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Effect of Post weld Heat Treatment and Filler metals on Microstructures and Mechanical Properties of GTAW and SMAW Weldments between P11 and P91 Steels

A. Eissa Abd elmaoula[1], Hussein. M. Abdelaziz[1], E. S. Mosa[1], M. A. Morsi[2], A. Atlam[1]
(1) Al-Azhar University, Faculty of Engineering , Mining and Petroleum Engineering Department.
(2) Central Metallurgical Research and Development Institute (CMRDI) Egypt.

Abstract— The aim of this work is to conduct an optimized conditions of the post weld heat treatment of the GTAW(gas tungsten arc welding) and SMAW (shielded metal arc welding) weld joint between P11 (1.1 Cr) and P91 (8.5 Cr) steels; using E9018B3/ER90SB and E9015B9/ER90SB9 as filler metals. The post weld heat treatment was conducted at 750°C for holding times 0.5, 1 and 2 hours for the evolution of the microstructure, hardness and Tensile Strength ; required for high mechanical performance; at elevated temperatures. The investigated results showed that: the optimum conditions of the post weld heat treatment is 750°C for 1 hour with E9018B3/ER90SB as a filler metal and post weld heat treatment at 750°C for 0.5 hour with E9015B9/ER90SB9 as a filler metal are the proper conditions to reduce the hardness of heat affected zone (HAZ) of P91 steel and regular Hardness distribution.

Key words: P11, P91, Post weld heat treatment, Microstructure, Hardness, Heat Affected Zone,

1 Introduction

THE Post weld heat treatment (PWHT) is the most common technique employed for relieving; the residual stresses caused by welding and its repair. Besides, the primary purpose of reducing the effect of stresses induced by welding, PWHT is also intended to temper the metallurgical structure of the heat affected zone (HAZ) [1]. In steam power plants of the Electricity Generating Authority of Thailand (EGAT), the dissimilar TIG weld joints between P22 (2.25Cr) steel and P91 (9Cr) steel using Income 625 as filler metal After welding, high hardness values of the heat affected zone (HAZ) of those dissimilar weld joints were possibly Hardness between P91 steel and weld metal leading to prior crack and failure during high obtained. This high hardness value at HAZ resulted, due to the austenite transformation to martensite because the high cooling rate [2]. Heat treatment is accomplished through three major stages; the first stage is Heating the metal slowly; to ensure a uniform temperature distribution, the second Stage is Soaking (holding) the metal at a given temperature for a given time and the third Stage; is Cooling the metal to room temperature [3],[4]

Number of different parameters that must be considered during the implementation of a PWHT process. First, the lower critical transformation temperature must not be exceeded. This requires that the chemical composition of both the base and filler metals be known so that the lower critical temperature (A1) can be estimated. Next, the required duration of time at temperature is dependent upon the thickness of the material [5]. The aim of this research work is to determine the suitable PWHT conditions, which provides the proper microstructure and hardness to avoid earlier component failure; for long-term high temperature service.

2 Material and Experimental Procedures:

Single V-groove (included bevel angle: 40°) butt welds were prepared by welding 10 mm thick Pipes of Alloy P11 (condition: Ferrite) and P91 (condition: tempered martensite) using ER90SB9 and ER90SB3 filler wires for the first two root passes and E9015B9 and E9018B3 electrodes for the subsequent filler passes. The chemical compositions of P11 steel, P91 steel, E9018B3/ER90SB3 and E9015B9/ER90SB9 are illustrated in Tables 1, 2, 3 and 4, respectively. Table 5 shows the TIG and SMAW Welding parameters used in this work and Table 6 shows Coding system for different sample condition (Heat Treatment). All sections P11 steel samples were welded with section P91 Pipe samples using E9015B9/ER90SB9 and E9018B3/ER90SB3 as filler metals as shown in Figure 1 followed by PWHT at 750°C for 0.5,1 and 2 hours. Subsequently, they were ground and polished using standard metallographic technique, and afterwards etched in a Villella's Reagent (25 ml ethanol, 1.5ml HCl and 0.3 g Picric acid) Picric acid is mixed with ethanol then HCl is added. The microstructures of all samples were viewed using optical microscopy.

Table 1

Chemical composition of P11 (1.1Cr).

Chemical Composition of P11, wt%							
C	Si	Mn	P	S	Ni	Cr	Mo
0.13	0.53	0.52	0.01	0.001	0.06	1.1	0. 46

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Table 2

Chemical composition of P91 (8.5 Cr).

Chemical Composition of P91, wt%						
C	Si	Mn	P	S	Ni	Cr
0.1	0.26	0.31	0.012	0.002	0.10	8.5
Mo	Al	V	Nb	N	Cu	
0.88	0.002	0.215	0.077	0.04	0.03	

Table 3

Chemical composition of E9018B3 and ER90SB3.

Electrode/Rod	C	Si	Mn	Mo	Cr
ER90S-B3	0.04	0.5	1.1	0.9	2.4
E9018-B3	0.05	0.6	1.1	1	2.6

Table 4

Chemical composition of E9015B9 and ER90SB9.

Electrode /Rod	C	Si	Mn	P	S	Ni	**Cr**
ER90SB9	0.09	0.2	0.49	0.004	0.003	0.66	8.7
	Mo	Cu	Al	V	Nb	N	
	0.9	0.03	0.006	0.19	0.08	0.05	
E9015-B9	0.11	0.13	0.85	0.01	0.007	0.7	8.1
	Mo	Cu	Al	V	Nb	N	
	1.12	0.0015	0.24	0.22	0.09	0.053	

Table 5

TIG and SMAW welding parameters Sample 1 and 2.

Process /layer No.	Current		Av. Volt	Av. Starting Temp. °C	Filler Metal / Electrode	
	Type/ Polarity	Av. amp.			Type	Dia. (mm)
Sample 1 and 2						
GTAW (Root)	DC/EN	112.8	12.7	219	ER90S-B9	2.4
SMAW (1)	DC/EP	137	22.73	230	E9015-B9	2.5
SMAW (2 to 7)	DC/EP	137	22.73	230	E9015-B9	2.5

Table 6

Sample Code	Condition		
	Time	Temp.°C	Filler metals
S1L1	30 min.	350	ER90S-B9 / E9015-B9
S1L3	30 min.	750	
S1L5	60 min.		
S1L7	120min.		
S2L2	30min.	350	ER90S-B3 / E9018-B3
S2L4	30 min.	750	
S2L6	60 min.		
S2L8	120min.		

Coding system for different sample condition (Heat

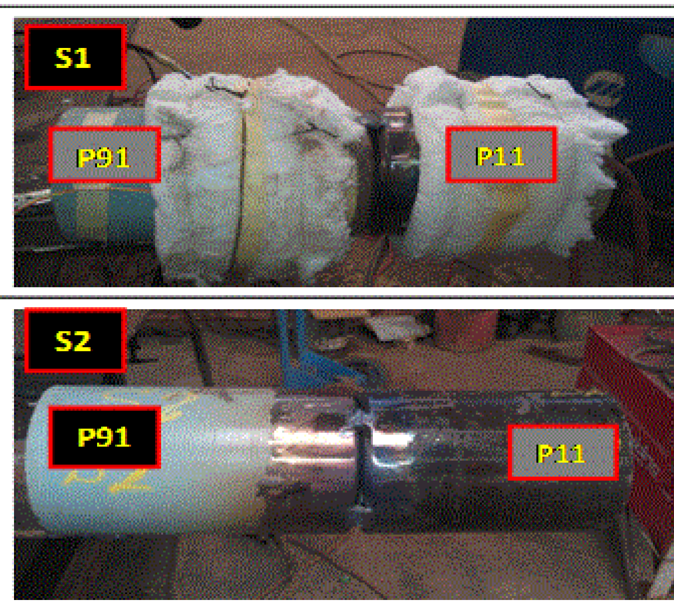

Fig. 1 Weld joint between P91 and P11 Pipe (a) Sample 1 (b) Sample 2

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3. Results and Discussion

3.1. Microstructure evolution

3.1.1 Microstructure evolution before welding

Figure 2 a shows the microstructure of P91 base metal is temper martensite phase. Figure 2 b shows the microstructure of P11 base metal is ferrite and pearlite phase.

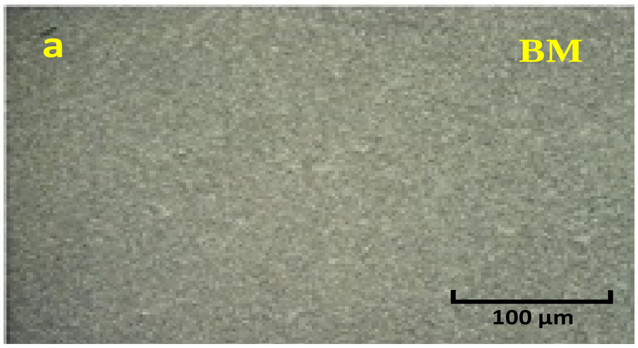

Fig. 2a P91 Base Metal

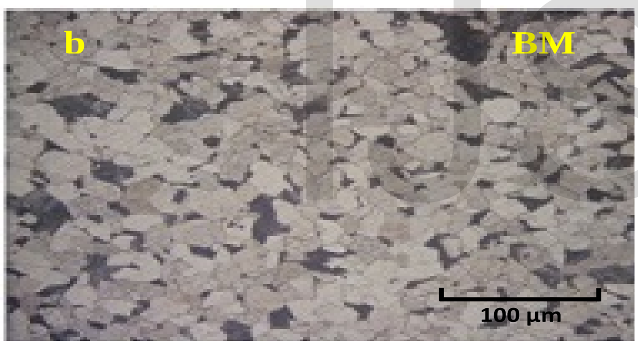

Fig. 2b P11 Base Metal

Figure 2 P91 and P11 base metal Microstructures

3.1.2 Microstructure evolution of steel weldments after welding and intermediate PWHT

3.1.2.1. Using filler metal ER90S-B9/E9015-B9

Figure 3 shows the microstructures of P91 base metal is temper martensite phase. This zone is far away from weld zone and no effect of welding heat was observed. The same results were obtained [6, 7].

The optical micrographs of the sample after intermediate PWHT conditions are shown in Figs. 4 a, b and c. Figure 4 a shows HAZ microstructure. It is coarse grain zone of martensite phase this could be attributed to the raising of temperature of the zone to more than 1100 ^{o}C as shown in Fig. 5. Also, there is a grain refinement region this could be attributed to the raising of temperature of the zone from 850 ^{o}C to 1100 ^{o}C as shown in Fig. 5. The existence of martensitic structure due to the highly cooling rate at this ragon as shown in Fig. 6. Figure 4 b show the interface zone near E9015B9/ER90SB9 weld metal, which consists of higher grain size structure than that of HAZ this could be attributed to the high temperature during welding also assisted in carbide decomposition resulting in no carbide inhibiting grain growth and which show a typical untempered martensite structure. Micro-etch clearly shows the GTAW root pass with multiple SMAW filling beads in the as-welded condition. The fusion zone beads are partly tempered by subsequent beads. A small amount of martensite exists along the inter-dendritic boundaries in the weld metal as shown in Fig. 4 c the same results were obtained in welding of P91 with P22 by Inconel 625. [8].

Figures 7 a, b and c show the microstructure of P11. Base metal shows ferrite phase and Pearlite phase with grain refinement as shown in Fig. 7 a this zone is far away from weld metal. No effect of welding heat was observed at this zone. Figure 7 b shows HAZ microstructure consists of ferrite and pearlite phases with grain refinement and spherodized pearlite. Figure 7 c shows the P11 microstructure connected to weld metal (inter face). However, it is bainitic structure that is coarser than that at HAZ. This result is supported by the re-

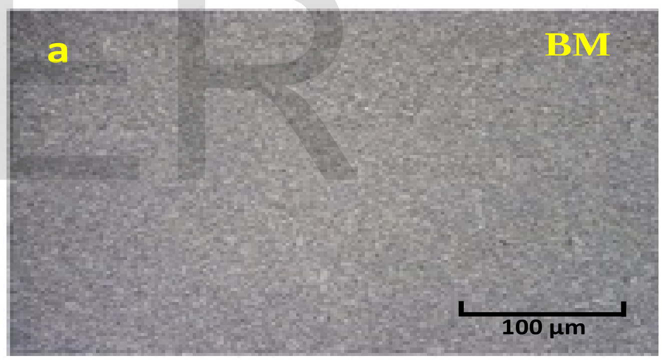

Figure 3 P91 base metal Microstructures after welding and intermediate PWHT

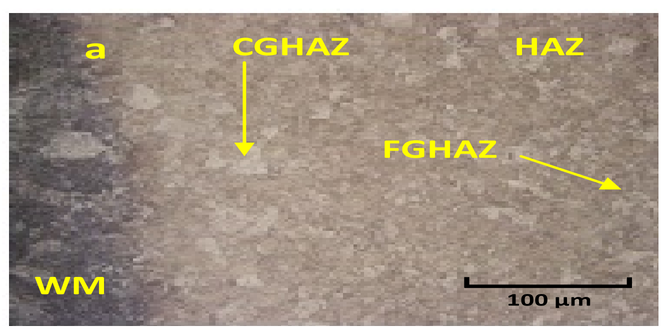

Fig. 4a HAZ of P91

- CG = Coarse grain
- FG = Fine grain

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- IF = Inter face

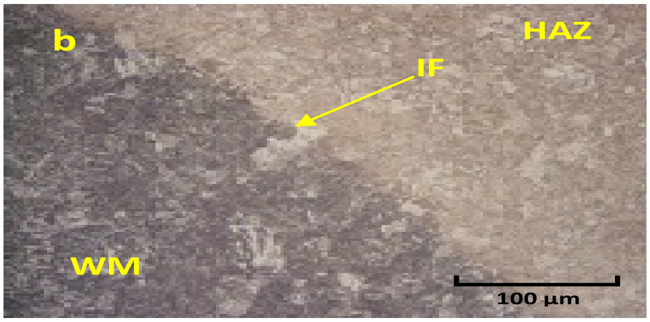

Fig. 4b Interface of P91 with weld metal

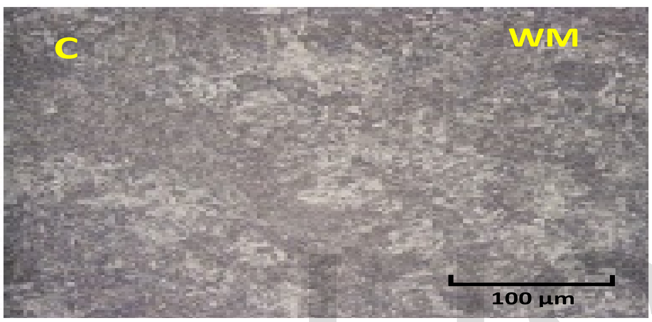

Fig. 4 c weld metal of P91 sample

Figure 4 (a, b and c) HAZ and weld metal Microstructures using E9015B9 / ER90SB9 filler metal.

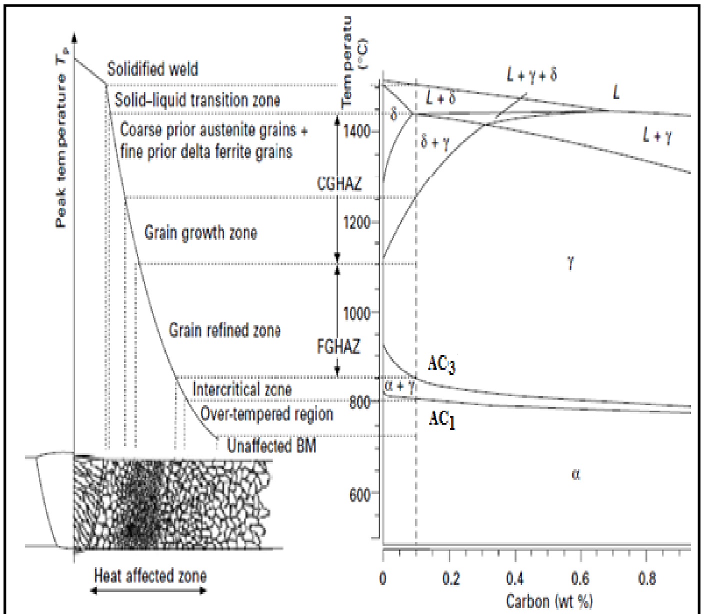

Figure 5 Schematic representations of microstructures developed in weld metal and HAZ as function of peak temperature during welding of P91[6].

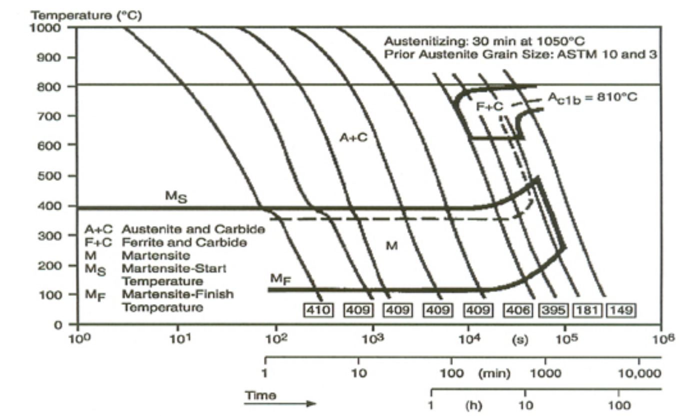

Figure 6 CCT diagram of steel P91[6].

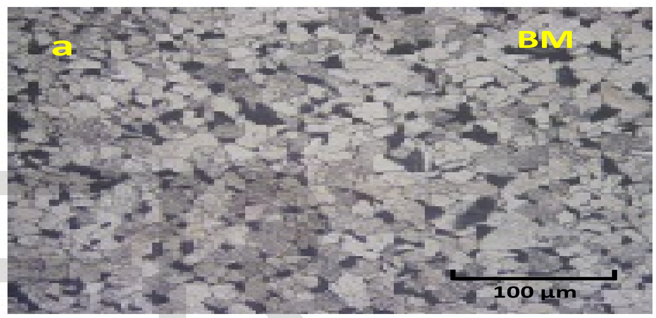

Fig. 7a Base Metal of P11

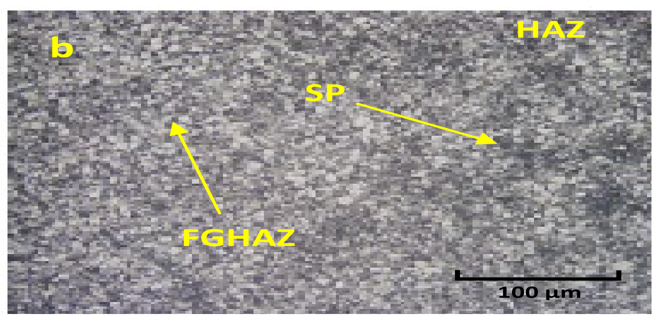

Fig. 7b HAZ of P11

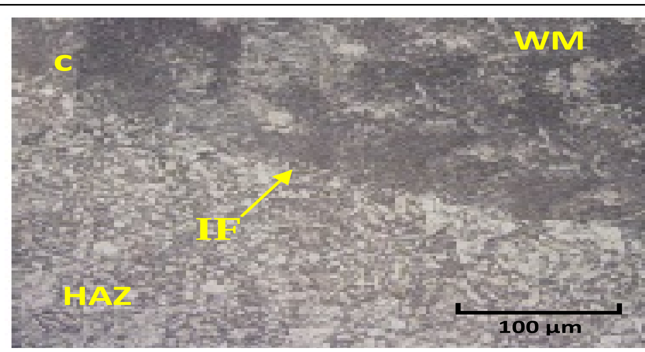

Fig. 7c Interface of P11

Figures 7 P11 Microstructures using E9015B9/ER90SB9 filler metal.

3.1.2.2. Using filler metal ER90S-B3/E9018-B3

Figure 8 shows the microstructures of P91 base metal is temper martensite phase. This zone is far away from weld metal and no effect of welding heat was observed. the same results were obtained by [8, 9].

The optical micrographs of HAZ after intermediate PWHT conditions are shown in Figs. 9a, b and c. Figure 9a shows HAZ microstructure. It is Corse grain zone of martensite phase this could be attributed the razing of temperature of the zone to more than 1100 ºC as shown in Fig. 5 . Also, there is a grain refinement region this could be attributed the razing of temperature of the zone from 850 ºC to 1100 ºC as shown in Fig. 5 . The existence of martensitic structure due to the highly cooling rate at this ragon as shown in Fig. 6. Figure 9b show the interface zone near ER90SB3/E9018B3 weld metal, which consists of higher grain size structure than that of HAZ this could be attributed to the high temperature during welding also assisted in carbide decomposition resulting in no carbide inhibiting grain growth and which show a typical untempered martensite structure. Micro-etch clearly shows the GTAW root pass with multiple SMAW filling beads in the as-welded condition. The fusion zone beads are partly tempered by subsequent beads. A small amount of martensite exists along the inter-dendritic boundaries in the weld metal as shown in Fig. 9 c the seam results were obtained in welding of P91 with P22 by Inconel 625. [8].

The microstructure of the P11 base metal shows ferrite phase and Pearlite phase with grain refinement as shown in Fig. 10a This zone is far away from weld metal. No effect of welding heat was observed at this zone. Figure 10b show HAZ microstructure consists of ferrite and pearlite phases with grain refinement and spherodized pearlite. Figure 10c show the P11 microstructure connected to weld metal (inter face). However, it is bainitic structure that is coarser than that at HAZ .

This results is supported by the results of hardness distribution discussed in section 3. 2. 1. 1

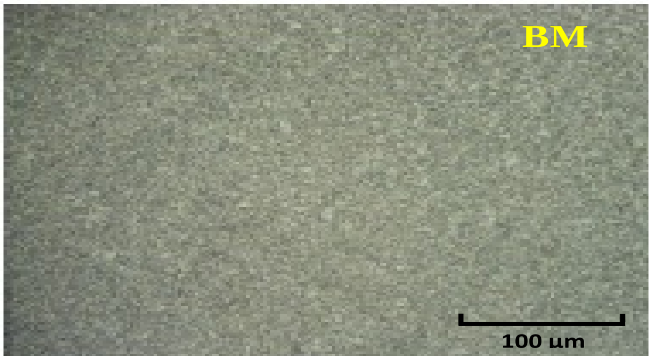

Figure 8 P91 base metal Microstructures after welding and intermediate PWHT

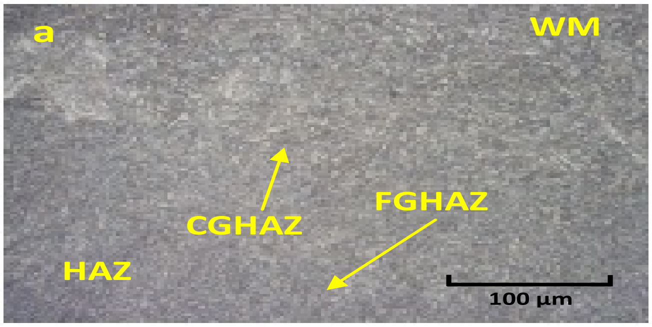

Fig. 9a HAZ of P91

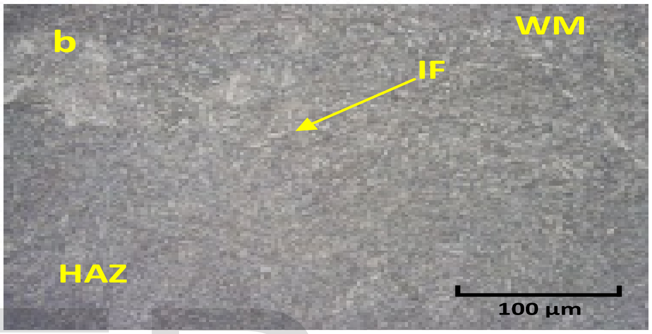

Fig. 9b Interface of P91 with weld metal

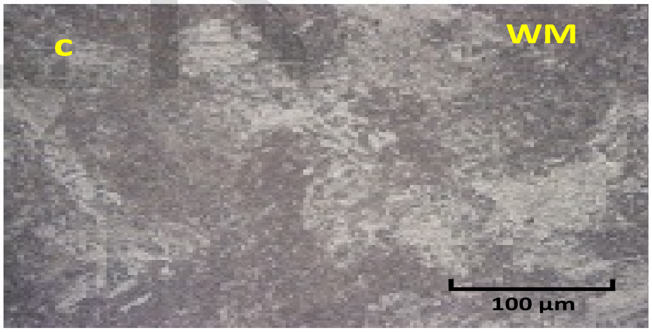

Fig. 9c weld metal of P91

Figure 9 HAZ and weld metal Microstructures using ER90SB3/E9018-B3 filler metal.

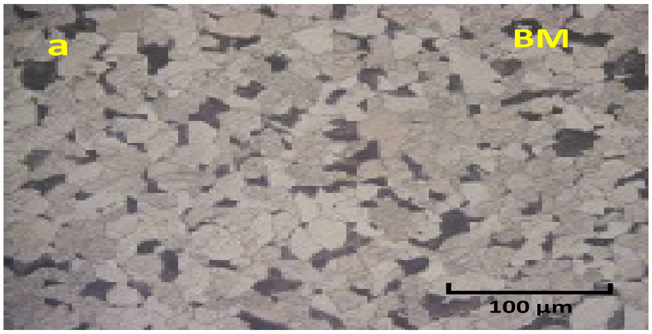

Fig. 10a Base Metal of P11

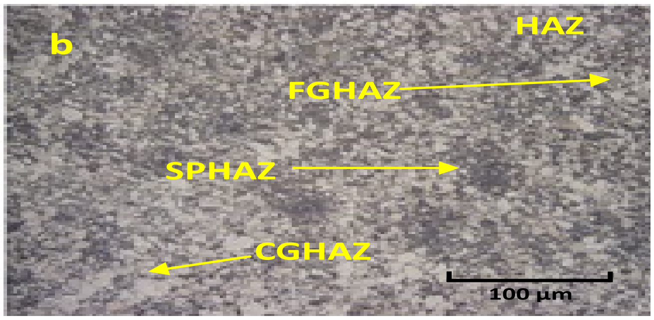

Fig. 10b HAZ of P11

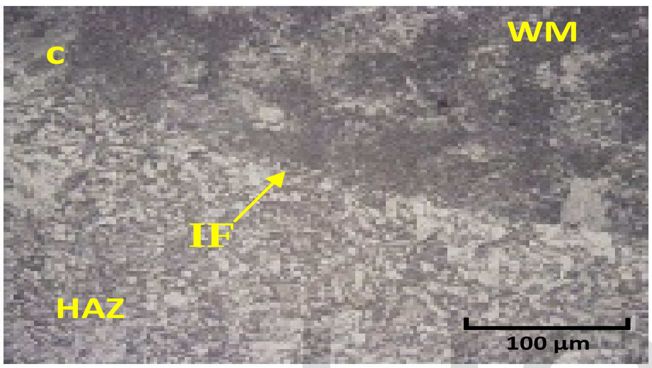

Fig. 10c Interface of P11

3.1.3. Microstructure evolution of steel weldment after post weld heat treatment

3. 1.3. 1. Using filler metal E9015B9/ER90SB9 at 750°C

Figures 11a, b and c show microstructures of P91 base metal after applying post weld heat treatment at a temperature of 750°C for 0.5, 1 and 2 hours, respectively. No significant difference in micro structural characteristics was observed using this temperature for different time intervals. However, it should be noted that all received microstructures were temper martensite. the same results were obtained by. [7, 8, 10 and 11]. These similar characteristics were also found in HAZ after PWHT; as show in Figures 12a, b and c. However, temper martensite grain structures of post weld heat treated HAZ are finer than those of post weld heat treated base metal microstructures. Figures 12a, b, and c show post weld heat treated microstructures of interface zone adjacent to weld metal after heating at a temperature of 750°C for 0.5, 1 and 2 hours, respectively. It was found that microstructures in these interface areas consist of more coarsening grain size compared to those of base metal and HAZ microstructures; this could be attributed to the sufficient welding heat that providing phase transformation from martensite to bigger austenite grain structure. When these coarse austenite grain structures were cooled down, they would finally retransform to coarse martensite grain structures. The same results were obtained by Ma. Al-lam, et al. [7]. Heat treatment resulted tempering of the martensitic structure in the weld metal, heat affected zone and base metals. This results is supported by the results of hardness distribution discussed in section 3.2.1.1.

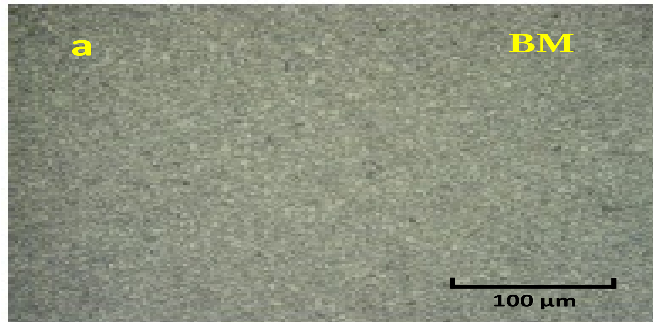

Fig. 11a 0.5 hour

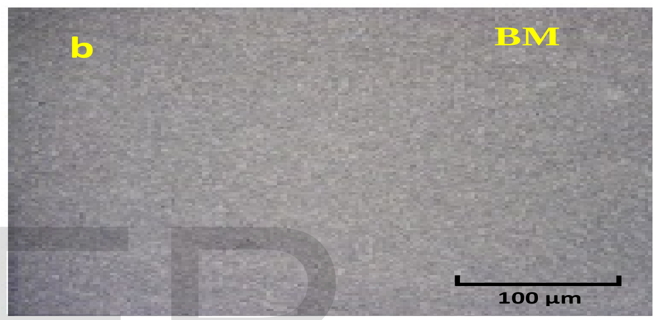

Fig. 11b 1 hour

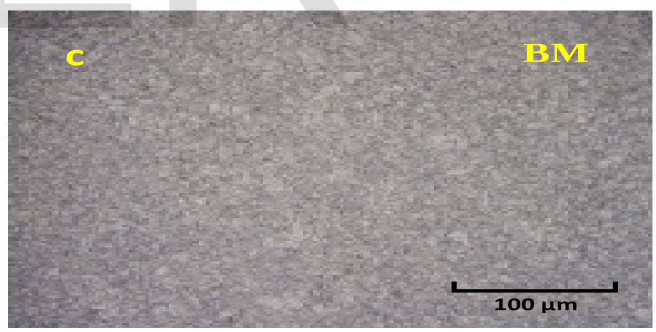

Fig.11c 2 hours

Figure 11 Microstructures of P91 steel base metal after PWHT at 750°C.

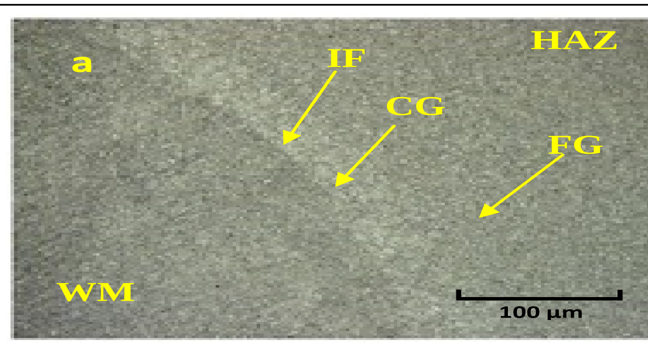

Fig.12a 0.5 hour

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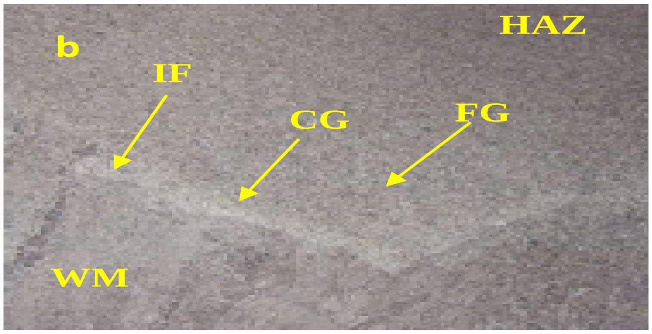

Fig.12b 1 hour

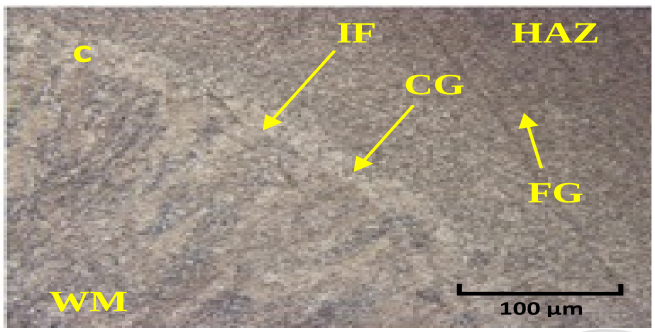

Fig.12c 2 hours

Figure 12 Microstructures of P91 steel HAZ and Interface P91 contact with ER90SB9/E9015B9 weld metal after PWHT at 750°C

Figures 13a, b and c show microstructures of P11 base metals after applying PWHT at a temperature of 750°C for 0.5, 1 and 2 hours, respectively. All these microstructures consist of ferrite and ferrite with carbides (perlite). No significant effect of different PWHT durations on the microstructure was found. Figures 14a, b and c, d show HAZ microstructure after PWHT at 750°C for 0.5, 1 and 2 hours, respectively. These post weld heat treated HAZ microstructures are much fine than those of post weld heat treated base metals. Ferrite grains were found in these post weld heat treated HAZ. Figures 15a, b and c show microstructures of P11 interface connecting to weld metal after PWHT was done at 750°C for 0.5, 1 and 2 hours, respectively. These obtained microstructures are different from those of P11 HAZ and base metal zones. In general, the microstructures consist of more coarsening grain structures occurring due to a sufficient level of welding heat to transform the structure to coarsen austenite grain structure, and cooled down later to be coarsening bainite grain structure instead. However, after applying PWHT at 750 °C, all microstructures would transform again to ferrite structure with carbide precipitation. This result is supported by the results of hardness distribution discussed in section 3. 2. 1. 2. 1

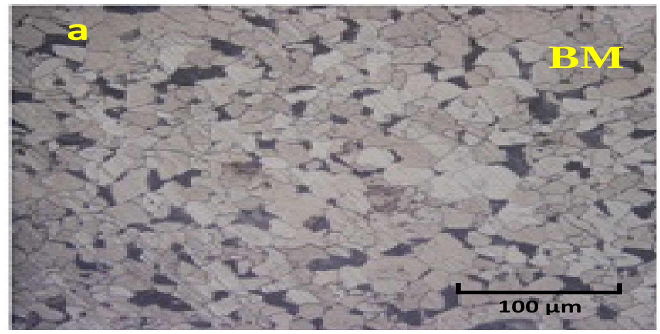

Fig.13a 0.5 hour

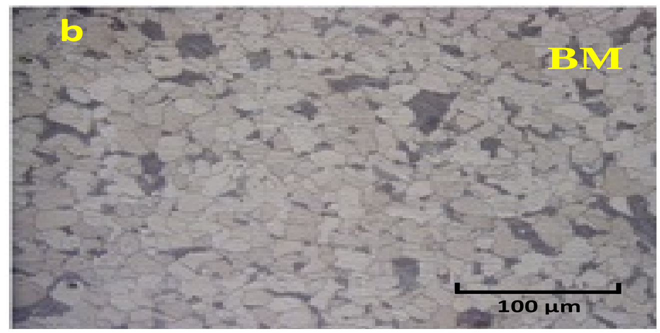

Fig.13b 1 hour

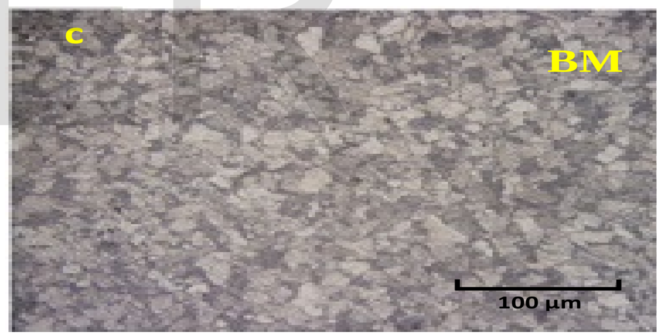

Fig.13c 2 hours

Figure 13 Microstructures of P11 steel base metal after PWHT at 750°C .

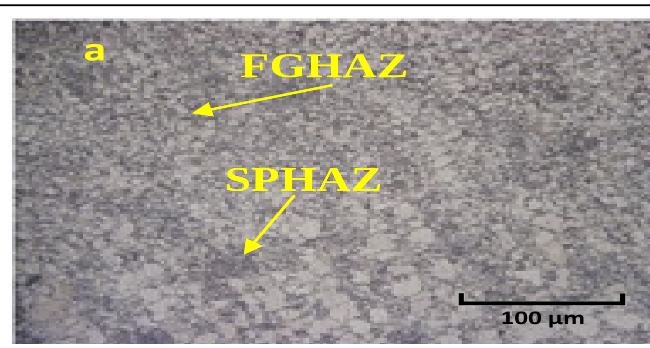

Fig.14a SPHAZ and FGHAZ 0.5 hour

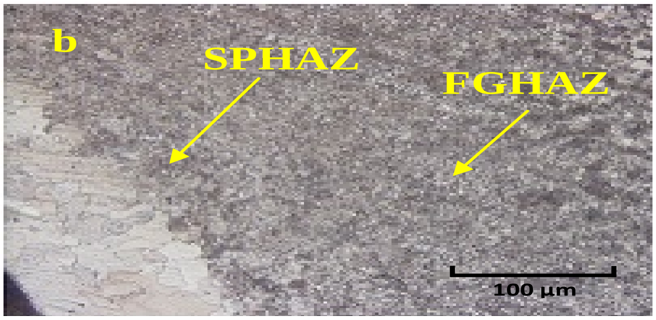

Fig.14b SPHAZ and FGHAZ 1 hour

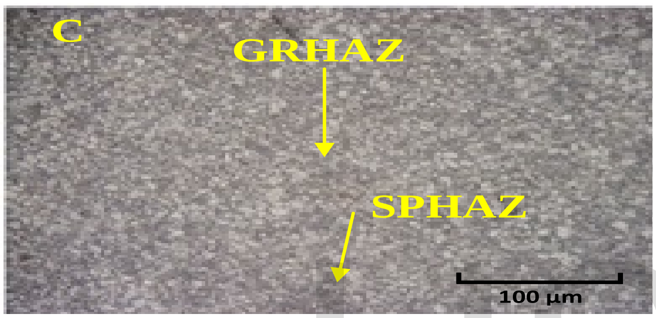

Fig.14c SPHAZ and FGHAZ 2 hours

Figure 36. Microstructures of P11 steel HAZ after PWHT at 750°C.

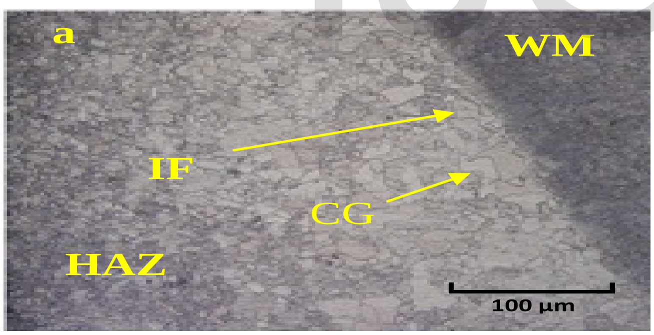

Fig.15a I.F 0.5 hour

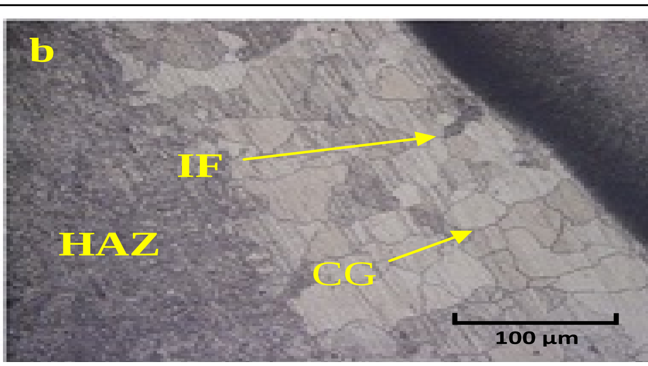

Fig.15b I.F 1 hour

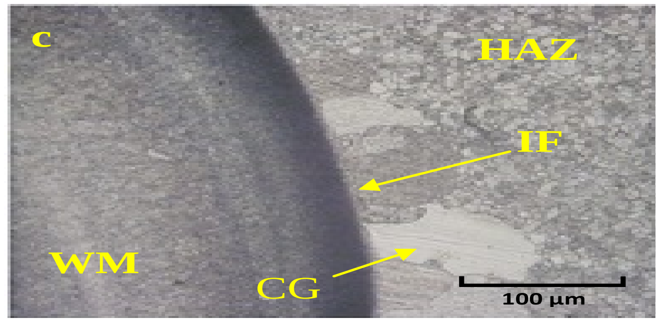

Fig.15c IF 2 hours

Figure 15 Microstructures of IF(inter face zone) P11 after PWHT at 750 ^{O}C

3.1.3.2. Using filler metal E9018B3/ER90SB3 at 750°C

Figures 16a, b and c show microstructures of P91 base metal after applying post weld heat treatment at a temperature of 750°C for 0.5, 1 and 2 hours, respectively. No significant difference in micro structural characteristics was detected in these specimens. However, it should be noted that all received microstructures were temper martensite. these similar characteristics were also found in HAZ after PWHT; see Figures 17a, b and c. However, temper martensite grain structures of post weld heat treated HAZ are finer than those of post weld heat treated base metal microstructures. Figures 17a, b, and c show post weld heat treated microstructures of interface zone adjacent to weld metal after heating at a temperature of 750°C for 0.5, 1 and 2 hours, respectively. It is found that microstructures in these interface areas consist of more coarsening grain size compared to those of base metal and HAZ microstructures, due to sufficient welding heat providing phase transformation from martensite to bigger austenite grain structure. When these coarse austenite grain structures were cooled down, they would finally retransform to coarse martensite grain structures. Heat treatment resulted tempers of the martensitic structure in the weld metal, heat affected zone and base metals. Figs. 17a, b, and c show post weld heat treated microstructures of weld metal adjacent to interface zone after heating at a temperature of 750°C for 0.5, 1 and 2 hours, respectively. It is found that microstructures in these interface areas consist of more coarsening grain size this result from transform the structure to coarsen austenite grain structure, and cooled down later to be coarsening bainite grain structure instead. However, after applying PWHT, all microstructures would transform again to ferrite structure with carbide precipitation. P11 microstructures the seam pervious result subsection 4.1.3.1 see figs. No 13, 14 and 15. This results is supported by the results of hardness distribution discussed in section 3. 2. 1. 2. 2

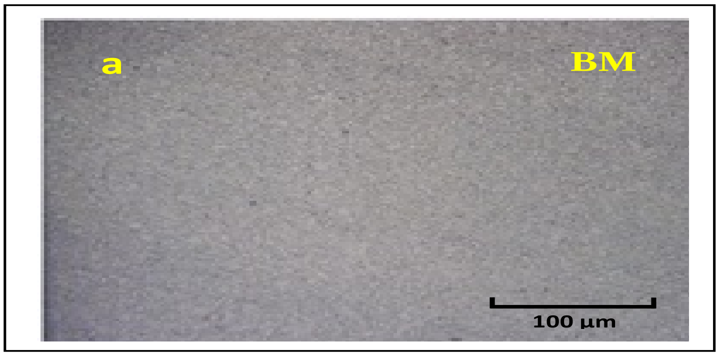

Fig.16a 0.5 hour

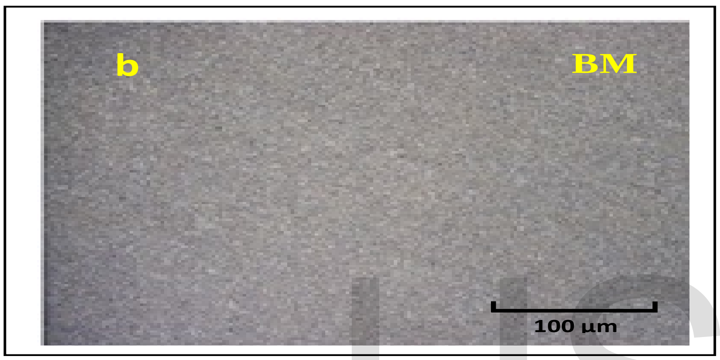

Fig.16b 1 hour

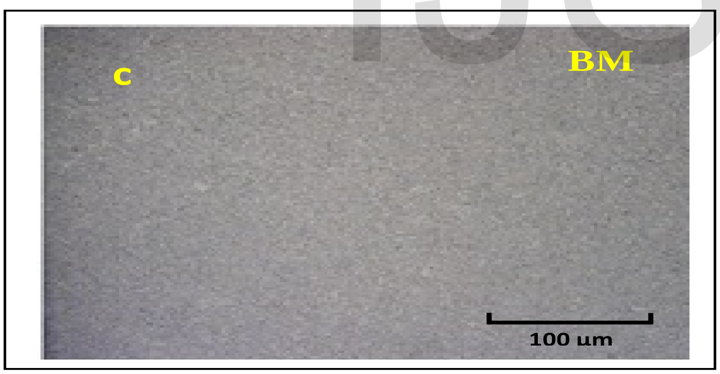

Fig.16c 2 hours

Figure 16 Microstructures of P91 steel base metal after PWHT at 750°

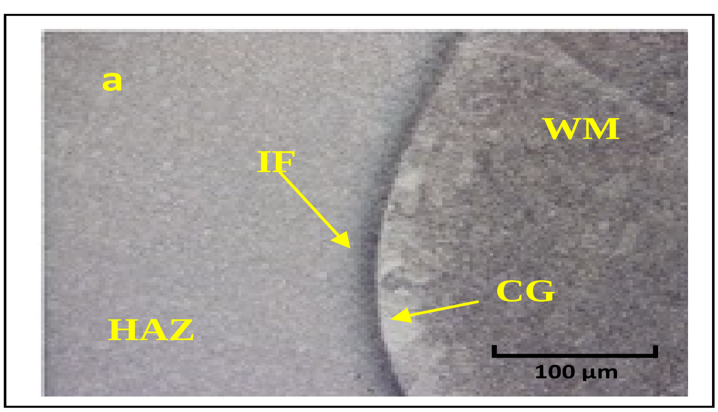

Fig.17a 0.5 hour

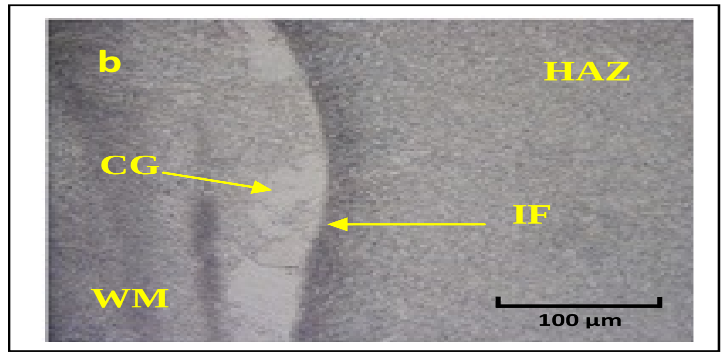

Fig.17b 1 hour

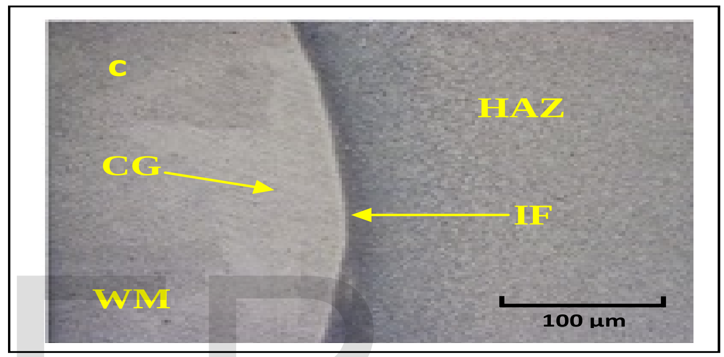

Fig.17c 2 hours

Figure 39. Microstructures of P91 steel HAZ, weld metal and the region of Interface P91 contact with ER90SB3/E9018B3 after PWHT at 750°C.

3. 2. Mechanical Properties:

3. 2. 1. Hardness Testing

3.2.1. 1. Hardness Testing Results after welding:

Sample no. S1L1 Figure 18 shows hardness profile of welded specimen. The hardness values of HAZ of P91 steel are over than 360HV, which is a generally limited hardness of carbon steel HAZ [8, 12]. This is due to the martensite micro-structure as shown in Figs. 3, 4 and 7 However; the hardness value of the P11 HAZ was not higher than 205 HV. P91 HAZ has a higher hardness value than P11 HAZ because of its higher hardenability. The interaction between the too high hardness microstructure with hydrogen can result in the crack initiation. This mechanism is well known as hydrogen in-duced cracking (HIC) [8] Therefore, the post weld heat treat-ment is needed to reduce this high hardness HAZ.

Sample no S2L2 Figure (19) shows hardness profile of welded specimen. The hardness values of HAZ of P91 steel are over 340 HV, which is a generally limited hardness of carbon steel HAZ [5, 8]. This is due to the martensite microstructure as shown in Figs. 8, 9 and 10 However; the hardness value of the P11 HAZ was not higher than 210 HV. P91 HAZ has a higher hardness value than P11 HAZ because of its higher hardenability. Also, the risk of hydrogen induced cracking is voluble Therefore, the post weld heat treatment also required to reduce this high hardness HAZ.

from Figures 18 and 19 show hardness profile of welded specimen. The hardness values of HAZ and weld metal of S1L1 sample its higher than S2L2 this back to increase the Cr percentage in filler metals this Cr is a ferrite stabilizer and carbides formers; forms hard (often complex) carbides, increasing steel hardness and strength.[10]

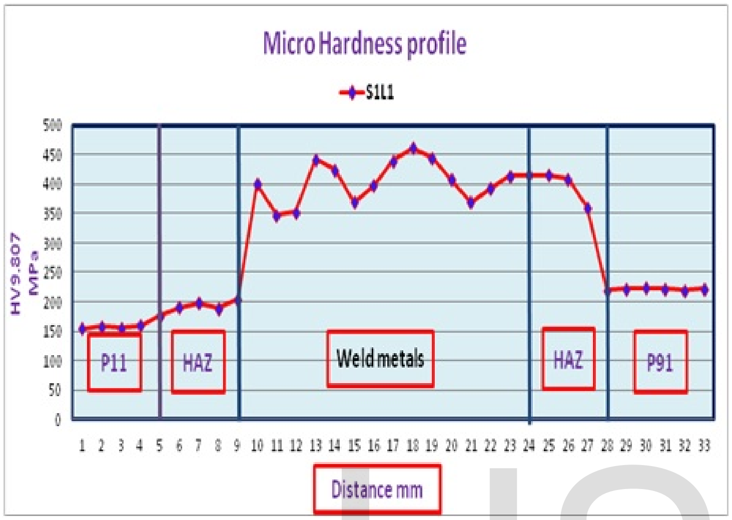

Figure 18. Hardness profile of dissimilar weld joint between P91 and P11steel with E9015B9/E90SB9 filler metals.

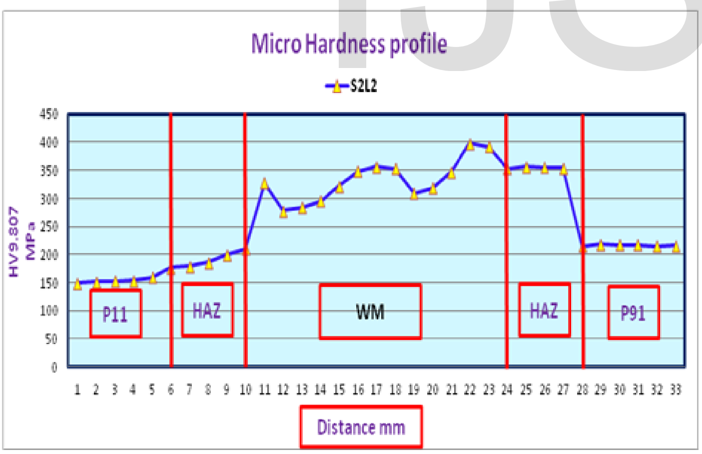

Figure 19. Hardness profile of dissimilar weld joint between P91 and P11steel with E9018B3/ER90SB3 filler metals.

3.2.1.2. Hardness Testing Results after PWHT

3.2.1.2.1.Hardness Testing Results after PWHT at 750°C and E9015B9/ ER90SB9 :–

fusion Weld zone microstructure at 750oC and E9015B9 and ER90SB9 changes during PWHT. Figures 20 a, b and c show the effect of heat treatment temperature on the hardness. The as-welded microstructure is a mixture of tempered martensite and some un tempered martensite, with a 460Hv hardness. PWHT at 750°C for 0.5, 1 and 2 hr significantly tempers the microstructure, to tempered martensite. to ferrite. The hardness decreases even more to 300Hv as fig. a,b and 260Hv as fig. c. shown in Fig. 12. The hardness of HAZ of P91 regions with PWHT at 750°C temperatures consistently decreases as martensite gets tempered. The hardness of HAZ of P11 regions consistently decreases as grain coarsening occurs. The no significant change in base metals hardness at 750°C. the seam results was obtained by [5, 11].

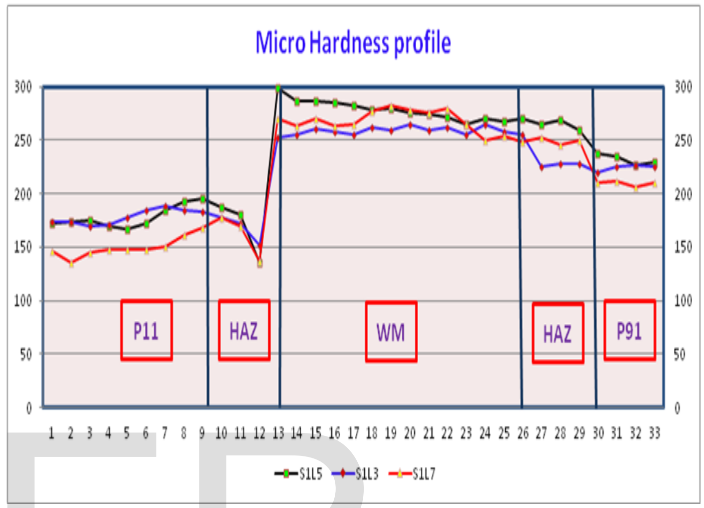

Figure 20. Hardness profile of dissimilar weld joint between P91 and P11steel with E9015B9/E90SB9 filler metals at 750°C 0.5hr, 1hr and 2hrs.

3.2.1.2.2. Hardness Testing Results after PWHT at 750°C and E9018B3/ ER90SB3:–

Figures 21a, b and c show hardness profiles of the welded samples after PWHT at 750°C for 0.5, 1 and 2 hours. In the zone of P91, it is found that PWHT could drastically reduce the hardness, and no significant different hardness was found with various PWHT durations. This hardness decrease occurred due to phase transformation from martensite to tempering martensite as shown in Figures 16 and 17. The hardness decrease was also found in the P11 zone due to phase transformation as well. The hardness results obtained in E9018B3/ER90SB3 filler metal zone are very similar. Therefore, the PWHT at 750°C for 1 hours should be suggested to be the suitable condition in this work. the seam results was obtained with Nattaphon Tammasophon [5, 8]. Fusion Weld zone microstructure at 750°C and E9018B3 and ER90SB3 changes during PWHT. Figure 16 show the effect of heat treatment temperature on the hardness. The as-welded microstructure is a mixture of tempered martensite and some un tempered martensite, with a 400Hv hardness. PWHT at 750°C for 0.5, 1 and 2 hr significantly tempers the microstructure to tempered martensite. The hardness decreases even more to 265Hv as shown in figs.21a and c and 225Hv as shown in fig.52b. The Hardness of fusion Weld zone contact to P91 fusion line at 750°C and E9018B3 and ER90SB3 is the softest region as martensite gets decomposed to largest grain size from ferrite as shown in Fig. 17. The hardness of HAZ of P91 regions with PWHT at 750°C temperatures consistently decreases as martensite gets tempered at the HAZ of P11 regions consistently decreases as grain coarsening from ferrite and increase as spheroidized pearlite. The hardness of P91 and P11 base metal regions after PWHT no significant change in base metals Hardness occur at 750°C as shown in Fig 13.

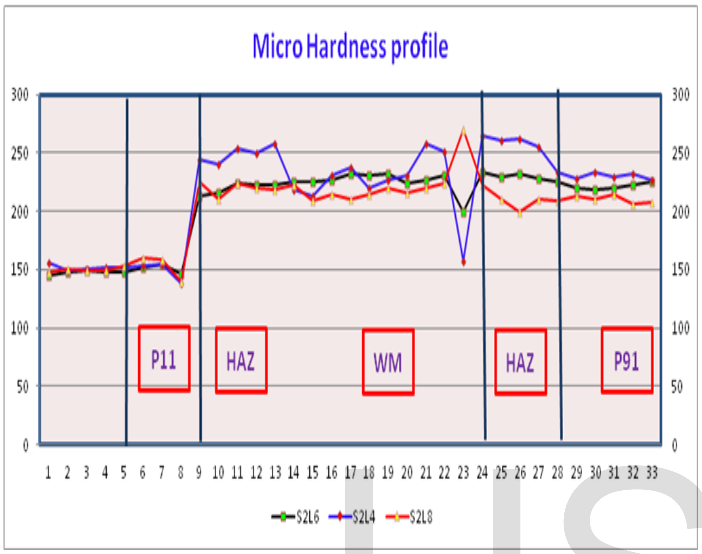

Figure 21. Hardness profile of dissimilar weld joint between P91 and P11steel with E9018B3/E90SB3 filler metals at 750oC 0.5hr, 1hr and 2hrs.

3.2.2 Tensile Testing Results

Figures 22 and 23 show the UTS values of specimens studied in this work. as welded condition and PWHT; The tensile strength decreased with the increase in Soaking Time. This could be attributed to the grain coarsening and over tempering .

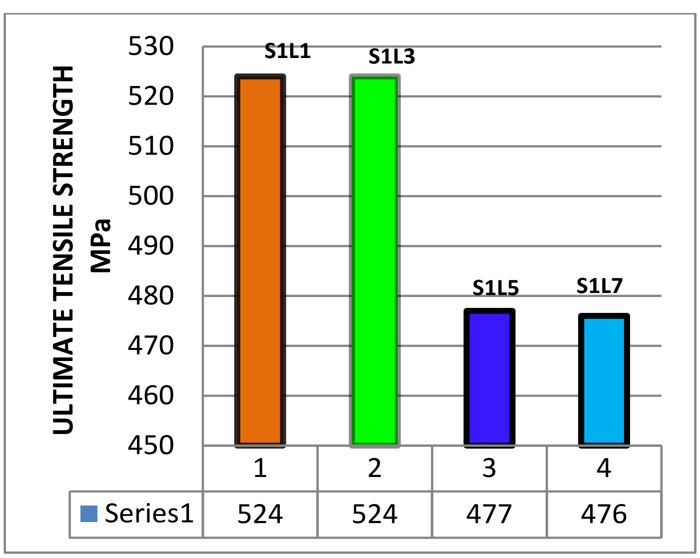

Fig.22. Ultimate tensile strength of different heat treatment Sample S1L1, S1L3, S1L5 and S1L7

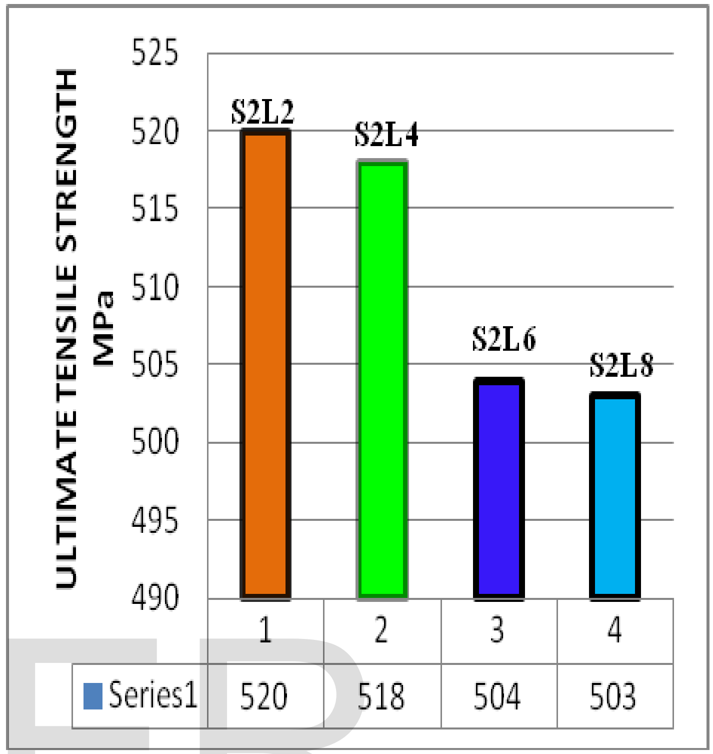

Fig.23. Ultimate tensile strength of different heat treatment Sample S2L2, S2L4, S2L6 and S2L8

Conclusions

The effect of post weld heat treatment at 750°C for 0.5, 1 and 2 hours on microstructures, hardness and Tensile of TIG and SMAW weldment between P11 and P91 Pipe using E9018B3/ER90SB3 and E9015B9/ ER90SB9 as filler metals was studied. The following conclusions can be drawn.

1. Post weld heat treatment provided more homogeneous microstructures after welding process and reduced hardness differences in welded microstructures, which could lead to a decrease in weld cracking.

2. the most suitable post weld heat treatment condition for these TIG and SMAW weld joints is at 750°C for 0.5 hours for Sample 1 and at 750°C for 1 hour for Sample 2. This condition provides the Tensile Strength and the minimum hardness of the weld zone between P91 steel and weld metal as well as minimum hardness difference between P11 and weld metal.

3. Tensile strength decreased with increase in temperature and soaking time

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REFERENCES

1- A. Aloraier, R. Ibrahim, P. Thomson, "FCAW process to avoid the use of post weld heat treatment", International Journal of Pressure Vessels and Piping, Vol.83, pp.394–398,2006

2-Electricity Generation Authority of Thailand, Failure report, (2008).

3- Basic heat treatment, section 2, pp.2, www.globalsecurity.org

4- "POST WELD HEAT TREATMENT OF WELDED STRUCTURES", Guidance Note 6 PWHT, welding technology institute of australia, info@wtia.com.au, pp. 1-10, February 2003

5- Leijun Li, "Effect of Post-Weld Heat Treatment on Creep Rupture Properties of Grade 91 Steel Heavy Section Welds", Utah State University, Project No. 09-799, pp.16-72, 2012

6- V. Thomas Paul, S. Saroja, M. Vijayalakshmi "Microstructural stability of modified 9Cr–1Mo steel during long term exposures at elevated temperatures" Journal of Nuclear Materials. vol. 378, pp. 273–281, 2008

7- Ma. Allam, "Investigation on the influence of Heat input and heat treatments on mechanical properties and creep resistance of Boiler Steel P91 weldments (9Cr-1Mo-V-Nb)", pp.104-145 , Ph. Dessirt, Cairo university, 2012.

8- T. Nattaphon, H. Weerasak, L. Gobboon " Effect of Postweld Heat Treatment on Microstructures and Hardness of TIG Weldment between P22 and P91 Steels with Inconel 625 Filler Metal" Journal of Metals, Materials and Minerals, Vol.21 No.1 pp.93-99, 2011.

9- G. Qiuzhi , D. Xinjie, L. Yongchang, Y. Zesheng, "Recovery and recrystallization in modified 9Cr-1Mo steel weldments after postweld heat treatment", International Journal of Pressure Vessels and Piping vol.93-94,pp. 69-74,2012

10- J. F. Lancaster, "Metallurgy of welding" (6th ed.). Cambridge: Abington Publishing: pp. 244-249, 1999

11- H. Yoonjin., K .Sanghoon , L. .Jeongho , "Effects of post-weld heat treatment cycles on microstructure and mechanical properties of electric resistance welded pipe welds", Materials and Design, Vol. 34, pp.685–690, 2012