plate for Ship Hull Production

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Abstract

Shielding gas is an important thing to protect the weld metal from impurities during the welding process. Ar, CO2, and mixing gas of Ar-CO2 are often used as a shielding gas in the marine industry. Differences in shielding gases and the current welding could affect the microstructure and mechanical properties of the welded metal. This research was conducted to find the most effective variations in welding parameters to achieve the highest mechanical properties for ship hull production and as a reference for choosing mixing gas. This research analyzed the microstructure and hardness from the FCAW process of the Shipbuilding Steel Plate using different compositions of shielding gas (100% CO2, 80% Ar + 20% CO2, and 75%Ar + 25% CO2) with variations of current 180 A and 195 A. The microstructure for the weld metal with 100% CO2 shielding gas was pearlite, widmanstatten ferrite, grain ferrite, and polygonal ferrite; otherwise, for mixing shielding gas of 80% Ar + 20% CO2 and 75%Ar + 25% CO2, the structure of pearlite, grain ferrite, and acicular ferrite were found on the weld metal area. The shielding gas composition and welding current variation that obtained the highest hardness value were 80% Ar + 20% CO2 and a current of 195 A, resulting in a hardness of 159,62 HVN in the weld metal area. A higher percentage of CO2 resulted in lower hardness values.

1. Introduction

Flux-cored arc welding, or FCAW, is an arc welding technique in which the arc is maintained between the weld pool and a filler metal electrode that is fed constantly during the welding process. The process can be performed with or without additional shielding from an externally supplied gas [1]. In the FCAW process, the molten metal transfer greatly influences welding performance and stability.

When it involves welding parameters, the welding current and shielding gas were considered to have a significant impact on how metal is transferred [2]. Shielding gas is a crucial part of gas arc welding. It is used to protect the weld pool from direct contact with atmospheric gas and increase penetration depth [3],[4]. The selection of shielding gas affects welding quality. CO_2, Ar, He, and mixed gases are commonly used shielding gases. CO_2 gas is used because it promotes spray-mode transfer, increasing penetration in the entire arc welding area and reducing spattering. The addition of CO_2 also reduces the surface tension of the weld pool, resulting in higher wettability of the molten metal [5]. Combining CO_2 and Argon will reduce the arc area penetration while increasing the penetration around it [4].

While having good penetration, CO_2 has the disadvantage of oxygen absorption into the molten weld metal. This can lead to defects in the form of gas holes or porosity. Mixing CO_2 and Argon gas can be used to overcome this problem. The use of this mixing resulted in the removal of molten metal grains becoming more frequent, reducing the spattering, and making the arc more controlled [6]. The value of the welding current also influences the depth of penetration.

Applying shielding gas in the welding process affects the chemical and microstructure composition of the weld metal. It also significantly impacts the physical characteristics of the electric arc and the weld pool and affects the joint strength properties [7]. M.T. Liao et al. [8] evaluate the effect of shielding gas on the microstructure of welded stainless steel. The high percentage of CO_2 will increase the carbon content and reduce the amount of ferrite. Research by D. Katherasan et al. [9] also shows that variations of shielding gas used in the FCAW method affect the impact toughness and ferrite number in the weld metal area. The result shows that increasing the CO_2 composition reduces the impact toughness and ferrite number. Habibi et al. [10] analyzed the effect of shielding gas variations on the properties of stainless steel joined by Metal Inert Gas welding. The research showed that using a shielding gas composition of 100% Argon has the highest hardness due to the quenching effect during welding.

The previous research by Tillah et al. [6] evaluated the effect of using 100% CO_2 and mixing gas (Argon + CO_2) in the FCAW process. Using 100% CO_2 results in more undercut and incomplete fusion defects, and the application of mixing gas produced undercut, incomplete fusion, and overspatter. The exact composition of the mixing gas was not described. In this research, variations in mixing gas were added, and the welding current also varied.

This research highlights the application of steel plates in ship hull manufacturing. Steel plates are transformed into individual components and assembled through welding; therefore, the parts can be used to form hull blocks [11]. The shipbuilding steel plates were welded using the FCAW process with varying shielding gas, including 100% CO_2, Ar + 20% CO_2, and Ar + 25% CO_2, as well as different welding currents of 180 A and 195 A. The microstructure and hardness of the welded shipbuilding steel plate were evaluated to determine the most effective parameters for better mechanical properties and as a reference for choosing better mixing gas variations.

2. Methods

2.1. Materials

For the study, ASTM A36 steel plates with dimensions of 300 mm x 100 mm x 5 mm were used. The details of the specimen can be seen in Figure 1. Its chemical composition was examined to ensure the material complied with shipbuilding regulations, and the results can be seen in Table 1.

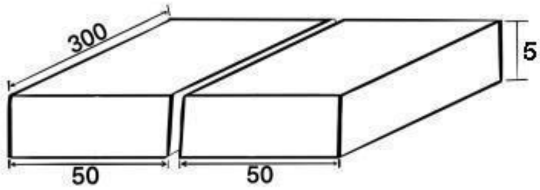


Figure 1. Dimension of the specimen

Table 1. Chemical Composition of A36 Steel (wt %)

C	Si	Mn	P (×1000)	S (×1000)
0,20	0,24	0,01	0,025	0,024

2.2. Welding Procedure

Flux-cored arc welding was performed with three variations of shielding gas composition (100% CO_2; 80% Ar + 20% CO_2; and 75% Ar + 25% CO_2) and two welding current levels (180 A and 195 A). The plates were welded in square butt joint configuration and flat-position (1-G). The filler metal used is type A 5.20 E-71T1 with a diameter of 1.2 mm. Each specimen has two passes, meaning that each has two progressions of welding along a joint. The welding process was performed on six joints. FCAW process using 100% CO_2 as the shielding gas was conducted on joints A1 and A2. A shielding gas of 5% Ar + 25% CO_2 was used in the welding process of joints B1 and B2, while joints C1 and C2 were made using 80% Ar + 20% CO_2 as the shielding gas. The welded specimen can be seen in Figure 2. Measurements were made of variables such as voltage, travel speed, and heat input. The welding parameter can be seen in Table 2. The current and voltage were measured during the welding process. A stopwatch was used to count the welding time, and a thermos gun was used to observe the temperature to follow the Welding Procedure Specification. The travel speed was evaluated using the welding time, and the heat input was calculated using the equation below.

$$HI = \frac{V \, x \, I \, x \, \epsilon}{\upsilon} \tag{1}$$

HI = Heat input (kJ/mm); V = Voltage (V); I = Current (A); υ = Travel Speed (mm/m); and ϵ = Efficiency.

Table 2. Welding parameter

Specimen code	Pass	Current (A)	Voltage (V)	Travel Speed (mm/m)	Heat Input (kJ/mm)
A1	1	180	23,4	253,5	996,8
	2		23,2	300,0	835,0
A2	1	195	24,4	352,9	808,8
	2		24,6	310,3	927,4
B1	1	180	23,3	290,3	866,7
	2		23,5	300,0	846,0
B2	1	195	24,4	321,4	888,1
	2		24,6	321,4	895,4
C1	1	180	23,3	276,9	908,7
	2		23,5	285,7	888,3
C2	1	195	24,4	305,8	933,5
	2		24,6	290.3	991,3

Figure 2. Welded specimens

2.3. Specimen Preparation

To perform hardness testing and microstructure investigation, welded plates were sectioned, polished, and etched.

2.4. Microstructure Analysis

Microstructure analysis was conducted to observe the microstructure changes during the welding process using 100% CO2, 80% Ar + 20% CO2, and 75% Ar + 25% CO2. Samples were prepared by cutting, mounting, grinding using sandpaper up to 1000 grit, polishing, and etching. For microstructure analysis, the fine polished welded sample was etched using 98% alcohol and 2 ml of HNO3. Microstructure observation was conducted on an optical microscope with 200x and 500x magnification.

2.5. Hardness Test

To assess the impact of welding current and shielding gas on mechanical qualities, Vickers hardness tests were performed on the weld metal area. Samples were prepared by cutting, polishing using sandpaper up to 400 grits, and etching. Vickers Hardness Testing was performed using 1 kgf of load and 15 seconds of holding time on a Future Tech Multi-Vickers Hardness Tester FLC-50VX. The hardness test was carried out three times for each specimen in the weld metal area, as shown in Figure 3. The dots represent the test area.

Figure 3. Location of hardness test in the weld metal

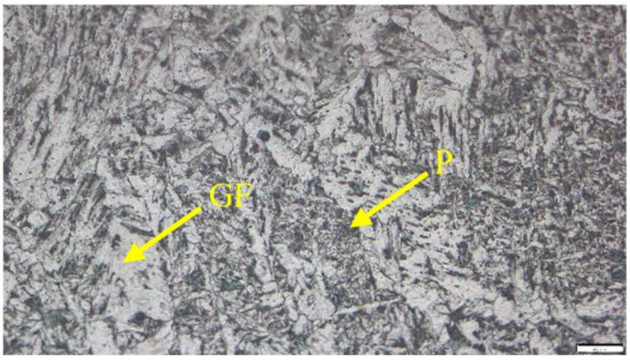
2.6. Data Analysis and Validation

The ideal parameters for ship hull welding were identified by comparing the outcomes to the typical characteristics of ASTM A36 steel.

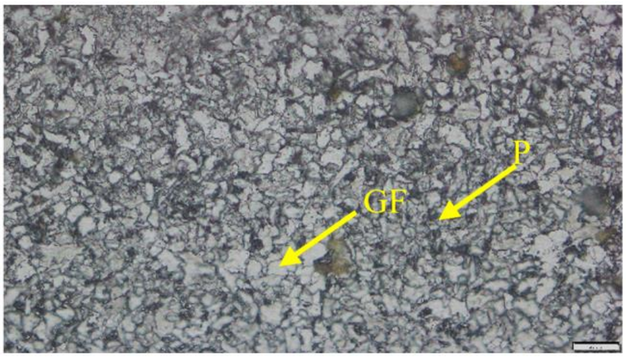
3. Results and Discussion

3.1. Data Analysis and Validation

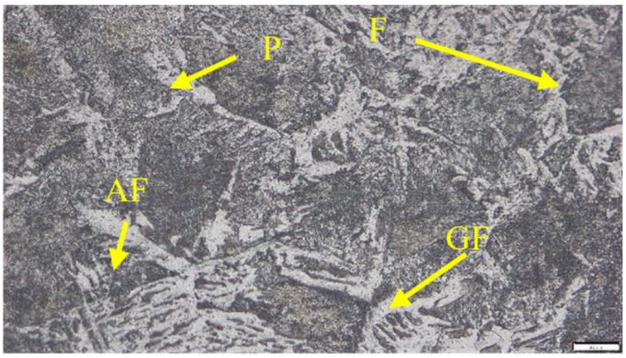
Microstructure analysis was conducted to identify phases present due to using different shielding gases on the material after the welding process. Microstructure testing was performed on the weld metal area of each shielding gas variation. Figure 4 shows the microstructure analysis results on weld metal with shielding gas variations of (A1) 100% CO2, (B1) Ar 75% + CO2 25%, and (C1) Ar 80% + CO2 20%, with a welding current of 180 A.



(A1)

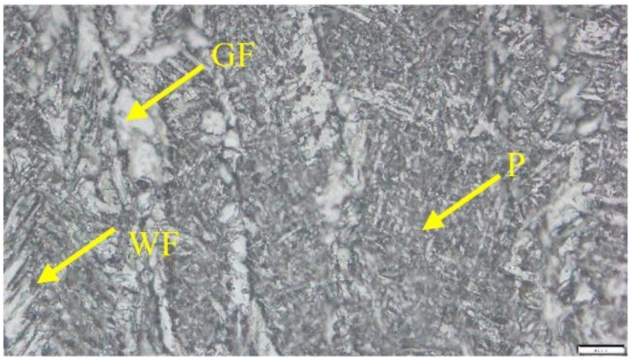


(B1)

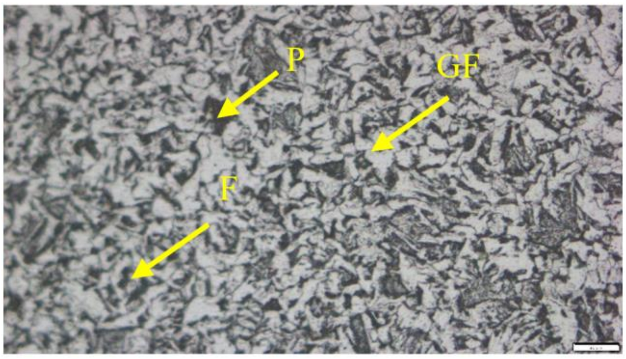


(C1)

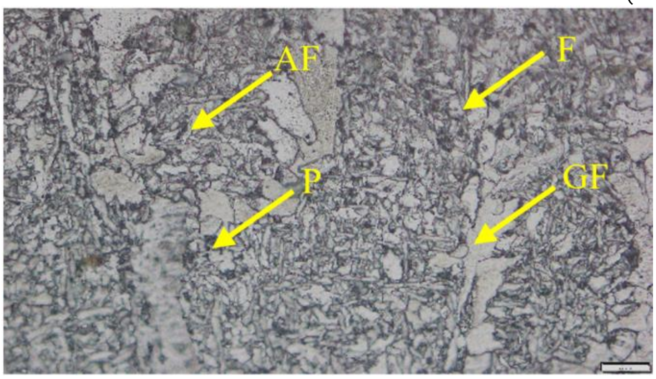
Figure 4. Microstructure of weld metal with variations of shielding gas (A1) 100% CO_2; (B1) Ar 75% + CO_2 25%; (C1) Ar 80% + CO_2 20%; with the welding current of 180 A



(A2)



(B2)



(C2)

Figure 5 Microstructure of weld metal with variations of shielding gas (A2) 100% CO_2; (B2) Ar 75% + CO_2 25%; (C2) Ar 80% + CO_2 20%; with the welding current of 195 A

Based on the microstructure analysis result of the weld metal area above, Figure 4 (A1) and (B1) show the occurrence of pearlite and grain boundary ferrite (GF) structures. The presence of grain boundary ferrite reduces the ductility and toughness of a material. Pearlite and ferrite were found on the material and recognized by their difference in color. The white areas on the microstructure are recognized as ferrite, and pearlite has a black appearance [12]. While in Figure 4 (C1) shows the formation of acicular ferrite (AF), pearlite, and grain boundary ferrite. The presence of acicular ferrite (AF) increases the toughness and ductility of a material [13]. Acicular ferrite has needle-shaped characteristics with random orientation. It also has a higher hardness value than widmanstatten ferrite and grain ferrite.

Figure 5 shows the microstructure analysis results on weld metal with shielding gas variations of 100% CO_2, 75% + CO_2 25%, 80% + CO_2 20%, and a welding current of 195 A. The microstructure can affect the mechanical properties of the material. The microstructure of the weld metal area, using mixing shielding gas of 75% Argon + 25% CO_2, as seen in Figure 5, displays pearlite and grain ferrite phases. Mixing shielding gas of 80% Argon + 20% CO_2 results in acicular ferrite, pearlite, and grain ferrite phases. Widmanstatten ferrite is characterized by a long triangular pyramid shape, as can be seen in Figure 5 (A2) [14]. Using 100% CO_2 results in pearlite, widmanstatten ferrite (WF), and grain boundary ferrite on the microstructure. Based on microstructure analysis, the variations of welding current do not give significant changes in microstructure. Microstructural changes are more prominent in shielding gas variations.

There is also polygonal ferrite. However, unlike grain ferrite, it does not form a veining. Increasing CO_2 composition in the shielding gas results in decreasing acicular ferrite and increasing widmanstatten ferrite, whereas reducing the CO_2 composition results in increasing acicular ferrite and decreasing widmanstatten ferrite. Ebrahimnia et al. [15] evaluate the effect of adding CO_2 percentage in the shielding gas composition on the weld microstructure. It shows that the number of porosity and inclusions decreases as the composition of CO_2 increases. The nucleation of acicular ferrite occurs from the inclusion within the prior austenite grains [16]. Reduction in the number of inclusions results in a decrease in acicular ferrite number. Research conducted by Gadallah et al. [17] showed that increasing the percentage of CO_2 lowers the percentage of acicular ferrite. As the percentage of CO_2 increases, the amount of widmanstatten ferrite also increases. The plasma temperature in the arc also increases when a high amount of CO_2 is added, leading to increased heat input in the weld pool. Subsequently, the total cooling time lengthens, leading to a microstructure with lower non-equilibrium phases [15].

The use of CO_2 gas provides excellent penetration due to high ionisation energy. Still, it cannot maintain spray transfer because the usage of CO_2 gas promotes the transfer of globular droplets and arcs that are very unstable and have a lot of sparks. In the application of mixing gas with a composition of 80% Argon + 20% CO_2 and 75% Argon + 25% CO_2, the percentage of CO_2 or oxygen depends on the type of steel used in the welding process and the metal transfer mode. Argon has much lower ionization energy and is able to maintain spray transfer above 24 V.

3.2. Hardness Test Analysis

The hardness of Shipbuilding Steel Plate was also evaluated after the welding process. The hardness test on each specimen was repeated as many as three points each. The hardness test results on the weld metal area can be seen in Figure 6.

Figure 6. Hardness Test Results

The hardness testing results on the three variations of shielding gas have shown that the welded specimen C2 with a current of 195 A and using mixing gas of Argon 80% + 20% CO_2 obtained higher hardness results, with an average hardness value of 159,62 HVN. Based on this research, the high percentage of argon in the shielding gas composition leads to increased hardness value. It is attributed to the rapid heat loss that occurs in the weld metal area. The specimen C2 receives a high heat input, with an average of 962,4 kJ/mm, followed by a quenching effect due to the gas applied to the specimen. A higher heat coefficient accelerates the cooling rate, producing the highest hardness value. Additionally, the grain size of the material will affect the hardness value. Smaller grain size contributes to higher hardness value. The specimen encounters a faster cooling rate, which prevents the grains from transforming into larger sizes, which could lower the hardness value [18]. The lowest hardness value was obtained on specimen A1, using CO_2 as the shielding gas and 180 A of a current, with an average hardness value of 144,87 HVN. Specimen A1, using pure CO_2, experienced a higher heat input value. It underwent a slower cooling rate, resulting in a lower hardness value. The hardness values of the specimen may decrease by increasing the percentage of CO_2 due to the reduction of certain alloying elements, such as Mn and Si, during the welding process [17]. Based on these results, there are differences in hardness at currents of 180 A and 195 A. At a current of 195 A and using a mixing gas of 80% Argon + 20% CO_2, the weld metal area has a higher hardness value, with an average hardness value of 159,62 VHN. The lowest hardness value was obtained using a current of 180 A and CO_2 as the shielding gas, with an average hardness value of 144,87 HVN. This variation can be attributed to the increased heat generated during the welding process [19]. Putra and Nugroho [20] also evaluated the hardness of A36 steel welded using the FCAW process. For a gas flow rate of 15 L/min, yielded a hardness value 158,7 HVN in the weld metal area. It aligns with the hardness values observed in this study, particularly for specimen C2, with 159,62 HVN.

The application of 100% CO_2 as the shielding gas during the welding process decreases the hardness value in the weld metal area [17]. The higher percentage of CO_2 decreases the acicular ferrite, resulting in a lower hardness value. Acicular ferrite is associated with a higher hardness value. However, the hardness will increase along with the reduction in the percentage of CO_2 as the shielding gas, as shown in Figure 6. The hardness increases when the shielding gas used is 75% Argon + 25% CO_2, and the highest hardness is obtained by using 80 % Argon + 20% CO_2 shielding gas. Increasing CO_2 content results in higher heat input than Ar, decreasing weld metal cooling rate. Hence, the hardness value is decreasing.

This study focuses on the hardness results of ASTM A36 shipbuilding steel weld metal under various FCAW parameters and shielding gas compositions. As a Grade A material, ASTM A36 steel usually has hardness values between 67 and 83 Rockwell or 121 and 158 HVN. Although hull hardness categories for Grade A material are not specified by Biro Klasifikasi Indonesia (BKI), the weld metal's hardness values (up to 159.62 HVN) fall within this range, indicating compatibility with the base material. These results confirm that the shielding gas compositions and welding conditions provide appropriate mechanical qualities for ship hull construction. The findings provide useful information for improving welding processes and guaranteeing the structural integrity of welded ship components, even though they do not create new regulations.

4. Conclusion

The microstructure analysis of the Shipbuilding Steel Plate material with the FCAW welding process showed that using 100% CO2 in the shielding gas composition results in pearlite, widmanstatten ferrite, grain ferrite, and polygonal ferrite in the weld metal area. Applying 75% Argon + 25% CO2 as shielding gas resulted in acicular ferrite, pearlite, and grain ferrite in the weld metal. Using 80% Argon + 20% CO2 results in acicular ferrite, pearlite, and grain ferrite microstructure in the weld metal. The hardness testing results on each specimen with different variations of shielding gas on the welding process show that the highest hardness value was found in specimen C2, using 80% Argon + 20% CO2, with a hardness value of 159,62 HVN. The presence of acicular ferrite increases the hardness value of the specimen, and increasing the percentage of CO2 in the shielding gas leads to a reduction in acicular ferrite and an increase in widmanstatten ferrite. Hence, the lower hardness value was obtained in specimen A1, using 100% CO2, with a hardness value of 144,87 HVN. Based on this research, variations of welding current do not affect microstructural changes. However, using a higher current value resulted in a higher hardness value. This research can be used as a reference or consideration when designing welding procedures for ship hull production. Further research can be done by analyzing the tensile strength, toughness of the material, and microhardness of each phase.

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References

[1] R. Singh, "Welding and joining processes," in *Applied Welding Engineering*, Elsevier, 2020, pp. 157–186.
[2] M. Ushio, K. Ikeuchi, M. Tanaka, and T. Seto, "Effects of shielding gas on metal transfer," *Welding International*, vol. 9, no. 6, pp. 462–466, Jan. 1995. https://doi.org/10.1080/09507119509548831
[3] D. Purnama and H. Oktadinata, "Effect of Shielding Gas and Filler Metal to Microstructure of Dissimilar Welded Joint Between Austenitic Stainless Steel and Low Carbon Steel," *IOP Conference Series: Materials Science and Engineering.*, vol. 547, no. 1, p. 012003, Aug. 2019. https://doi.org/10.1088/1757-899X/547/1/012003
[4] H. Wiryosumarto and T. Okumura, *Teknologi Pengelasan Logam*, 8th ed. Jakarta: Pradnya Paramita, 2000.
[5] D. Wallerstein, E. Vaamonde, A. Prada, E. Torres, S. Urtiga Filho, and T. Santos, "Influence of welding gases and filler metals on hybrid laser-GMAW and Laser-FCAW welds," *The Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science.*, vol. 235, no. 15, pp. 2754–2767, Aug. 2021. https://doi.org/10.1177/0954406220957053
[6] R. I. Tillah, P. Imawan, and E. Pranatal, "Pengaruh Variasi Jenis Gas Pelindung Pada Pengelasan FCAW Dengan Material SS 400," in *Seminar Teknologi Kebumian dan Kelautan (SEMITAN)*, 2020, doi: https://doi.org/10.31284/j.semitan.2020.1063
[7] W. Haupt, K. C. Riffel, C. L. Israel, R. H. G. Silva, and A. Reguly, "Effect of wire electrode and shielding gas compositions on the mechanical properties of DOMEX 700 steel welded by the GMAW-P process," *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 40, no. 4, p. 174, Apr. 2018. https://doi.org/10.1007/s40430-018-1117-5

[8] M. T. Liao and W. J. Chen, "The effect of shielding-gas compositions on the microstructure and mechanical properties of stainless steel weldments," *Materials Chemistry and Physics*, vol. 55, no. 2, pp. 145–151, Sep. 1998. https://doi.org/10.1016/S0254-0584(98)00134-5

[9] D. Katherasan, P. Sathiya, and A. Raja, "Shielding gas effects on flux cored arc welding of AISI 316L (N) austenitic stainless steel joints," *Materials and Design*, vol. 45, pp. 43–51, Mar. 2013. https://doi.org/10.1016/j.matdes.2012.09.012

[10] I. Habibi, J. T. Prasetyo, N. Muhayat, and T. Triyono, "Effect Of Shielding Gas On The Properties Of Stainless-Steel Sus 304l Plug Welded," *Jurnal Rekayasa Mesin*, vol. 13, no. 3, pp. 899–910, Jan. 2023. https://doi.org/10.21776/jrm.v13i3.1251

[11] P. Virliani, S. J. A. Rahadi, R. Rina, D. P. Sari, A. Ismail, B Maruf, A. Bisri, "Proposed Quality Plan for Shipbuilding in Indonesia Based on ISO 10005:2018," *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan*, vol. 20, no. 3, pp. 359–368, Oct. 2023. https://doi.org/10.14710/kapal.v20i3.58691

[12] Y. R. Pratiwi and S. S. Wibowo, "Pengaruh Jenis Elektroda Dan Jumlah Pass Terhadap Uji Kekerasan Hasil Pengelasan Dan Struktur Mikro Pada Proses Pengelasan Shielded Metal Arch Welding," *Briliant J. Ris. dan Konseptual*, vol. 4, no. 2, p. 159, May 2019. https://doi.org/10.28926/briliant.v4i2.287

[13] R. A. Azis, S. Suharno, and H. Saputro, "Pengaruh Variasi Diameter Elektroda E7018 Terhadap Kekuatan Tarik, Kekerasan, dan Struktur Mikro Pengelasan pada Baja Karbon Rendah Jenis SS400 dengan Metode SMAW," *Jurnal Teknik*, vol. 17, no. 2, pp. 94–105, Dec. 2019. https://doi.org/10.37031/jt.v17i2.53

[14] A. Bhattacharya, K. Mondal, C. S. Upadhyay, and S. Sangal, "A phase-field study on the evolution of Widmanstätten-ferrite plates under mixed-mode of transformation," *Computational Materials Science*, vol. 180, p. 109718, Jul. 2020. https://doi.org/10.1016/j.commatsci.2020.109718

[15] M. Ebrahimnia, M. Goodarzi, M. Nouri, and M. Sheikhi, "Study of the effect of shielding gas composition on the mechanical weld properties of steel ST 37-2 in gas metal arc welding," *Materials & Design*, vol. 30, no. 9, pp. 3891–3895, Oct. 2009. https://doi.org/10.1016/j.matdes.2009.03.031

[16] R. Ghomashchi, W. Costin, and R. Kurji, "Evolution of weld metal microstructure in shielded metal arc welding of X70 HSLA steel with cellulosic electrodes: A case study," *Materials Characterization*, vol. 107, pp. 317–326, Sep. 2015. https://doi.org/10.1016/j.matchar.2015.07.032

[17] R. Gadallah, R. Fahmy, T. Khalifa, and A. Sadek, "Influence of Shielding Gas Composition on the Properties of Flux-Cored Arc Welds of Plain Carbon Steel," *International Journal of Engineering and Technology Innovation*, vol. 2, no. 1 SE-Articles, pp. 1–12, Jan. 2012. https://ojs.imeti.org/index.php/IJETI/article/view/25

[18] T. Tarmizi, N. A. Hananda, and I. Irfan, "The Effect of Heat Input on Welding Combination of GTAW and SMAW SA537 Material on Mechanical Properties and Microstructure," *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan*, vol. 19, no. 2, pp. 56–63, Jun. 2022. https://doi.org/10.14710/kapal.v19i2.45028

[19] R. Sufyani and Y. L. B, "Pengaruh Arus Las Pada Proses Las FCAW Terhadap Struktur Mikro Dan Kekerasan," *Isu Teknol. STT Mandala*, vol. 13, no. 1, pp. 1–12, 2018.

[20] H. E. Putra and N. Y. Nugroho, "Sifat Fisik dan Mekanik Pengelasan FCAW terhadap Tekanan Alir Gas pada Baja ASTM A36," in *Implementasi Hasil Riset Sumber Daya Laut dan Pesisir Dalam Peningkatan Daya Saing Indonesia*, 2019.