Jurnal
Teknologi

Full Paper

THE IMPACT OF POST-WELD HEAT TREATMENT ON RE-WELDING IN SHIELDED METAL ARC WELDING JOINT ST42 STEEL

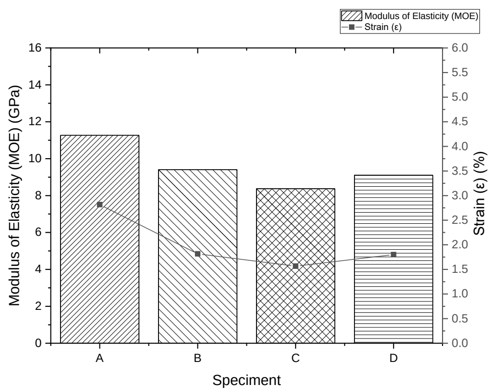
Kiryanto, Ahmad Firdhaus*, Untung Budiarto, Eko S. Hadi, M. Haiqal Al Ihsan

Department of Naval Architecture, Faculty of Engineering, Diponegoro University, Indonesia

Article history
Received
30 April 2023
Received in revised form
28 April 2024
Accepted
28 April 2024
Published Online
17 October 2024

*Corresponding author
ahmadf@lecturer.undip.ac.id

Graphical abstract



Abstract

Re-welding is a technique used to repair welds that are deemed defective and in danger of causing harm. Post-weld heat treatment is a method for improving welding-induced residual stresses, microstructural changes, hardness, and toughness. This work investigated the influence of post-weld heat treatment on the mechanical characteristics of ST 42 steel re-welding utilizing the SMAW technique and E6013 filler. Four samples with varying degrees of rewelding and post-welding treatment were analyzed. Based on the result, re-welding using SMAW to the St42 steel material led to a 20-40% decrease in mechanical properties, with the most significant reduction observed in the modulus of elasticity after two re-welding cycles. Conversely, post-weld heat treatment (PWHT) applied to the St42 steel subjected to two re-welding processes resulted in a 6-20% increase in mechanical properties, notably a 20% increase in the modulus of elasticity. These findings underscore the effectiveness of PWHT in enhancing mechanical properties, particularly microstructure recovery, in materials that have undergone re-welding.

Keywords: Re-welding, post-weld heat treatment, ST42 Steel, SMAW

1.0 INTRODUCTION

Welding is a method of joining two metals without reducing their strength or shape. Welding is now employed in the industrial sector for both manufacturing and maintenance. The shipping sector is one that heavily relies on welding. Welding accounts for one-third of all shipbuilding production [1]. Welding is commonly utilized in ship materials connecting because it gives a lower connection weight than metal joining using rivets or nuts and bolts[2], [3]. Due to their cheap cost, greater efficiency, and shorter repair times, electric welding techniques, including shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and flux-cored arc welding (FCAW), are widely used in the transportation industry [4]–[6].

ST42 steel is a type of low-carbon steel that is commonly used in the shipbuilding industry. One of the main reasons for this is its high tensile strength and excellent welding properties, making it suitable for constructing ship hulls, decks, and other structural components [7]. Another advantage of ST42 steel is its excellent corrosion resistance, which is critical for ships operating in saltwater environments. ST42 steel is often used for shipbuilding due to its high strength, good weldability, toughness, and corrosion resistance, making it a popular choice in the industry [8], [9].

It is typical for re-welding or repair welding to occur during field welding techniques. Detecting faults in the weld metal is essential to re-welding incidence. Mechanical characteristics, physical properties, composition, and microstructure will all be affected by this repair welding [10]. Consequently, it is vital to investigate the re-welding procedure to produce ideal outcomes for the demands of the shipbuilding industry.

Post-weld heat Treatment (PWHT) can be required in circumstances where it is needed to relieve the locked-up stresses produced by the welding process [11]. PWHT may improve the toughness of shielded steel metal arc welding (SMAW) welds on micro-alloyed steel used in offshore constructions [12]. Jorge *et al*. indicated that PWHT may be performed without causing significant changes in mechanical properties [13], [14]. A good relationship between mechanical strength and impact toughness can be obtained, according to some previous works that evaluated the behaviour of high-strength SMAW process [15], [16]. This was discovered regardless of the fact that these works had several limitations.

Despite the benefits of PWHT, re-welding a previously welded joint can lead to new defects and a reduction in the quality of the joint. Therefore, it is necessary to investigate the impact of PWHT on re-welding in SMAW joints to improve the quality of the welding process. This research explores the implications of PWHT on re-welding in SMAW joints made of ST42 steel, a high-strength, low-alloy steel commonly used in the shipbuilding industry.

2.0 METHODOLOGY

Plates made of ST 42 steel, which typically have a thickness of 10 millimetres and are intended for use in maritime applications like plates and tanks, served as the study's specimens. The specimen will first be cut to the size indicated for each test before any attempts are made to connect it or use welding. After cutting the models to an extent specified in advance, each specimen will be flattened using a grinding hand along the longer side. This is done to simplify the welding process and achieve the outcomes that are wanted from the welding. The dimensions of the specimens utilized for this investigation can be found in Table 1, while the mechanical characteristics of the ST 42 steel can be found in Table 2.

Table 1 Specimen Dimension

Dimension	Value
Length	800 mm
Wide	100 mm
Thickness	10 mm
Amount	Two pcs

Table 2 Mechanical Properties of ST 42 [17]

Mechanical Properties	Value
Yield Strength (Mpa)	290
Tensile Strength (Mpa)	490
Elongation (%)	20
Hardness (Hb)/(HV)	123

A single v-butt joint type weld, the plate thickness of 10 mm, AWS E6013 electrode type with a diameter of 3.2 mm, and a current of 120 amps are utilized in the SMAW welding process. This investigation employed shielded metal arc welding throughout the welding process (SMAW). Table 3 displays the WPS (Welding Procedure Specification) utilized for SMAW welding in this study.

Table 3 Welding Procedure Specification

Items	Notes
Electrode	E6013
Currents	120 A, DC+ Polarity
Voltage	26-29 V
Travel Speed	8-12 cm/min
Welding Position	1G
Connection type	60 ° Single V butt joint
Layers	Root, fill, cap

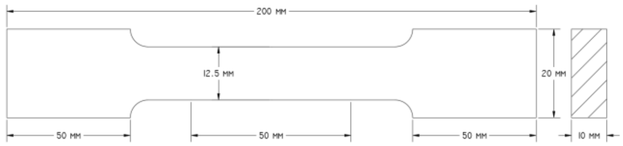
The process for the first weld (Specimen A) along the initial material's three layers, namely root, fill, and cap, was as follows. Finally, for the third welding (specimens C and D), the remainder of the second welding was crushed into filler before being re-welded. The variants of the specimen are detailed in Table 4.

Table 4 Specimen Variation

Specimen	Re-welding (times)	PWHT	Amount of Specimens
Model A	-	No	3
Model B	1	No	3
Model C	2	No	3
Model D	2	Yes	3

Temperatures for post-weld heat treatment typically fall between 150 and 600 degrees Celsius below the critical temperature (723 degrees Celsius), with waiting durations varied with material thickness. This study's temperature was 600 °C for 60 minutes, and this treatment was only performed on specimens of the 2x re-welding variety. PWHT is performed by placing the material in the furnace, increasing the temperature to a certain degree, and holding it for a specified period [18].

Testing for tensile strength followed, performed on the Universal Testing Machine (UTM) Type WEW-1000B at the Laboratory of Ship Material and Strength at Diponegoro University (Figure 1). The ASTM E8/E8M-13a standard was followed in this investigation, and a 200mm x 20mm x 10mm specimen was employed. [19]. Three different specimens are being examined in this test. Tests of tensile strength are performed to round out the information and contribute to the fundamental design of the material's strength. When a material is subjected to a tensile test, several characteristics may be determined about it, including its tensile strength ($\sigma_{tensile}$), strain (ε) , and modulus of elasticity (MOE).



(a)

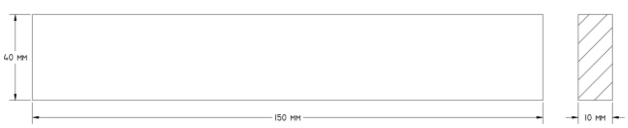
(b)

Figure 1 (a) Sample size determined using ASTM E8/E8M-13a, (b) Material for a tensile test

Afterwards, a WEW-1000B Universal Testing Machine was used at the Laboratory of Ship Material and Strength at Diponegoro University to conduct the bending test. There were a total of four different samples that were analyzed. The standard test employed in the bending test is ASTM E290-14 [20]. This can be seen in Figure 2 by taking a 150 mm x 40 mm x 10 mm in size specimen. The following characteristics are derived from the bending test:

$$\sigma = \frac{3FL}{2bd^2} \quad (1)$$

Where σ represents bending strength, F represents the maximum load (N), L represents the length of the support (mm), b represents the width of the specimen (mm), and d represents the thickness of the model (mm).



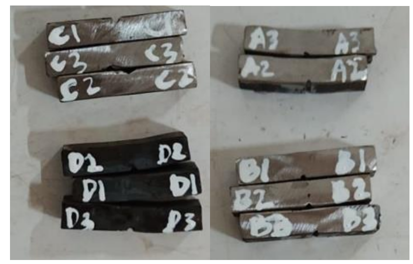
(a)

(b)

Figure 2 (a) Standards for bending test specimens in accordance with ASTM E290-14, (b) Bending test specimens

Impact Testing Impact testing is carried out to determine the value of notch toughness on steel, plastics, and ceramics. The impact test category can be classified in terms of loading method (pendulum blow or drop weight loading) and the specimen type seen from the notch's shape. The JB-300B Charpy Impact Test Machine was used for the impact test conducted at the Laboratory of Ship Material and Strength on the campus of Diponegoro University. In this investigation, the ASTM E23-16b was used [21] according to the norm shown in Figure 3, with a specimen size of 55 mm x 10 mm x 10 mm. Three different specimens are being examined in this test.

(a)



(b)

Figure 3 (a) Sample size according to ASTM E23-16b, b) Impact test sample

3.0 RESULTS AND DISCUSSION

3.1 Tensile Test Result

Each specimen's utmost load (P_{max}) is determined using the Universal testing machine (UTM) and tensile test specimens. The test results are tensile strength ($\sigma_{tensile}$), strain (ε), and modulus of elasticity (MOE). The tensile strength of each model was determined by calculating maximum stress using the maximum load values obtained from the machine. Subsequently, the results were evaluated according to the minimum standard requirement for mechanical properties set by the Indonesian Bureau of Classification (BKI) of 400 MPa [22], as outlined in Table 5.

Table 5 ST 42 Steel Tensile Strength Test Results

Model	No	P_{max} (kN)	$\sigma_{tensile}$ (Mpa)	Mean $\sigma_{tensile}$ (Mpa)	SD	% Diff (%)
	1	51.5	431			
A	2	49.7	417	423.56	7.02	
	3	48.8	423			
	1	50.6	381			
B	2	46	390	382.45	7.09	-9.70
	3	51.5	376			
	1	48.2	331			
C	2	46.7	347	332.35	14.05	-21.54
	3	48.4	319			
	1	48.4	368			
D	2	47.2	379	368.64	10.02	-12.97
	3	48.3	359			
BKI Standard [22]				**400**		

The data from the tensile test indicate that the restoration procedure significantly impacts the material's strength. The rewelding ST 24 steel procedure decreased the tensile strength starting from the value after repair welding.

Table 5 and Figure 4 provide the data on the tensile strength of ST 24 steel both before and after undergoing repair welding operation. The base material without re-welding used in this study demonstrated the highest tensile strength value of 423.56 MPa, surpassing the requirements set by the BKI standard [22]. The specimen with one-time re-welding showed a tensile strength value of 382.45 MPa, while the two times re-welding material displayed a value of 332.35 MPa. The two-times repair material with post-weld heat treatment showed a tensile strength value of 368.64 MPa.

There is a downward trend after the material has been rewelded and then an increase after it has been repaired by welding twice with post-weld heat treatment. The lowest tensile strength value from the two times repair welding process without post-weld heat treatment is 332.35 Mpa. There was an increase in tensile strength of 11% when heat-treated ST42 steel by re-welding two times. Hence, the ST 24 steel underwent two times repair welding process with post-weld heat treatment, which is still feasible because the tensile strength value is still higher than the value of ST 24 steel without repair welding.

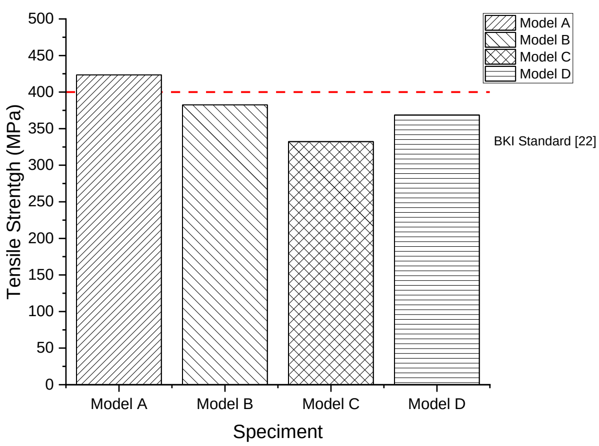


Figure 4 Average Tensile Stress under four different test variants

Tables 6 and 7 show the comparative findings for tensile strain and MOE under various repair welding variations. Figure 5 shows the specimens with the maximum strain without rewelding (model A), followed by one-time repair welding (model B), two-time repair welding with PWHT (model D), and two-time repair welding (model C). When a force is applied to a specimen, MOE is used to determine its resistance to elastic deformation. The slope of the stress-strain curve in the elastic deformation zone was defined as a specimen's MOE. Figure 8 indicates that different amounts of repair welding resulted in different MOE values. The representative without repair welding (Model A) had the greatest MOE of 11.27 GPa. A specimen with one times rewelding (model B) had a 20% lower MOE than a specimen without repair welding (model A). Furthermore, the samples with two-time repair welding with PWHT (Model D) had a higher trend, around 27%, than those without (Model C).

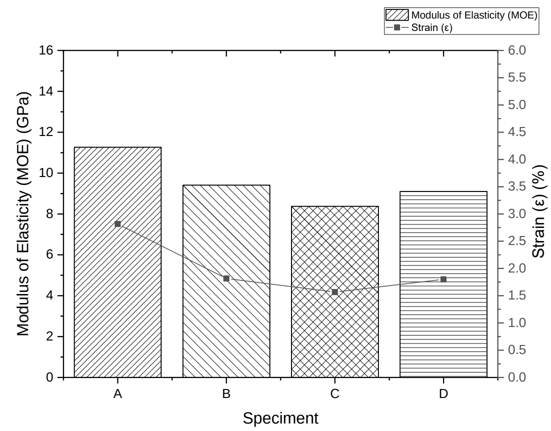


Figure 5 Modulus elasticity and strain results for several test versions

Table 6 ST 42 Steel Tensile Strain Test Results

Variation	No	l_0 (mm)	Δl (mm)	Mean Δl (mm)	ε (%)	Mean ε (%)	SD
	1	200	6.00		3.00		
A	2	200	5.10	5.63	2.55	2.82	0.24
	3	200	5.80		2.90		
	1	200	3.70		1.85		
B	2	200	3.80	3.63	1.90	1.82	0.10
	3	200	3.40		1.70		
	1	200	3.00		1.50		
C	2	200	3.50	3.13	1.75	1.57	0.16
	3	200	2.90		1.45		
	1	200	4.70		2.35		
D	2	200	3.00	3.60	1.50	1.80	0.48
	3	200	3.10		1.55		

Table 7 ST 42 steel modulus of elasticity test results

Model	No	$\sigma_{tensile}$ (Mpa)	ε (%)	MOE (GPa)	Mean MOE (GPa)	SD	% Diff (%)
	1	431	3.75	11.49			
A	2	417	3.40	12.26	11.78	0.42	
	3	423	3.65	11.59			
	1	381	4.15	9.18			
B	2	390	4.25	9.18	9.37	0.34	-20.44
	3	376	3.85	9.77			
	1	331	5.25	6.30			
C	2	347	5.10	6.80	6.91	0.75	-40.90
	3	319	4.10	7.78			
	1	368	4.10	8.98			
D	2	379	4.00	9.48	8.81	0.76	-25.23
	3	359	4.50	7.98			

3.2 Bending Test Result

Flexural testing was performed to ascertain the sample's capacity to withstand the utmost bending strain before it fractures. The ST 42 steel buckling test refers to the ASTM E290-14 [20]; the test was conducted on each variation without re-welding and re-welding variations in 12 specimens, with identical test dimensions for each model. Beginning the testing procedure is the preparation of the computer and hydraulic machinery. In addition, the specimen is deposited on the machine and then dragged by a hydraulic machine beginning at 0 kg, causing the object to deform at its maximal capacity.

The test outcomes are displayed in Tables 8 and Figure 6. The model without re-welding treatment (Model A) has a maximum bending stress value of 662.41 MPa. Re-welding resulted in a 7.87% reduction in bending stress value for one-time re-welding (Model B) with a bending stress value of 611.50 MPa and a 27.20% decrease in bending stress value for two-times re-welding (Model C) with a bending stress value of 482.20 MPa. The treatment of the model that got two re-welds and a post-weld heat treatment (Model D) was found to enhance the bending stress value of the specimen by 13% when compared to the model that had two times re-reasoning (Model C), which had a bending stress value of 544.35MPa. In addition, the bending stress of every model used in this study was more than the cutoff value established by BKI (305 MPa) [22], which was used as a benchmark.

The correction of bending stress values for steel that has been re-welded twice occurs because post-weld heat treatment affects the microstructure of the base material and the weld area where heat treatment during PWHT can improve the microstructure of the base material due to re-welding as found by Selvabharathi [23] where the Ferrite ratio decreased in the PWHT coated samples due to the involvement of heat which improved the bending strength.

Table 8 ST 42 Steel Bending Test Results

Model	No	P_{max} (kN)	$\sigma_{bending}$ (Mpa)	Mean $\sigma_{bending}$ (Mpa)	SD	% Diff (%)
	1	21.22	636.6			
A	2	22.01	660.3	662.41	27.07	
	3	23.02	690.6			
	1	20.63	618.9			
B	2	19.93	597.9	611.50	11.81	-7.87
	3	20.59	617.7			
	1	16.13	483.9			
C	2	16.45	493.5	482.20	12.24	-27.20
	3	15.64	469.2			
	1	18.96	568.8			
D	2	18.3	549.0	544.35	26.83	-17.82
	3	17.19	515.7			
BKI Standard [22]				305		

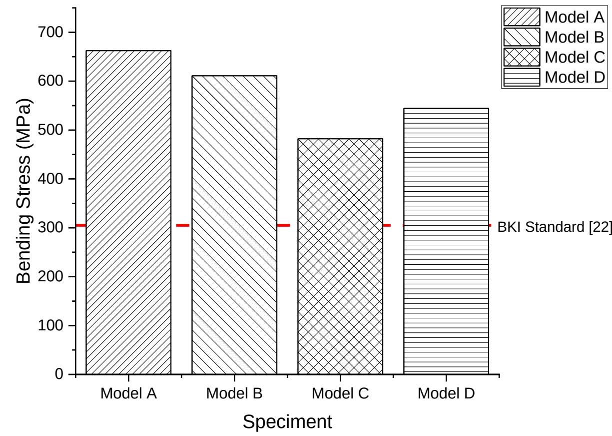


Figure 6 Average Bending Stress under four different test variants

3.3 Impact Test Result

In the given Charpy impact test scenario, the word "impact strength" was used to refer to the material's capability to withstand the energy demands of a load rapidly applied to it. An impact test is carried out whenever a ship structure is subjected to impact load due to a slamming phenomenon, a ship collision, a collision between a ship and a pier, a collision between a ship and its bridge, etc. The brittleness of the test specimen had to be evaluated concerning an impact load, which was the reason for the impact testing. Impact testing demands a significant amount of energy in order to splinter the specimen in a single blow using a hammer of a certain weight that is dropped from a certain angle. After testing every model of a particular material, the impact energy of that material, measured in joules per meter, is obtained and can be found in Table 9.

Table 9 ST 42 Steel Impact Test Results

Model	No	E_{TC} (J)	I_s (J/m)	Mean I_s (J/m)	SD	% Diff (%)
	1	60.13	751.6			
A	2	59.72	746.5	744.83	7.76	
	3	58.91	736.4			
	1	52.13	651.6			
B	2	51.03	637.9	642.76	7.57	-13.70
	3	51.14	639.3			
	1	47.19	589.9			
C	2	46.12	576.5	586.79	9.15	-21.22
	3	47.52	594.0			
	1	49.72	621.5			
D	2	50.80	635.0	630.12	7.49	-15.40
	3	50.71	633.9			
BKI Standard [22]				**470**		

As shown in Figure 7, the impact energy of the PWHT samples (Model D) is higher than that of the no PWHT samples (Model C) for every design put through the testing process. However, the specimens that have never been rewelded (Model A) and those that have been rewelded once (Model B) have the highest values, with 744.83 J/m and 642.76 J/m, respectively. Because re-welding treatment causes the weld joint to endure repeated heating, changing the microstructure and affecting the impact strength. The sample with two re-weldings without PWHT had the lowest impact energy value of all the variations, at 586.79 J/m. This was due to the fact that the weld joint was subjected to repeated heating [24].

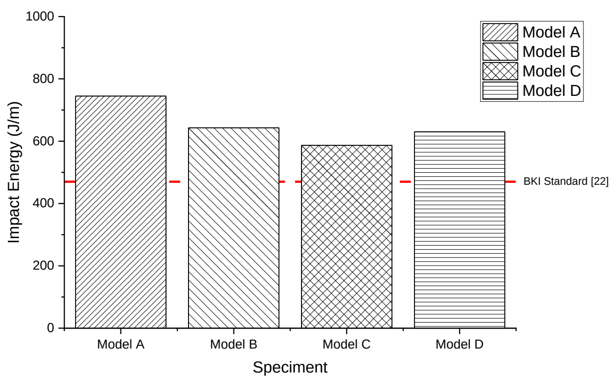


Figure 7. Average Impact Energy under four different test variants

Ahead of annealing, it was discovered that the re-welding procedure for all variants (Model B - D) had lower impact energy than the sample without rewelding (Model A). Compared to model A, the impact energies were reduced by 13% to 21%, with the most significant reduction of 21.22% happening in the model with repeated welding two times without heat treatment. The impact strength of the samples may have diminished because internal tensions (residual stresses) were released during the annealing phases [25], [26]. The impact strength value increases by 7% in the model with two times rewelding with heat treatment (Model D) compared to the model with two times rewelding without heat treatment (Model C) due to the recovery process in the dislocation structure through heat treatment at the base material. This is consistent with prior findings by Schönmaier *et al*. [27]. PWHT at a specific temperature reduces dislocation density significantly compared to the as-welded condition. Regardless of the phenomena seen in all test models, the impact energy due to re-welding and PWHT in this research met the BKI Impact Energy requirement of 470 MPa [22].

4.0 CONCLUSION

Various mechanical tests were conducted to investigate the influence of post-weld heat treatment on re-welding in shielded metal arc welding joints constructed of ST42 steel. According to the results of the experimental testing, there was a 20-40% decrease in the value of the mechanical properties as a result of re-welding to the St42 steel material, with the most significant reduction in mechanical properties for the modulus elasticity of St42 steel with two times re-welding.

The results of the post-weld heat treatment (PWHT) performed on ST42 steel by re-welding twice compared to ST42 steel by re-welding twice without heat treatment revealed an increase of 6-20% in the mechanical property values, with the most significant growth occurring in the modulus elasticity value, which increased by 20%. As a whole, the appropriate use of PWHT on materials that have been re-welded can affect microstructure recovery through heat treatment of the base material.

Several gaps in our findings around microstructure in material follow from our results. Further research would benefit, including exploring the microstructural changes induced by PWHT during repair welding, which is crucial. The study should delve deeper into understanding how PWHT affects phases, grain boundaries, and precipitates in the repaired zone. This could lead to a better understanding of how microstructural transformations influence the weldments' mechanical properties and long-term performance.

List of Abbreviations

Abbreviation	Definition
ASTM	American Society for Testing Materials
AWS	American Welding Society
BKI	Indonesian Bureau Classification (In Indonesia)
FCAW	Flux Cored Arc Welding
GMAW	Gas Metal Arc Welding
MOE	Modulus of Elasticity
PWHT	Post-Weld Heat Treatment
SD	Standard Deviation
SMAW	Shielded Metal Arc Welding
UTM	Universal Testing Machine
WPS	Welding Procedure Specification

Acknowledgement

The RKAT Fund of the Faculty of Engineering funded this research in 2023, Diponegoro University, with a scheme Strategic Research No: 31/UN7.F3/HK/VI/2023.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

References

[1] A. F. Zakki and S. Jokosisworo. 2012. Analisa Kekuatan Tarik Penyambungan Pelat dengan Ketebalan Berbeda pada Type Sambungan Butt Joint. *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan*. 5(3): 152-158.

[2] N. M. Hunter and H. W. Townshend. 1935. Shipbuilding by Welding. *Nature*. 136(3449): 906-907. Doi: 10.1038/136906c0.

[3] R. W. Jr. Messler. 2004. Chapter 6 – Welding as a Joining Process.

[4] S. Bruni and F. Braghin. 2009. 15 - Effect of Damage on Vehicle Dynamics. In Lewis and U. Olofsson (Eds.), *Wheel–Rail Interface Handbook* (456-476). R. Woodhead Publishing. Doi: https://doi.org/10.1533/9781845696788.1.456.

[5] M. F. Mat, A. F. Musah, A. G. Tham, and S. A. Sulaiman. 2015. Evaluation of Rail Head Surface Repair using smaw Process with Pre Heating Condition. *J Teknol*. 76(6). Doi: 10.11113/jt.v76.5682.

[6] O. Popovic and R. Prokic-Cvetkovic, "Surface Welding as a Way of Railway Maintenance," in *Mechanical Engineering*, M. Gokcek, Ed., Rijeka: IntechOpen, 2012, p. Ch. 10. doi: 10.5772/35403.

[7] S. Shinichi, R. Muraoka, T. Obinata, E. Shigeru, T. Horita, and K. Omata. 2004. Steel Products for Shipbuilding. JFE Technical Report.

[8] J. Billingham. 1994. Steel: A Versatile Advanced Material in Marine Environments. *Ironmaking & Steelmaking*. 21: 452-458.

[9] H. Lücken, A. Dr.-Ing. Kern, and U. Schriever. 2008. High-Performance Steel Grades for Special Applications in Ships and Offshore Constructions. *International Offshore and Polar Engineering Conference*, Canada.

[10] N. Bailey. 1994. 2 - Potential Welding Problem Areas. In N. Bailey (Ed.), *Weldability of Ferritic Steels* (45–53). Woodhead Publishing. Doi: https://doi.org/10.1533/9781845698935.45.

[11] M. Stewart. 2021. 11 - Tubular Heat Exchanger Inspection, Maintenance, and Repair. In M. Stewart (Ed.), *Surface Production Operations* (555-668). Boston: Gulf Professional Publishing. Doi: https://doi.org/10.1016/B978-0-12-803722-5.00011-2.

[12] J. E. M. Braid and J. A. Gianetto. 1986. The Effects of pwht on the Toughness of Shielded Metal Arc Weld Metals for Use in Canadian Offshore Structure Fabrication. In Welding Institute of Canada (Ed.), *Welding for Challenging Environments* (145-155). Pergamon. Doi: https://doi.org/10.1016/B978-0-08-031866-0.50018-4.

[13] J. C. F. Jorge *et al.* 2019. Influence of Welding Procedure and PWHT on HSLA Steel Weld Metals. *Journal of Materials Research and Technology*. 8(1): 561-571. Doi: 10.1016/j.jmrt.2018.05.007.

[14] L. D. J. Jorge *et al.* 2018. Mechanical Properties and Microstructure of SMAW Welded and Thermically Treated HSLA-80 Steel. *Journal of Materials Research and Technology*. 7(4): 598-605. Doi: 10.1016/j.jmrt.2018.08.007.

[15] H. N. Farneze, J. C. F. Jorge, L. F. G. de Souza, and I. de S. Bott. 2010. Comparative Study of High-strength steel Weld Metals Obtained by the SMAW and FCAW Processes for Offshore Applications and Mooring Chains. *Welding International*. 24(12): 903-910. Doi: 10.1080/09507110903568943.

[16] A. J. M. Gomes, J. C. F. Jorge, L. F. G. de Souza, and I. de Souza Bott. 2013. Influence of Chemical Composition and Post Welding Heat Treatment on the Microstructure and Mechanical Properties of High Strength Steel Weld Metals. *Materials Science Forum*. 758. Doi: 10.4028/www.scientific.net/MSF.758.21.

[17] J. R. Davis and Davis & Associates. 1996. ASM Specialty Handbook - Carbon and Alloy Steels. In ASM Handbooks Series. OH: ASM International. https://books.google.co.id/books?id=RnNoQgAACAAJ

[18] M. Stewart. 2021. 11 - Tubular Heat Exchanger Inspection, Maintenance, and Repair. In M. Stewart (Ed.), *Surface Production Operations* (555-668). Boston: Gulf Professional Publishing. Doi: https://doi.org/10.1016/B978-0-12-803722-5.00011-2.

[19] ASTM International. 2013. E8/E8M - 13a Standard Test Methods for Tension Testing of Metallic Materials. Doi: 10.1520/E0008_E0008M-13A.

[20] ASTM International. 2014. E290 - 14 Standard Test Methods for Bend Testing of Material for Ductility. Doi: 10.1520/E0290-14.

[21] ASTM International. 2016. E23−16b: Standard Test Methods for Notched Bar Impact Testing of Metallic Materials. Doi: 10.1520/E0023-16B.

[22] Biro Klasifikasi Indonesia. 2022. Rules for Welding. In *Part 1 Seagoing Ships*. www.bki.co.id.

[23] R. Selvabharathi. 2019. Effect of Post Weld Heat Treatment and TiAlSiN Coating on the Tensile Strength of Autogenous Plasma Arc Welding of Duplex/super Austenitic Stainless Steels. *J Manuf Process*. 38: 135-147. Doi: 10.1016/j.jmapro.2019.01.008.

[24] C. M. Lin, H. L. Tsai, C. Der Cheng, and C. Yang. 2012. Effect of Repeated Weld-repairs on Microstructure, Texture, Impact Properties and Corrosion Properties of AISI 304L Stainless Steel. *Eng Fail Anal*. 21: 9-20. Doi: 10.1016/j.engfailanal.2011.11.014.

[25] N. A. Raji and O. O. Oluwole. 2012. Effect of Soaking Time on the Mechanical Properties of Annealed Cold-Drawn Low Carbon Steel. *Materials Sciences and Applications*. 03(08): 513-518. Doi: 10.4236/msa.2012.38072.

[26] I. Oladele, D. Alonge, T. Betiku, A. Barnabas, and S. Shittu. 2019. Distinctiveness of Welding Joints Design Based on Mechanical and Corrosion Environmental Influence on Low Carbon Steel. *Advanced Technologies & Materials*. 44(2): 13-19. Doi: 10.24867/atm-2019-2-003.

[27] H. Schönmaier, C. Fleißner-Rieger, R. Krein, M. Schmitz-Niederau, and R. Schnitzer. 2021. On the Impact of Post Weld Heat Treatment on the Microstructure and Mechanical Properties of Creep Resistant 2.25Cr–1Mo–0.25V Weld Metal. *J Mater Sci*. 56(36): 20208-20223. Doi: 10.1007/s10853-021-06618-2.