Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin

e-ISSN	: 2549-1999	No.	: 1	Month	: February
p-ISSN	: 1693-5462	Volume	: 21	Year	: 2023

Received on 2022-12-30, Reviewed on 2023-02-01, Revised on 2023-02-09, Accepted on 2023-02-09, Copy edited on 2023-02-12, Layout edited 2023-02-25 and Available online on 2028-02-28

Mechanical properties analysis of ASME SA-106 Grade B pipe material welded joints in combination of SMAW and GTAW Welding

Marzuki*, Turmizi, Bukhari, Nawawi Juhan, Akhyar Ibrahim, Aris Khatami

Department of Mechanical Engineering, State Polytechnic of Lhokseumawe, Lhokseumawe 24301, Indonesia
*Correspoding author: marzuki@pnl.ac.id

Abstract

ASME SA 106 Grade B pipe material or more familiarly known as API 5L Grade B Pipe in the oil and gas industry is widely used in distribution pipes with quite high pressure and temperature, especially in gas and steam distribution lines. During operation, damage and leakage often occur due to earthquakes and other external loads. The strength of the resulting welded joint and the selection of the appropriate welding method are strategic issues to be studied and researched. This study aims to determine the hardness and strength of the welded joint of 6 inch schedule pipe 80 API 5L Grade B using a combination Gas Tungsten Arc Welding (GTAW) and Shielded Metal Arc Welding (SMAW) welding process and setting welding parameters with different current variations for 6 layers design. The electrode used is ER 70S-6 for root pass welding using the GTAW process, and the SMAW process uses the E 7016 electrode for hot pass and cover pass welding, the groove used is the singgle V groove with an angle of 60 degrees. The tests carried out are non-destructive testing, tensile testing and hardness tests. The results of the study showed an increase in the value of tensile strength reaching 499 Mpa, yield strength reaching 364 MPa and elongation is became 13%. The hardness test show that the highest hardness is in the weld metal area with an average hardness reaching 68.10 HRC, then in the Heat Affected Zone (HAZ) area with an average value of 63.55 HRC and the average hardness value in the parent material or based metal area reaches 61.00 HRC. These results indicate the combination welding method between GTAW and SMAW process are suitable to be applied for joinning API 5L or ASME SA 106 Grade B pipes material.

Keywords:
GTAW, SMAW, Tensile Strength, Hardness, HAZ

1 Introduction

Mechanical properties contained by a material such as ductility, hardness, strength, and toughness. Mechanical properties are the basic reference for carrying out subsequent fabrication processes for a material in advanced. The advanced fabrication process will of course change the mechanical properties previously conceived. Therefore, destructive and non-destructive tests are needed to determine changes in mechanical properties after the fabrication process [1].

The welding process is a fabrication process that is very commonly used in the petroleum and natural gas industries, because almost all pipe installation fabrications use welded joints. This is because the welding process has high integrity and efficiency, leak-proof, strong, durable, and a very rational cost [2] [3].

ASME SA-106 Grade B material, which is also known as ASTM A106 pipe, is a seemless carbon steel pipe [4][5]. In the pipe industry, it is better known as American Petroleum Institute (API) 5L pipe. This pipe is generally used by the petroleum and natural gas industries to distribute pressurized fluids and high temperature resistance [6]. This is in accordance with the specifications required in industrial world standards to be applied as a raw material for natural gas transmission pipes that meet API 5L standards.

Leaks in API 5L Grade B pipes will have impacts that will harm humans such as fires and environmental pollution. in Indonesia, especially in the Aceh province, the existing API 5L Grade B pipelines are mostly located in residential areas, areas of human traffic, industry and agricultural land (plantations and rice fields) [7].

The pipe joinning SA-106 can be done with Gas Tungsten Arc Wleding (GTAW) and Shielded Metal Arc Welding (SMAW) processes or a combination of the two to get good quality and strength of API 5L pipe joints [8][9]. GTAW welding is welding with good quality, but this type of welding is classified as expensive welding [10]. Whereas SMAW is welding with lower economic value and welding quality [2]. In SMAW welding generally there are still frequent defects at the time of penetration due to not being shielded by the gas. Therefore, the combination of these two types of welding began to be carried out in several types of welding joints to cover the shortcomings of each weld.

The GTAW process uses Argon or Helium as a shielding gas to prevent Oxygen and Hydrogen from entering the weld area. The SMAW process is an electric arc welding process in which heat energy for welding is generated by an electric arc formed between the wrapped metal electrode and the work piece. Heat energy in the SMAW welding process is generated due to the electric ion (cathode and anode) jumps that occur at the tip of the electrode and the surface of the material.

The selection of filler metal used between the two types of welding is fundamentally different, therefore the selection of filler rods and electrodes is very important because they must have similar characteristics between the two fillers and the material to be welded. The results of combined two welding processes are still often found to have porosity defects between the mixing of filler metal between these two welding processes. Some other research has been done on other material specifications related to combinations welding, the result generally has shown the mechanical properties such as Tensile strength and hardness test there was increased [11] [12] [13] [14] [15].

The purpose of this research is intended to analyze the mechanical properties, which are tensile strength and hardness from the process of joining two different welding processes using different electrodes or filler metals. The quality and performance of the welds can be tested by visual inspection, Non destructive test and macro examination before hardness and tensile test is performed [16].

1.1 Gas Tungsten Arc Welding

This welding method is generally used to weld geometric and seam joints of plates, sheets, pipes, tubes and other structural shapes with a thickness of less than 10 mm. [2] [3] [17]. Applications in the oil and gas industries this method is often used for full welding of pipe joints with a diameter of less than 2 inches or only for root pass welding.

Welding or often also called Tungsten Inert Gas (TIG) is a form of electric arc welding that uses inert gas as a shield with tungsten or wolfram as a conductor of electric current to produce welds [18]. This process joints metals by heating them so that they melt through an arc formed from the tungsten electrode and the metal. The electrode used is intended as a foundation for the creation of an electric arc. The results of this welding can be used in almost all metals and have very good quality result [19].

In general, filler metal (filler rod) originating from outside aims to fill the gas at the joint, the electric arc melts the filler metal together with the base metal that occurs between the electrode and the base metal.

In GTAW welding, filler metal is also known as filler rod which functions to fill in the root pass position, which is carried out at the earliest stage of welding or at the initial joining stage.

The quality of GTAW welding results is highly dependent on the correct and appropriate setting of welding parameters, such as;

The use of electric current in accordance with the allowable current:

1. Appropriate welding voltage settings
2. DCEN polarity determination for DC and DCEP for AC
3. Setting the appropriate welding speed
4. Selection of the type and diameter of the filler rod according to the parent material and the width of the root gap

1.2 Shielded metal arc welding

SMAW welding is the most flexible because it can be applied to most ferrous and nonferrous metals with various thicknesses, shapes, and positions and is relatively economical [20].

SMAW welding is a manual arc welding process in which welding heat is generated by an electric arc between the flux-protected electrode and the workpiece. The base metal in this welding experiences melting due to heating from the electric arc that arises between the tip of the electrode and the surface of the workpiece. The electric arc is generated by the welding machine. The electrode used is in the form of a wire wrapped in a shield in the form of flux. This electrode during welding will melt together with the base metal and freeze together to become part of the weld metal [21].

The molten metal transfer pattern greatly affects the weldability of the metal. The metal has high weldability when the transfer occurs with fine grain. The pattern of fluid transfer is affected by the highs and lows of the current and the composition of the flux material used. The flux material used to cover the electrode during welding melts and forms a slag that covers the molten metal which collects at the joint and acts as an oxidation barrier [22].

The quality of SMAW welding results is highly dependent on the correct and appropriate setting of welding parameters, such as [20] [23] ;

1. The use of electric current in accordance with the allowable current
2. Appropriate welding voltage settings
3. Correct polarity determination
4. Setting the appropriate welding speed
5. Selection of the type and diameter of the electrode according to the parent material and the width of the root gap
6. Proper and suitable polarity selection

1.3 Material ASME SA-106 Grade B

In ASME Section IX, SA-106 Grade B materials are grouped into a group of materials with P-No.1 Group Number 1 and A Number 1, AWS API 5L grade B standard specifications for seamless pipes, with a minimum tensile strength of 415 Mpa, minimum yield strength of 240 MPa and Elongation 20% [4][16]. API 5L standard specification covers seamless and welded line pipe [24]. This pipe is manufactured from the hot rolling process for coil or plate. The final deformation is carried out in a certain temperature range, leading to a material condition with certain properties that cannot be achieved or repeated by heat treatment alone, and such deformation is followed by cooling, possibly with increased cooling rates, with or without tempering. [24][25] [26].

The purpose of this standard is to provide pipe standards suitable for use in the distribution of gas, air, and oil in both the oil and natural gas industries. So, the ASME SA-106 Grade B material is only intended to distribute high-pressure and high-temperature fluids.

Carbon steel pipes are widely used in the oil and gas industry. This pipe has high strength, supple, weldable and durable. The weakness is that it is not resistant to corrosion and sea water attacks. Because of this, pipes that are installed under the sea or in the ground will use a special coating cathodic protection so that it is not in a series of corrosive substances.

API 5L Grade B pipe is a high-strength steel pipe specification for pipeline construction purposes where high strength and pressure resistance are required. Fully killed is a type of steel that has been processed by adding deoxidizing elements such as aluminum (Al) and silicon (Si) in certain levels. The process is usually carried out in a mold where after freezing the steel shows shrinkage on the top (top of the ingot) [24], [27].

The main advantages of using pipes according to the API 5L standards are [3]:

1. Resistance to dispersive cracking forces in long pipes
2. Resistance to high pressure and temperature
3. Long-life service and low cost
4. Has good weldability

2 Materials and methods

The material used in this study is a 6” schedule 80 SA-106 Grade B pipe. Then the material is to be machined for the welding process with a length of 150 mm and a thickness of 11 mm, the groove design angle is 30 deg. The polarity of GTAW welding is the Direct Current Electrode Negative (DCEN and the SMAW welding is Direct Current Electrode Positive (DCEP) with welding butt joint single V groove position 6G up-hill.

The type of gas used for the GTAW process is Argon with a quality of 99.9% pure, amount of gas volume or flowmeter setting is 10 liter/minute. Type of tungsten electrode used is Lanthanium pure with an electrode diameter of 2 mm with color blue (EWLa-2/WLa 20) which current use permitted 70-150 ampere in DCEN Polarity. The filler rod used is ER70S-6 which is classified with AWS/ASME SFA 5.18 ER70S-6 which is commonly used for general structural steels, pipe steels, and root pass pipe welding. Setting the welding parameters as shown in Table 1.

Table 1. Setting the welding parameters

Layer Numb.	Filler Rod/ Electroda	Electrode Diameter	Volt/ Ampere	Speed (mm/menit)
1	ER 70S-6	2,4 mm	12/90	45
2	ER 70S-6	2,4 mm	12/100	50
3	E 7016	3,2 mm	22/120	90
4	E 7016	3,2 mm	23/125	110
5	E 7016	3,2 mm	23/125	110
6	E 7016	3,2 mm	23/125	110

The chemical composition of the SA-106 Grade B pipe is based on the Mill certificate issued by the product manufacturing company as listed in Table 2.

Table 2. Chemical Composition of SA-106 Grade B

ChemicalCompositions	Amount(%)
C	0.174
Si	0.24
Mn	0.79
P	0.012
S	0.009
Cr	0.120
Ni	0.080
Mo	0.030
Cu	0.140
Al	0.041

The groove design for combined GTAW and SMAW welding is shown in Fig.1. Fig.1 Informs that GTAW welding is for a two-layer root pass with a thickness of 4 mm, while SMAW welding is for a four-layer hot pass with a thickness of 6 mm plus a cover pass of 1.5 mm.

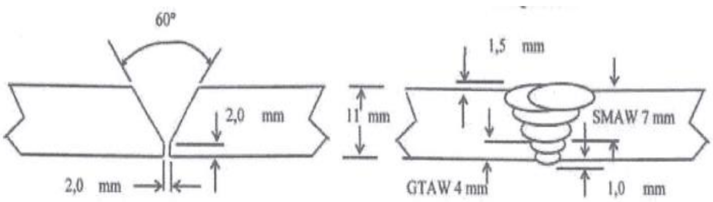


Fig. 1. The groove design for combined GTAW and SMAW welding

The welding process is carried out by a certified welder, and to ensure that the welding results are free from defects. Testing for quality and performance was carried out by penetrant testing, 2 Root bends, 2 face bends and radiography. After ensuring that the welding results are free from defects and discontinuities, then a tensile test specimen is made using the ASME Section IX standard QW.462.1(c) as shown in Fig.2 [16]. The specimen has been set by dimension width 20, length 200 mm mm and thick 12 mm.

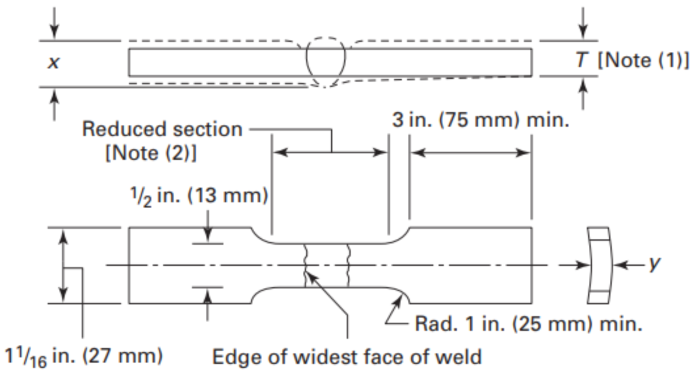


Fig. 2. Tensile test specimen according to ASME SEC.IX QW.462.1(c).

The next stage is making specimens for hardness testing. A hardness test is performed on specimens using the HRC (Hardness Rockwell cone) method in accordance with ASME Section IX [28]. The determination of test points which are located on based metal, weld metal, and Heat Affected Zone (HAZ) as shown in Fig. 3.

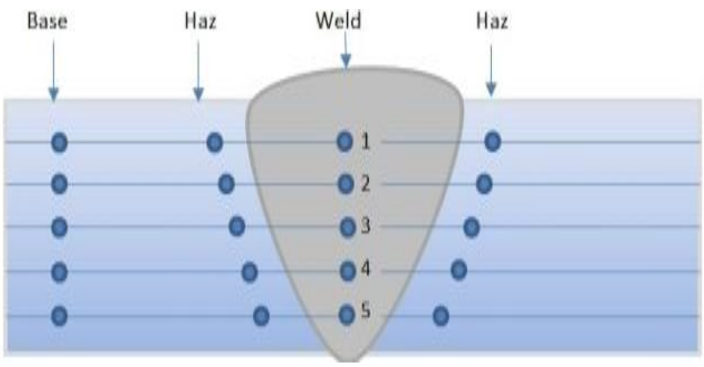


Fig. 3. Determination of hardness test points

The step of this research is preparation for making sampel for performance and quality welding result by using macro examination or macro etching. For technical samples for testing the performance and quality of welding results, refer to ASME Section IX QW463.2 as shown in Fig. 4 [16].

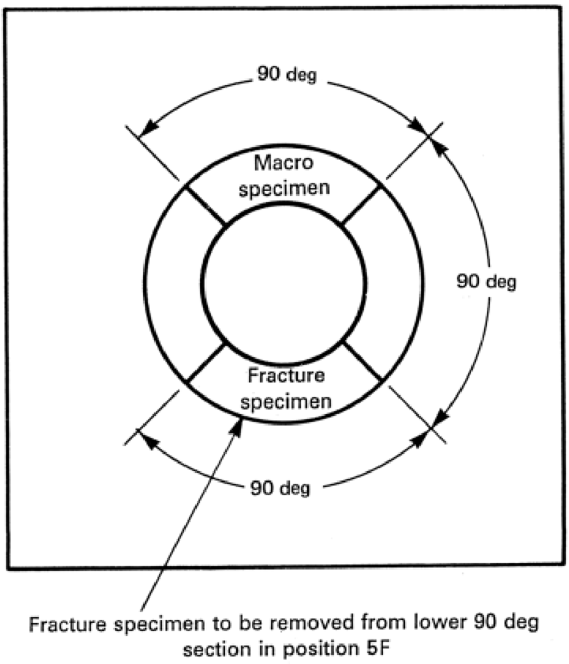


Fig. 4. Technical Specimen Retrieval Procedure ASME Section IX for Macro examination QW463.2 (h)

Macro examination is a visual assessment of a cross-section of a weld at low magnification, often used to evaluate carbon and low alloy steel products such as billets, bars, blooms and forgings and welds. There are several procedures for grading steel specimens by a series of cross-sectional photographs of the welds which show the occurrence of certain conditions and are applicable to carbon steels and low alloy steels.

Macro examinations is also carried out on the weld metal cross-section of the material being welded. During the inspection, a number of features can be determined including the order in which the welds are performed. Any defects in the test specimens will be assessed to meet the relevant specifications, such as; slag, porosity, lack of weld penetration, lack of sidewall fusion, and poor weld profile. Such defects are sought either by standard visual inspection or by magnification of up to 5X [16].

3 Results and discussion

3.1 Testing the quality and performance of welded joints result

The results of the macro etching test with a fixel magnification of 3.75 times, obtained an image of the weld as shown in Fig. 5.

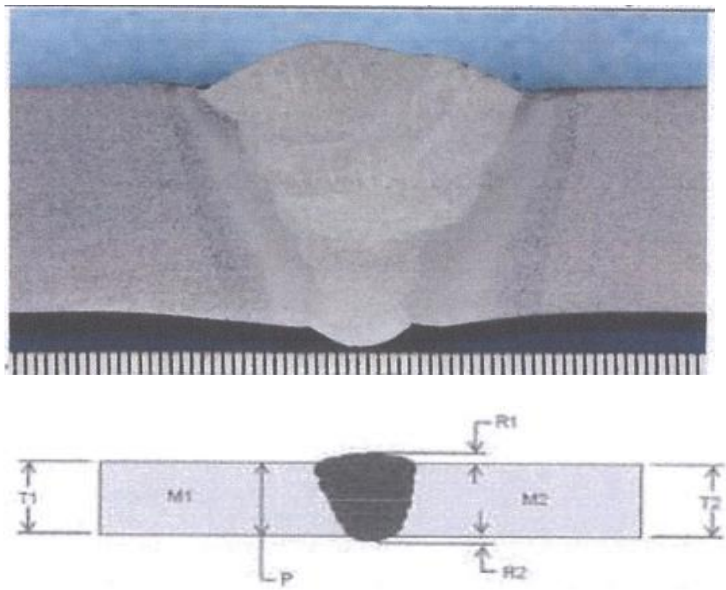


Fig. 5. Photo of macro etching results

Notes:
M1 = Material 1 Pipe SA 106 Gr.B
M2 = Material 2 Pipe SA 106 Gr.B
T1 = Thickness of material 1: 10.97mm
T2 = Thickness material 2: 10.97mm
R1 = Height of face reinforcement
R2 = Height of root reinforcement
P = joint penetration groove weld size

Fig. 5 Explains that the P value is 11.10 mm, the R1 value is 2.34 mm and the R2 is 1.10 mm. The results of this visual measurement did not reveal any defects in the left and right-side parent material, left and right side HAZ and welds metal.

Radiographic test results using isotope 1r-192 with double wall double viewing exposure, with exposure time of 3 minutes and 27 seconds, IQI placement film side did not find Incomplete Penetration, Incomplete Fusion, Worm Hole, Slag Inclusion, Porosity, and Crack.

3.2 Tensile strength testing result

The results of the tensile test of the API 5L Grade B pipe joints after GTAW and SMAW combined welding using the ASME Sec.IX standard, obtained the tensile strength as shown in Fig 6**.** Shows the location of the breakpoint of the test specimen after a tensile test. Fig.6 informs that the three specimens A1, A2, and A3 broke off or breakpoint in the parent material (Base Metal). This result was proof that weld metal has more strength than based metal. The data on the results of the tensile test that has been carried out on the API 5L Grade B pipe welded joints is shown in Fig. 7.

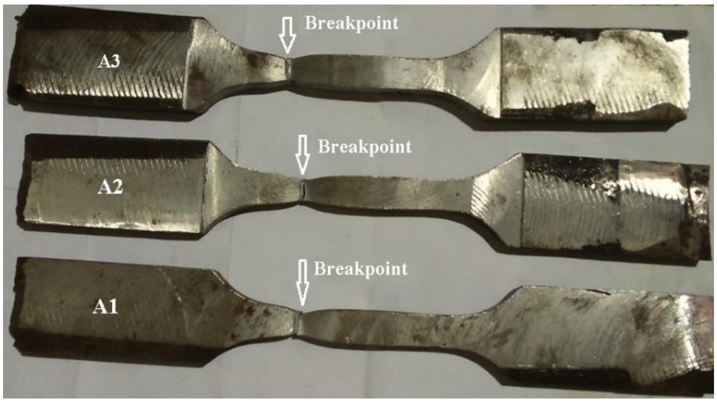
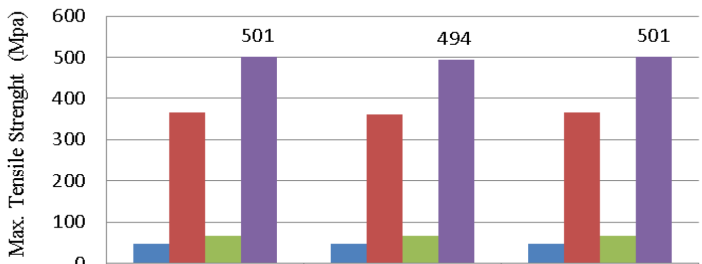


Fig. 6. Location of the breakpoint of the test specimen



	A1	A2	A3
Fy kN	48	48	48
σy Mpa	365	362	365
Fu kN	66	65	66
σu Mpa	501	494	501

Fig. 7. Data result of specimen Tensile test

From the results of the tensile strength test of the API 5L Grade B pipe welded joint, the maximum tensile strength (σu) was found in specimens A1 and A3. Maximum yield strength (σy) also occurs in specimens A1 and A3. So, the maximum tensile strength is directly proportional to the yield strength.

Based on Fig. 7**,** the value of the maximum tensile strength in API 5L grade B pipe welded joints by combining two types of welding methods, which is GTAW used for the root pass welding uses a current of 90 for layer 1 and a current of 100 A for layer 2, while SMAW is used for the hot pass and cover pass welding. welding of layer 3 uses a current of 120 A, and layers 4, 5, and 6 use a current of 125 A.

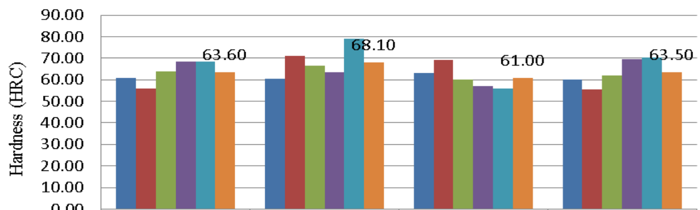
The maximum tensile strength value of the pipe joints at specimens A1 and A3 are the same at 501 Mpa (51.11 Kg/mm²), and the tensile strength value for specimen A2 is 494 Mpa (50.38 kg/mm²). The average value of the tensile strength of the three specimens for API 5L grade B pipe connections is 499MPa (51kg/mm²).

In specimen A2 the value of tensile strength decreased compared to specimens A1 and A3 up to 7 MPa, while the welding process and welding parameter settings used were the same. The decrease in the tensile strength value of the A2 specimen may be caused by the structural composition of the parent material itself and other influences outside the procedure which have not yet been identified.

Due to visual investigations, specimen A2 broke up in the same way, which has at the parent material and the percentage of elongation was the same as specimens A3 and A1. It's just that surface or broken cross-sections are a little different. This is possible for further studies using a Scanning Electron Microscope (SEM) to be able to ascertain the possible causes of the decrease in the tensile strength value. However, in the realm of research, these results are acceptable in reference to the ASME Section IX standard that the minimum tensile strength is 415 Mpa.

3.3 Hardness test results

Hardness testing using the Rockwell C method with a test load of 150 Kgf and a load time of 20 s produced data from specimens that were welded by combining two types of welding methods, namely GTAW and SMAW on pipe joints 6-inch schedule 80 API 5L Grade B, as shown in Fig. 8.



	HAZ 1	Weld Metal	Base Metal	HAZ 2
1	61.00	60.50	63.00	60.00
2	56.00	71.00	69.00	55.50
3	64.00	66.50	60.00	62.00
4	68.50	63.50	57.00	69.50
5	68.50	79.00	56.00	70.50
Average	63.60	68.10	61.00	63.50

Fig. **8.** Rockwell C hardness test results

Fig 8. Provides the hardness value at each test point, which is the base metal, weld metal, and HAZ. The average value of hardness in HAZ 1 is 63.60 HRC and HAZ 2 was 63.50 HRC, the average value of hardness on the weld metal was 68.10 HRC, and the average value of hardness on the based metal was 61.00 HRC.

The graph shows that the average hardness values for API 5L Grade B pipe joints in HAZ 1 and HAZ 2 are almost the same. The hardness value in the weld metal area is higher than the HAZ area and the based metal. This is might possible by the influence of the fusion process of two electrodes that differ in chemical composition from the parent material. GTAW welding process using filler rod ER 70S-6 has a minimum tensile strength of 482 MPa and a minimum hardness of 151 HV. Meanwhile, the SMAW process uses E 7016 electrodes with a minimum tensile strength of 482 MPa and a minimum hardness of 151 HV. So, the effect of the melting of the two electrodes and the parent material allows for the formation of a new structure that is denser and most solid, causing the highest hardness to be found in the weld metal area.

The HAZ region is an area that is prone to formation of very hard and easily cracked phases. This resulted in increased hardness testing in the HAZ area due to the brittleness of the material compared to the parent material. The HAZ area has a larger crystal structure due to the influence of heat during the welding process; residual stress is permanent and occurs due to uneven thermal cycles followed by uneven cooling cycles so that it has a higher hardness value than the base metal area.

4 Conclusions

Combination welding of ASME SA-106 Grade B pipe or API 5L pipe size 6″ Sch 80 using GTAW method for root pass welding using filler rod ER 70S-6 with currents of 90 and 100 A, and SMAW method for hot pass and cover pass welding with current 120 and 125 A. Welding quality testing using the non-destructive method, namely Penetrant test, macro examination, and radiography, showed that the welded product from the combination of GTAW and SMAW welding did not find any defects and indications of discontinuity. The tensile strength test showed an increase in the tensile strength value to an average of 499 MPa from the standard 415 MPa parent material, as well as the yield strength to 364 MPa from the minimum standard of 240 MPa, and all specimens broke up in the parent material or based metal. Hardness testing using the Rockwell C method showed that the highest average hardness occurred in the weld metal area (68.10 HRC), followed by the HAZ (63.55 HRC), and followed by the parent material area (61.00 HRC). Combination welding between GTAW and SMAW for ASME SA106 Grade B pipe material is very suitable for application in the oil and natural gas industry because it can increase tensile strength, and hardness value also can prevent leaks and other things that can be dangerous in pipeline distributions.

References

[1] S. Kumar and D. Mahto, "Recent Trends In Industrial And Other Engineering Applications Of Non Destructive Testing: A Review," *Int. J. Sci. Eng. Res.*, vol. 4, no. 9, pp. 183–195, 2013.

[2] "TEKNIK PENGELASAN - Google Books." https://www.google.co.id/books/edition/TEKNIK_PENGELASAN/X5RUEAAAQBAJ?hl=en&gbpv=1&dq=Teknik+Pengelasan+,+cara+menghindari+cacat&pg=PT1&printsec=frontcover (accessed Dec. 29, 2022).

[3] Suherman, Rahmawaty, S. Mizhar, A. Latif, and I. Abdullah, "Pengaruh Elektroda pada Sambungan Las Baja Sa106 Grade A Dengan Metode Pengaruh Elektroda pada Sambungan Las Baja Sa106 Grade A Dengan Metode SMAW," *Rotasi*, vol. 22, no. 4, pp. 246–252, 2020.

[4] S. K. Abdul Khadeer, P. Ramesh Babu, B. Ravi Kumar, and A. Seshu Kumar, "Evaluation of friction welded dissimilar pipe joints between AISI 4140 and ASTM A 106 Grade B steels used in deep exploration drilling," *J. Manuf. Process.*, vol. 56, no. April, pp. 197–205, 2020, doi: 10.1016/j.jmapro.2020.04.078.

[5] A. Astm, B. Seamless, P. Pipe, and A. Sa, "A106 GRADE B CARBON STEEL Datasheet for A106 Grade B Carbon Steel".

[6] A. F.-B. Teknika and undefined 2018, "ANALISIS SIFAT MEKANIK PIPA CARBON STEEL GRADE A A106 DAN GRADE B A53 UNTUK PROSES PRODUKSI PADA KILANG LNG," *ejournal.upnvj.ac.id*, vol. 14, pp. 119–129, 2018, Accessed: Dec. 29, 2022. [Online]. Available: https://ejournal.upnvj.ac.id/index.php/BinaTeknika/article/view/335

[7] "Pembuatan WPS dan PQR API 5L Gr.B untuk Manual SMAWPipe... - Google Scholar." https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Pembuatan+WPS+dan+PQR+API+5L+Gr.B+untuk+Manual+SMAWPipe+Supply+sesuai+Standar+API+%28American+Petroleum+Institute%29&btnG= (accessed Dec. 29, 2022).

[8] L. Li *et al.*, "Comparative analysis of GTAW+SMAW and GTAW welded joints of duplex stainless steel 2205 pipe," *Int. J. Press. Vessel. Pip.*, vol. 199, p. 104748, Oct. 2022, doi: 10.1016/J.IJPVP.2022.104748.

[9] M. Nofri and A. Fardiansyah, "Analisis Sifat Mekanik Pipa Carbon Steel Grade a a106 Dan Grade B a53 Untuk Proses Produksi Pada Kilang Lng," *Bina Tek.*, vol. 14, no. 2, p. 119, 2018, doi: 10.54378/bt.v14i2.335.

[10] S. Kumar *et al.*, "Experimental investigation on the effect of welding parameters of TIG welded joints using ANOVA," *Mater. Today* Proc., vol. 22, pp. 3181–3189, 2019, doi: 10.1016/j.matpr.2020.03.455.

[11] M. Properties, "P 2301-9069," vol. 19, no. 2, pp. 56–63, 2022.

[12] M. Khafifudin, "The Effect Of Current On SMAW Welding To Tensile Strength And Micro Structure Of Low Carbon Steel," *4th Int. Conf. Eng. Technol. Dev.*, no. Icetd, pp. 173–177, 2017, [Online]. Available: http://artikel.ubl.ac.id/index.php/icetd/article/view/1017

[13] S. Kumar and A. S. Shahi, "Effect of heat input on the microstructure and mechanical properties of gas tungsten arc welded AISI 304 stainless steel joints," *Mater. Des.*, vol. 32, no. 6, pp. 3617–3623, 2011, doi: 10.1016/j.matdes.2011.02.017.

[14] V. Balasubramanian, V. Ravisankar, and G. M. Reddy, "Effect of pulsed current and post weld aging treatment on tensile properties of argon arc welded high strength aluminium alloy," *Mater. Sci. Eng. A*, vol. 459, no. 1–2, pp. 19–34, 2007, doi: 10.1016/j.msea.2006.12.125.

[15] A. Fernandes da Rosa, F. Batista, V. I. Berbare Lemos, and R. H. Goncalves e Silva, "Experimental analysis on the performance of SMA welding electrodes." 2021. doi: 10.26678/abcm.cobem2021.cob2021-2010.

[16] H. P. Blavatsky, "Section Ix," *Secret Doctrin.*, pp. 91–97, 2012, doi: 10.1017/cbo9780511978371.011.

[17] A. Azwinur, M. Marzuki, and A. Anwar, "Pelatihan Las Argon Untuk Pekerja Usaha Bengkel Las Masyarakat Gampong Mesjid Punteuet Dalam Upaya Meningkatkan Pendapatan Masyarakat Masyarakat," *J. Vokasi*, vol. 2, no. 1, pp. 40–44, 2018.

[18] N. Ahmad, J. Sarjito, and Samuel, "Pengaruh Kuat Arus Listrik Dan Sudut Kampuh V Terhadap Kekuatan Tarik Dan Tekuk Aluminium 5083 Pengelasan Gtaw," *J. Tek. Perkapalan*, vol. 4, no. 1, pp. 256–264, 2016.

[19] A. Azwinur and S. Syukran, "Effect of variation of TIG welding current on tensile strength and hardness of aluminium A-6061," *J. Weld. Technol.*, vol. 3, no. 1, pp. 17–22, 2021.

[20] P. K. Baghel, "Heliyon Effect of SMAW process parameters on similar and dissimilar metal welds : An overview," *Heliyon*, vol. 8, no. August, p. e12161, 2022, doi: 10.1016/j.heliyon.2022.e12161.

[21] A. Sahputra, M. Marzuki, and A. Azwinur, "ANALISA KEKUATAN SAMBUNGAN LAS SMAW MENGGUNAKAN MATERIAL AISI 1050 DENGAN VARIASI ARUS," *J. Mesin Sains Terap.*, vol. 5, no. 2, pp. 71–78, 2021.

[22] M. Faizal and A. R. Salam, "Pengaruh Arus Pengelasan pada Baja ASTM SA 516 Gr70 Terhadap Kekuatan Tarik dan Ketangguhan Las SMAW dengan Elektroda E7018," *J. Tek. BIMA*, vol. 14, no. 2, pp. 55–62, 2018.

[23] F. Cao, S. Chen, and C. Du, "Investigation of hot-wire TIG welding based on the heat-conduction," *Energy Procedia*, vol. 144, pp. 9–15, 2018, doi: 10.1016/j.egypro.2018.06.003.

[24] American Petroleum Institute, "Line Pipe API Specification 5L," no. April, p. 205, 2018, [Online]. Available: https://www.api.org/products-and-

services/standards/important-standards-announcements/standard-5l

[25] G. R.-J. K. E. dan Manufaktur and undefined 2015, “Pembuatan Wps Dan Pqr Api 5l Gr. b Untuk Manual Smaw Pipe Supply Sesuai Standar Api (American Petroleum Institute)-1104,” *journal.unj.ac.id*, Accessed: Dec. 29, 2022. [Online]. Available: http://journal.unj.ac.id/unj/index.php/jkem/article/download/6326/4577

[26] S. Syukran, A. Azwinur, and F. Ferdiyansyah, “The Effect of Holding Time on Stress Relief Annealing Process to Hardness of Carbon Steel SA. 106 Grade B After Welding,” *SINTEK J. J. Ilm. Tek. Mesin*, vol. 14, no. 1, pp. 46–51, 2020.

[27] M. F. I. Purba and F. Fakhriza, “Pengaruh Variasi Temperatur PWHT Dan Tanpa PWHT Terhadap Sifat Kekerasan Baja ASTM A 106 Grade B Pada Proses Pengelasan SMAW,” *J. Weld. Technol.*, vol. 2, no. 1, pp. 13–18, 2020.

[28] ASTM, “Astm: E18-15,” *ASTM Int.*, 2021, doi: 10.1520/E0018-15.2.