EPI International Journal of Engineering
Volume 7, Number 2, February 2024, pp. 27-32
DOI: 10.25042/epi-ije.082024.05

*p*ISSN 2615-5109
*e*ISSN 2621-0541

Effect of Post Weld Heat Treatment (PWHT) on Mechanical Properties, Chemical Composition, and Microstructure on Carbon Steel Pipe SA-106 B with SMAW-GTAW Welding Combination

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Abstract

Welding is one of the company's success factors in connecting high-pressure pipes to welding technology implementation projects. The PLTU (Power Plant) construction project carries out the welding process in every construction activity that involves welding experts and various other disciplines. This research uses an experimental method with PWHT temperature variable on mechanical characteristics, microstructure, and chemical composition. The material used is SA-106 B carbon steel pipe with a 6G welding position. Welding is carried out using a combination of SMAW welding with E9016-G electrodes, and GTAW welding with ER90S electrodes. The higher the PWHT temperature, the tensile strength, hardness, and chemical composition of the carbon content and microstructure of the pearlite phase (dark etching) will decrease. Meanwhile, the impact energy will increase and the ferrite phase will experience growth in the ferrite grain structure (bright etching).

Keywords: chemical composition, mechanical properties, microstructure, PWHT

1. Introduction

Welding is one of the company's success factors in joining, especially in high-pressure carbon steel pipes in welding technology implementation projects. All PLTU / HRSG (Head Recovery Steam Generation Power Plant) construction projects carry out the welding process in every construction activity that involves welding experts and various other disciplines. Welding carried out on HRSG construction projects usually uses SMAW (Shielded Metal Arc Welding) and GTAW (Gas Tungsten Arc Welding) welding types because they can be applied to locations with various welding positions.

SMAW and GTAW welding have been investigated in various studies. Haryadi examined the effect of post weld heat treatment (PWHT) on SMAW welding, the higher the PWHT temperature, the higher the toughness value, and the lower the hardness value. The microstructure of the PWHT weld metal region increased the number of acicular ferrite structures and decrease the number of widmanstatten ferrite structures [1]. Sadeghi examined the effect of PWHT on GTAW welding, the results showed that the tensile strength and hardness decreased after PWHT was carried out and the microstructure had no significant effect on different joint areas [2]. Purba examined the effect of PWHT temperature variations on the hardness properties of A-106 B steel in the SMAW welding process, the results of the study showed that the increase in PWHT temperature causes the hardness value to decrease [3]. Arivazhagan researched PWHT and obtained the result that the higher the PWHT temperature, the toughness value will increase [4]. In SMAW and GTAW welding, several factors need to be considered to avoid welding defects ranging from human, machine, welding position, filler metal, connection type, welding rate, and various other reasons. Carbon steel welding defects are generally divided into six types: porosity (PO), crack (CR), slag (SL), incomplete fusion (IF), incomplete penetration (IP), and no defect (ND). Sugiarto examined the welding defects of the SMAW-GTAW combination welding on the ASTM A-106 B with the position of 1G and the variation of the welding current concluded that no weld defects were found, so a combination of welding could be recommended [5].

SA-106 B carbon steel pipe with composition by weight in (%) Carbon 0.30, manganese 0.29, phosphorus 0.035, sulfur 0.035, silicon 0.10, chromium 0.40, copper 0.40, molybdenum 0.15, nickel 0.40, and vanadium 0.08. The material content of the carbon steel pipe should not be less than 0.18 %. SA-106 is a manganese carbon steel

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intended for a wide range of high-temperature service applications. Heat treatment is preferably at 1200 °F (650 °C) or higher. Meanwhile, the tensile strength is 415 MPa and the yield strength is 240 MPa [6]. However, the material certificate shows a different chemical composition and tensile strength, which can be seen in table 1. and table 2.

Table 1. Mechanical properties SA-106 B [7]

Outside Diameter (mm)	Nominal Thickness (mm)	Hardness (HV)	Tensile Strength (MPa)		Yielding Strength (MPa)		Elongation (%)	
			Min.	Max.	Min.	Max.	Min.	Max.
152.4	21.9	117	490	505	340	355	38	40.5

Table 2. Chemical composition SA-106 B [7]

C	Mn	Si	P	S	Ni	Cr	Mo	Cu
0.19	0.44	0.25	0.008	0.009	0.004	0.05	0.001	0.16

Post weld heat treatment (PWHT) at temperatures of 650 °C and 850 °C was applied to defect-free NiTi/Ni/SS joints to improve their mechanical properties. As the PWHT temperature increased, more Ni3Ti was observed in the weld metal. This deposition strengthens the weld metal; so that the average hardness of the weld metal increases from 375 HV to 493 HV. Due to the micro homogenization of the joint after PWHT, the tensile strength of the joint is increased. The highest average strength of the joint reaches 643 MPa at a temperature of 850 °C with PWHT treatment, which is about 2.12 times higher than that of a welded joint. PWHT significantly affects the microstructure and strength properties of NiTi joints [8].

2. Research method

2.1. Welding process

The welding process for SA-106 B carbon steel pipe with a 6G position is carried out by a welder based on the WPS (Welding Procedure specification) that has been made by WI (Welding Inspection). The steps taken are to prepare the welding handlebar position 6G, SA-106 B carbon steel pipe, form the material with V-groove seams, brush the surface to be welded if dirty, preheat the material at a temperature of 20 °C, SMAW welding using E9016G electrodes with a diameter of 3.2 mm in filler and caping at a thickness of 16.9 mm, GTAW welding using ER90S electrodes with a diameter of 2.4 mm at the root pass and hot pass at a thickness of 5 mm. Figure 1 shows the SMAW-GTAW V-groove welding combination.

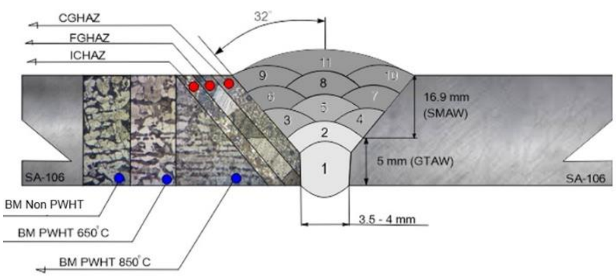


Figure 1. V-groove SMAW-GTAW welding combination [9]

2.2. Post weld heat treatment (PWHT)

PWHT is carried out on the specimen to be tested with several variables of temperature and holding time during the heat treatment process. The PWHT process and its variables include inserting the specimen into the heat treatment furnace, turning on the heat treatment machine, setting the temperature to 650 °C with a holding time of 60 minutes, waiting for the heating process to complete, then removing the specimen for cooling at room temperature, then repeat the previous step, with a temperature setting of 850 °C.

2.3. Tensile test

The stages of the tensile testing process are not carried out just like that, but need to form materials and heat treatment, namely by cutting and forming materials according to tensile testing standards. After that, turn on the tensile test machine then adjust the loading and the speed of the withdrawal time. Make sure the test specimen is broken so that the calculation results are as desired. Print out the tensile test results. The tensile test specimen refers to the standard ASTM E8M [10].

2.4. Hardness

Hardness testing was carried out with the ASTM E10 hardness Vickers standard [11]. First, do the preparation of materials or make specimens. Then mark each area or etching of the specimen to be observed. After that, prepare a hardness testing machine that will be used.

2.5. Impact testing

Stages of the impact testing process according to the size standard on the ASTM E23 standard with the Charpy impact testing method. The stages of testing are as follows: material preparation or specimen manufacture. model and size refer to the ASTM E23 standard [12].

2.6. Microstructure

Microstructure testing was carried out to analyze the changes that occurred in each area of the base metal (BM), heat attection zone (HAZ) SMAW-GTAW and weld metal (WM) SMAW-GTAW which were treated without PWHT, PWHT at 650 °C, and PWHT. temperature 850 °C. The testing stages are the preparation of materials or the manufacture of test specimens (mounting), after that sanding the surface of the material to be tested with the smallest to the largest sandpaper roughness (120-5000) and sanding in a polishing machine, etching the specimen using HNO_3 and alcohol before observation. If the surface is smooth then the material is ready for observation using a microscope.

2.7. Chemical composition

Chemical composition testing that will be observed on the SA-106 B material is carried out without PWHT, PWHT at 650 °C, and PWHT at 850 °C. Likewise on the electrodes E9016G and ER90S. The machine used for testing the chemical composition is an Optical Emission Spectrometric (OES) machine. Chemical composition testing refers to the ASTM E415 standard [13].

3. Results and Discussion

3.1. Effect of PWHT on tensile strength

The tensile strength at PWHT temperature of 650 °C is very influential because it can increase the tensile strength by 6 MPa and increase the strain by 0.03 from the material without PWHT which has been combined with SMAW-GTAW welding, see fig. 2 and fig. 3. While the tensile strength at PWHT temperature of 850 °C experienced a

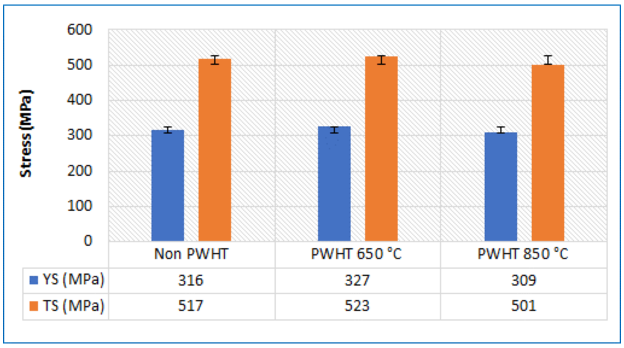


Figure 2. The effect of PWHT on tensile strength of the SMAW-GTAW welding combination

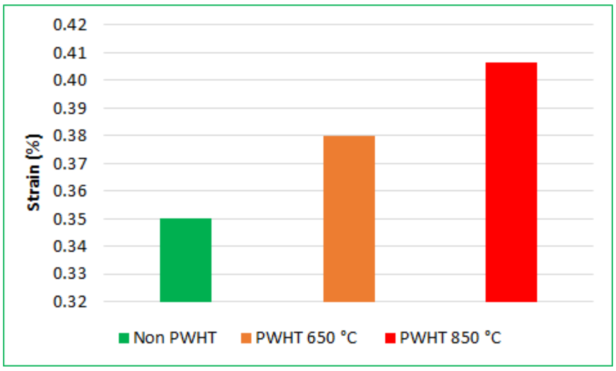


Figure 3. The effect of PWHT on strain of the SMAW-GTAW welding combination

decrease in tensile strength of 11 MPa due to PWHT temperature of 850 °C but had a strain value that increased by 0.03 from PWHT temperature of 650 °C [14].

The high temperature of PWHT will decrease the tensile strength, at a temperature of 850 °C followed by the addition of strain, but at a temperature of 650 °C, it will increase the tensile strength and reduce the value of the strain. The higher the PWHT temperature, the tensile strength will also decrease. The results of the tensile strength test above are the same as what has been done by Lim [15]. The high temperature will decrease the tensile strength of the PWHT treated material [8], [2].

The higher the PWHT temperature, the lower the tensile strength will be. The decrease in tensile strength at PWHT temperature of 850 ºC was caused by reduced carbon content (D carburizing) followed by changes in the microstructure in the HAZ region, see Fig. 7 and fig 8.

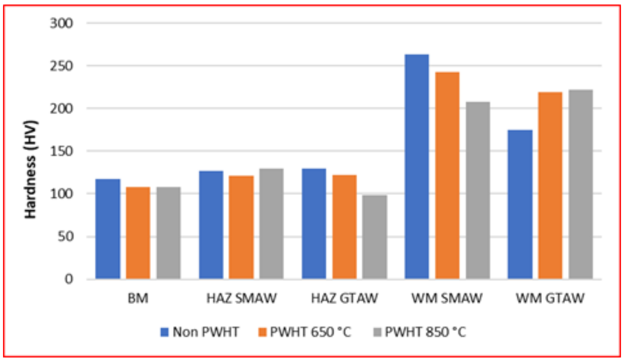


Figure 4. The effect of PWHT on hardness of the SMAW-GTAW welding combination

3.2. Effect of PWHT on hardness

This data shows the difference in hardness in the BM, HAZ, and WM areas. The highest hardness value in the BM area without PWHT was 117 HV and in the base metal area with PWHT the hardness decreased by 9 HV. The highest hardness in the WM SMAW area without PWHT was 263 HV and decreased by 20 HV at PWHT temperature of 650 °C and decreased hardness by 55 HV at PWHT temperature of 850 °C. Figure 4 the hardness graph shows the hardness value for each area, both with PWHT and without PWHT. The high PWHT temperature will be followed by the hardness value which will decrease with each PWHT temperature difference [3].

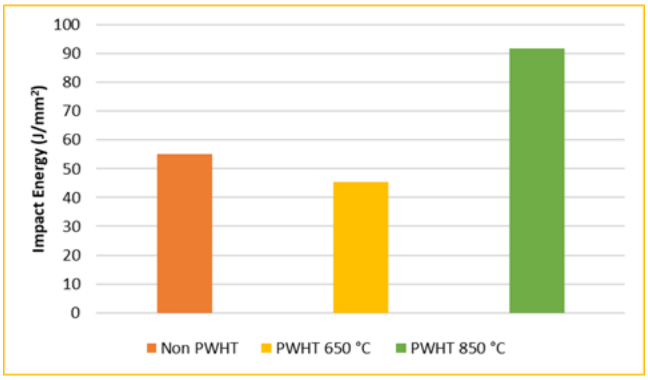


Figure 5. The effect of PWHT on impact energy of the SMAW-GTAW welding combination

3.3. Effect of PWHT on impact energy

Impact testing of the SMAW-GTAW welding combination on the SA-106 B carbon steel pipe was performed without PWHT and PWHT at temperatures of 650 °C and 850 °C. Impact testing is carried out in the combined welding area. Figure 5 from the impact test results were obtained where the impact price without PWHT is 55 J/mm^2, PWHT at 650 °C at 45 J/mm^2, and the highest at PWHT at 850 °C at 92 J/mm^2. In this study, the toughness increased at a temperature of 850 °C. This event indicates that the high temperature will increase the impact value or the toughness of the material which also increases [4].

3.4. Effect of PWHT on chemical composition

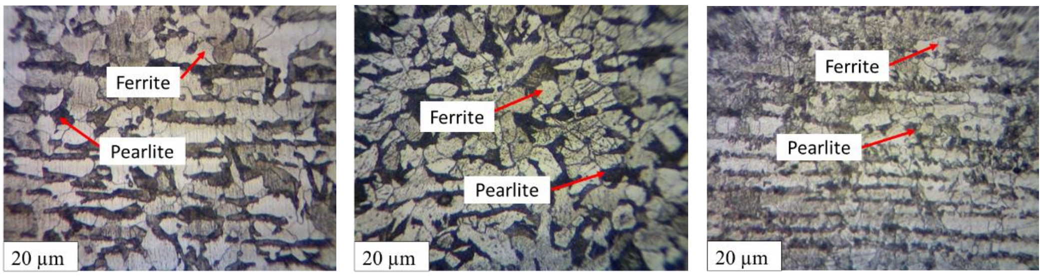
The results of chemical composition testing on carbon steel pipes SA-106 B, WM E9016-G, and ER90S were carried out without PWHT, and PWHT at temperatures of 650 °C, and 850 °C. In the SA-106 B carbon steel pipe without PWHT with a carbon weight of 0.297 % and at a PWHT temperature of 650 ºC with a carbon weight of 0.195 %, the difference is 0.102 % by weight of carbon without PWHT, while at PWHT at a temperature of 850 °C the difference is 0.078 % by weight of carbon from PWHT temperature 650 °C. Table 3 shows that the increase in PWHT temperature affects the carbon content, where the carbon content will decrease if the PWHT temperature is increased.

Table 3. Chemical composition SA-106 B

Weight (%)	C	Mn	Si	P	S	Ni	Cr	Mo	Cu
Non PWHT	0.297	0.64	0.45	0.02	0.004	0.04	0.20	0.02	0.07
PWHT 650 °C	0.195	0.63	0.34	0.02	0.001	0.05	0.17	0.02	0.09
PWHT 850 °C	0.117	0.6	0.33	0.02	0.001	0.05	0.17	0.02	0.09

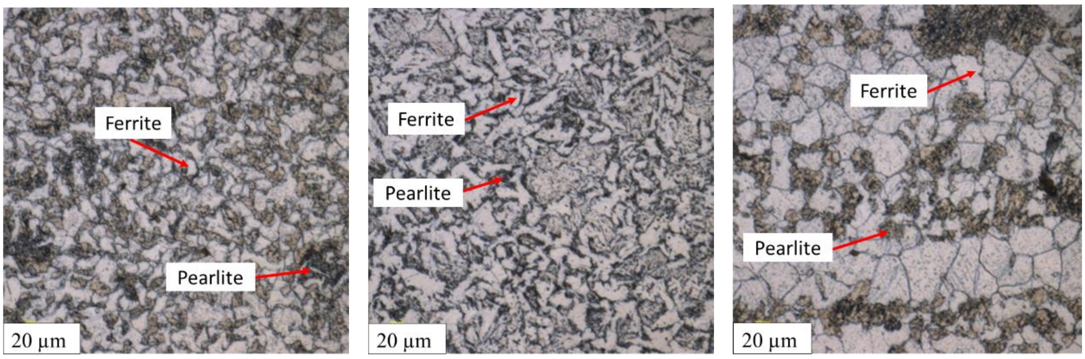
3.5. Microstructure observation results

The microstructure of the normalized SA-106 B carbon steel pipe is shown in Fig. 6 (b and c). This microstructure was produced by heating the steel to temperatures of 650 ºC and 850 °C for one hour, followed by air cooling. Note that the microstructure of BM with a uniform HAZ consists of ferrite and perlite grains. It appears that at PWHT temperature of 850 ºC the grain size of ferrite and pearlite is smaller. This possibility is influenced by the PWHT temperature; so, the carbon content decreases, see table 3. and the microstructure decreases at the PWHT temperature of 850 ºC. With increasing temperature, the pearlite phase will decrease so that the hardness also decreases [15].



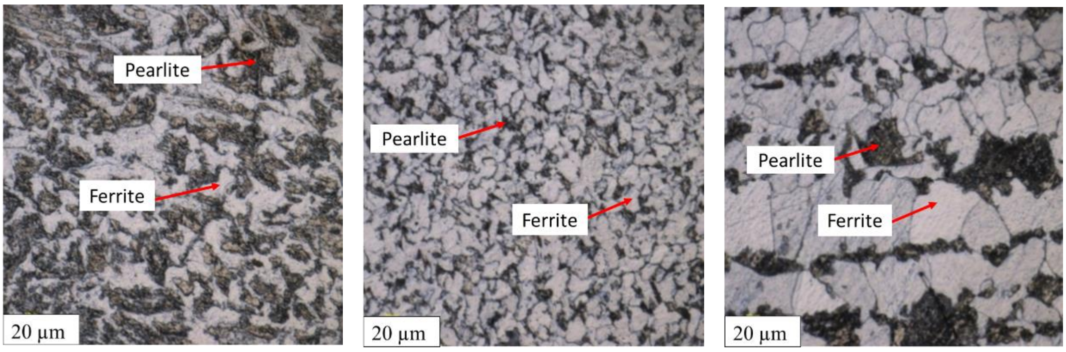
(a) (b) (c)

Figure 6. The effect of PWHT on the microstructure of BM (a) BM without PWHT (b) BM PWHT 650 °C and (c) BM PWHT 850 °C



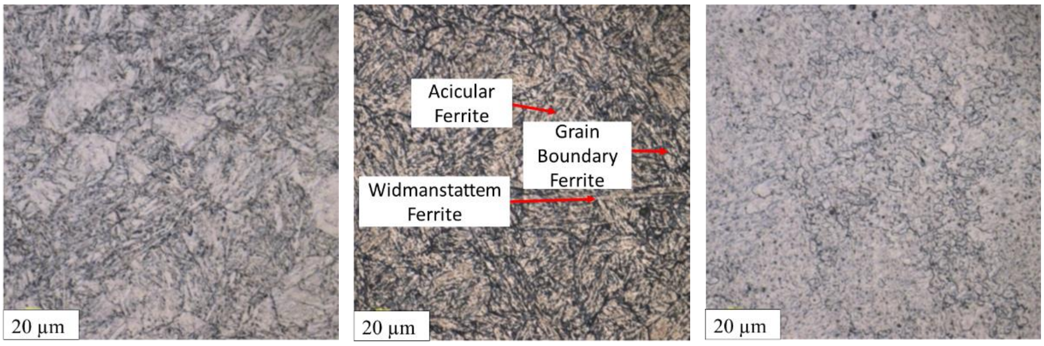
(a) (b) (c)

Figure 7. The effect of PWHT on the microstructure of HAZ SMAW (a) without PWHT, (b) PWHT 650 °C and (c) PWHT 850 °C



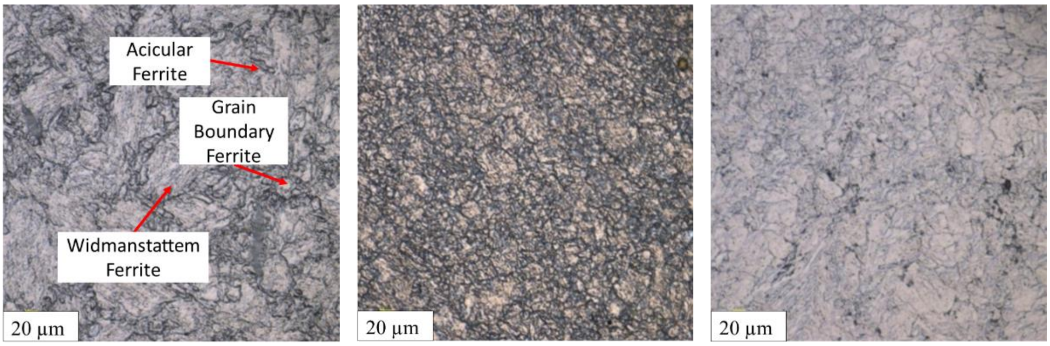
(a) (b) (c)

Figure 8. The effect of PWHT on the microstructure of HAZ GTAW (a) without PWHT (b) PWHT 650 °C and (c) PWHT 850 °C



(a) (b) (c)

Figure 9. The effect of PWHT on the microstructure of WM SMAW (a) without PWHT, (b) PWHT 650 °C and (c) PWHT 850 °C



(a) (b) (c)

Figure 10. The effect of PWHT on the microstructure of WM GTAW (a) without PWHT, (b) PWHT 650 °C and (c) PWHT 850 °C

Figure 7 and 8 show the microstructure of HAZ SMAW and HAZ GTAW, Fig. 7a and 8a microstructure without PWHT, Fig. 7b and 8b microstructure of PWHT at 650 ºC, and Fig. 7c and 8c structure micro PWHT temperature 850 °C. Figures 7 and 8 show the perlite phase (dark) which tends to be harder because the ferrite phase plus cementite is the same as perlite and the ferrite phase (light) is soft. Figure 7c and 8c shows the uniformity of the grains with Fig. 6a. This shows that the PWHT temperature of 850 °C can homogenize the grains in the HAZ SMAW and HAZ GTAW regions. The high PWHT temperature affects the grain size in the HAZ region, the higher the PWHT temperature, the microstructure will also experience grain uniformity [16].

Figure 9 shows the microstructure of the WM SMAW region (a) without PWHT, (b) the PWHT temperature of 650 °C, and (c) the PWHT temperature of 850 °C and Fig. 10 shows the microstructure of the WM GTAW region (a) without PWHT, (b) PWHT temperature 650 °C, and (c) PWHT temperature 850 °C. The effect of PWHT on the microstructure of WM SMAW without PWHT shows the grain boundaries of ferrite. The microstructure of WM SMAW without PWHT has a ferrite grain boundary consisting of widmanstatten ferrite (WF), acicular ferrite (AF), and grain boundary ferrite (GF).

The AF structure appears to be interrelated to form an interconnected structure. The GF structure has a round-grained structure, while the WF structure has a long-grained structure (columnar grains) and has brittle properties. At PWHT temperature of 650 °C, the microstructure of WM SMAW of ferrite grain boundaries was observed, it was seen that the GF structure was shrinking and the AF structure was growing more, then followed by the WF structure which grew within the GF structure. The microstructure at PWHT 850 °C looks pearlite and ferrite with small carbon elements. The difference in structure is visible in Fig. 9 and Fig. 10.

The decrease in hardness at WM SMAW PWHT 850 °C is influenced by the size of the ferrite and pearlite grains caused by the high temperature of the PWHT. The relationship between hardness, microstructure, and chemical composition is strongly influenced by the PWHT temperature. The higher the PWHT temperature, the carbon content will decrease (D carburizing) see table 3. The reduced carbon content will change the appearance of the microstructure see Fig. 6, then it will be followed by a decrease in the hardness value see Fig. 4 [1].

4. Conclusion

The results of the highest tensile strength of PWHT at a temperature of 650 °C of 523 MPa, and the lowest value of tensile strength of PWHT at a temperature of 850 °C of 501 MPa. From the tensile test results that the break area is in the BM area, it proves that the welding strength of the SMAW-GTAW welding combination can be recommended for SA-106 B carbon steel pipes, but what needs to be considered is the costs incurred. as a result of using the WM SMAW E9016-G and WM GTAW ER90S. Then the highest hardness results in each observed area were on the specimens without PWHT and the hardness decreased in each PWHT performed. The higher the PWHT temperature, the hardness will also decrease. The highest impact value is at a PWHT temperature of 850 °C and the lowest is at a PWHT temperature of 650 °C. The higher the PWHT temperature, the toughness will also increase, while the chemical composition of BM and WM if PWHT is carried out, the carbon content will also decrease. The higher the PWHT temperature, the lower the carbon content of the BM and WM materials. With the decrease in the value of carbon content, the grain size of ferrite will also experience growth. The microstructure affects the PWHT temperature rise. The higher the PWHT temperature was followed by the growth of the ferrite microstructure and the homogeneity of the microstructure.

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