International Journal of Research in Engineering, Science and Management
Volume-2, Issue-3, March-2019
www.ijresm.com | ISSN (Online): 2581-5792

Investigation on Metallurgical Effects of Delayed Heat Treatment on P-91 Pipes Welded by Orbital Hotwire TIG Welding

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***Abstract*: Now a days P91 Steels are increasingly being used for power plant piping applications. For the butt welding of P91 pipes, the processes which are widely employed are semi-automatic GMAW and GTAW processes. In addition to these processes, the recently developed orbital hot wire GTAW process (OHT-GTAW) can also be applied for the orbital welding of pipes. Since the process is free from human factor, the total time required for the welding process is less. In all these processes, which are used commonly for welding of P91 steel may have issues like hydrogen induced cracking due to improper heat treatment methods. The well-known Type IV cracking of P91 weldment occurred at the outer edge of HAZ because of its lower hardness. PWHT is the most effective way of relieving the welding stresses that are produced due to high heat input in the welding process and to achieve the required level of hardness in the weld as well as in the heat affected zones (HAZ) in thermal power plant main steam piping. Sometimes the delay prior to PWHT after welding of butt joints and attachment in long pipe may exceed 7 days and can go as high as 15 days. The paper makes a comparison of the OHW-GTAW process on P-91 materials with Post weld heat treatment and delayed post weld heat treatment for its effect on the mechanical and metallurgical properties.**

***Keywords*: Delayed Heat treatment, Heat Affected Zone, Orbital Hotwire TIG Welding, Post Weld Heat Treatment,**

1. Introduction

The growing energy demand lead to development of Creep strength enhanced ferrite (CSEF) steels. CSEFs are developed for high temperature application in fossil fired power plants. Creep Strength Enhanced Ferritic steels are widely used in fossil and nuclear power plants for the tubing and piping application because of their excellent creep strength oxidation resistance at higher temperature. P91, 9Cr-1Mo steel is a type of CSEF and has tempered martensitic microstructure.

For getting a satisfactory weld joint, the welding process has to be carefully selected with careful considerations of preheat temperature, inter-pass temperature, post heating and post weld heat treatment. These considerations are necessary since the material is prone for hydrogen related cracking issues. GTAW process plays an important role in weld fabrication in various industries because of its reliability & weld quality. One of the recent developments of GTAW is the orbital hot wire GTAW technique for the welding of pipes and tubes which cannot be rotated during welding. Welded joints of high -Cr ferritic heat-resistant steel, ASTM A335 Gr. P91, were subjected to post weld heat treatment (PWHT) to improve mechanical properties and to reduce residual stress. PWHT is also the most effective way of relieving the welding stresses that are produced due to high heat input in the welding process and to achieve the required level of hardness in the weld as well as in the heat affected zones (HAZ) in thermal power plant main steam piping.

PWHT is sometimes expensive and in many cases very complicated. The main opposition to PWHT is that the activity can considerably increase the cost of welding due to the significant time delays and the equipment required. This can be a particularly severe problem if PWHT is performed under conditions where control of temperatures is difficult. Sometimes factors such as geometry of component or the location of the repair may be an obstacle for PWHT. Hence the delayed heat treatment and its effects on the weldments of P91 to be investigated considering the extensive applications of these materials in coming years especially in Power Plant applications.

Generally, fabrication and repair of Cr–Mo steels requires a PWHT. The main advantages of PWHT are to relieve residual stresses and to enhance the HAZ properties. However, there is no enough work on the effect of delayed PWHT treatments on the metallurgical and Mechanical behavior of the weldment. In this paper, a comparative study of the delayed Post Weld Heat Treatment effects in the welding of a grade 91 pipe using orbital hot wire GTAW processes has been conducted for evaluating various Mechanical and metallurgical properties.

2. Experimental details

The welding trials on grade 91 pipe to pipe butt joints in 5G position were performed using Orbital hot wire GTAW (OHW-

GTAW) Welding process. The pipe conforms to ASME specification SA 335 Gr P91 and has the OD of 127 mm with a wall thickness of 20 mm. The chemical composition of grade 91 pipe is shown in Table 1. For these trials, matching filler wire conforming to ER90S-B9 was employed. The diameter of the filler wire was 0.8 mm for OHW-GTAW process. The edge preparation of the weld joint is as shown in Fig. 1.

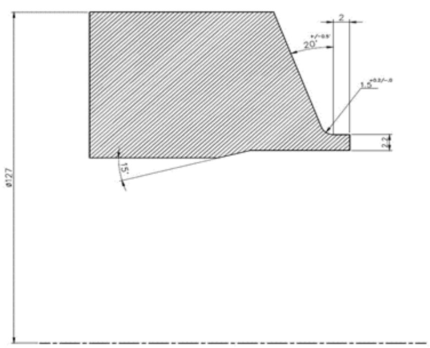


Fig. 1. Groove Design employed for the welding trials. (bevel angle is 20°, root face T is 2.2 mm and collar width L is 2 mm)

The welding was performed with a preheat temperature of 200 to 225°C. During multi pass welding, an inter pass temperature of 300 to 325°C was maintained.

Table 1
Chemical composition of P-91

Chemical Composition of P91 as per ASTM 335 P91 High Pressure Steel Pipe Chemistry (courtesy)			
C, %	Mn, %	P, %	S, %
0.08 – 0.12	0.3 – 0.6	0.02 max	0.01 max
Si, %	Cr, %	Mo, %	V, %
0.2 – 0.5	8.0 – 9.5	0.85 – 1.05	0.08 – 0.25
N, %	Ni, %	Al, %	Nb, %
0.03 – 0.07	0.4 max	0.04 max	0.06 – 0.10

Table 2
Welding Parameters employed for this process

Welding process	Welding position	Current (Amps)	Voltage (Volt)	Wire Feed (m/min)	Shielding Gas
OHW-GTAW	5G	160 - 305	13.0 – 15.0	0.7 – 6.5	100% Argon

A. Delayed post weld heat treatment

The welded Job was kept safely for nearly 1 month without immediate PWHT to assess the effect on the delayed heat treatment on the weld characteristics and environmental effects if any. The completed weld after a delay period of 1 month were post weld heat treated in a furnace at a temperature of 750 to 760°C with a soaking time of 2 h. After the completion of this delayed PWHT, the pipes were subjected to various non-destructive and destructive techniques to assess the quality of the welds.

3. Results & discussion

Fig. 2. Pipes welded using the Hot Wire Orbital TIG

Fig. 3. Root penetration of Orbital Hot Wire TIG

A. Radiography Test

Once the post weld heat treatment was completed weld cross section was cut in order to characterize the weldment with macro structural analysis, hardness test, bend test and metallurgical study. For macro structural analysis the specimen was milled, ground, polished and then etched using the Villella’s reagent (1g picric acid, 5 ml HCL, 100 ml methanol) and examined under the microscope. The radiograph test results of delayed post weld heat treated specimen is compared with the immediate post heat treated radiographic test results. The delayed heat treatment specimen was not shown any welding defect such as incomplete root fusion, lack of side wall fusion, weld porosity, undercut and excess reinforcement. The delayed Post weld heat treated specimen has not shown any indications in 100% radiography. So the delayed heat treatment has no effects on above weld defects. To further supplement the radiography test results, macro specimens were prepared showing the weld cross section. The macrostructures confirm the results of X-ray radiography.

Fig. 4. No defect- OHW GTAW with normal Post weld heat treatment

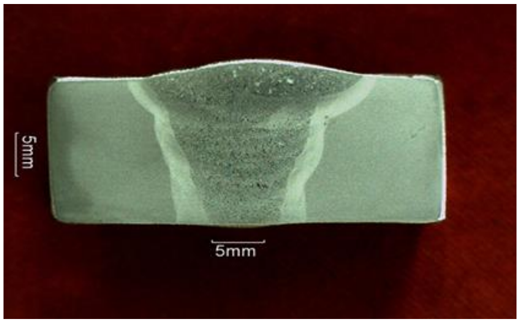


Fig. 5. No Defect- OHW-GTAW with delayed post weld Heat Treatment and Macrostructure of Welds

B. *Microstructure analysis*

Figure 6a shows the base metal micro structure at 500x magnification. The microstructure of SA213 P91 steel in the as received condition consist of fully tempered martensite. After welding this microstructure changes and degrades the properties of this material for high temperature application. The microstructure is refined by PWHT. The microstructure of weld metal heat treated at 760° C with soaking time 2h is shown in figure.

Weld interface, HAZ and weld microstructures of OHW-GTAW with and without delayed PWHT are shown in figure 6b and 6c. The microstructures show that welds have slightly under tempered structure in both these cases. Normal PWHT has exhibited good tempering compared to delayed PWHT job.

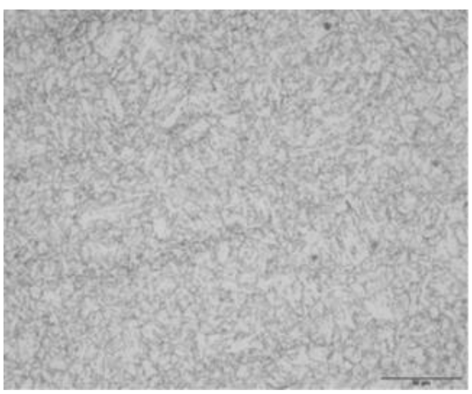
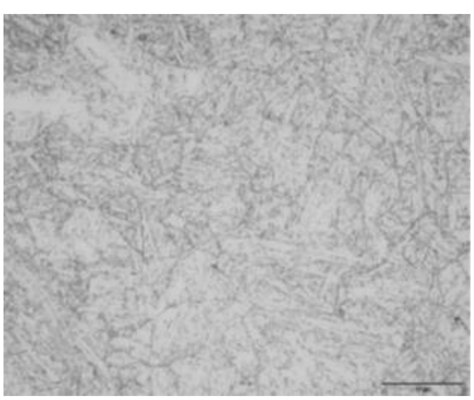
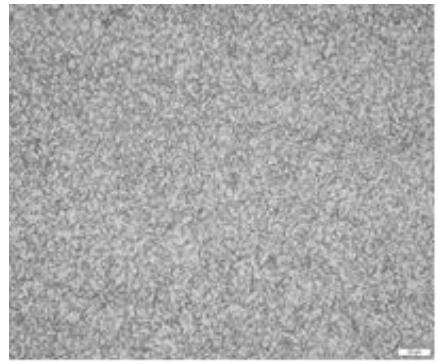


Fig. 6. (a) P91 Base Meal Micro Structure

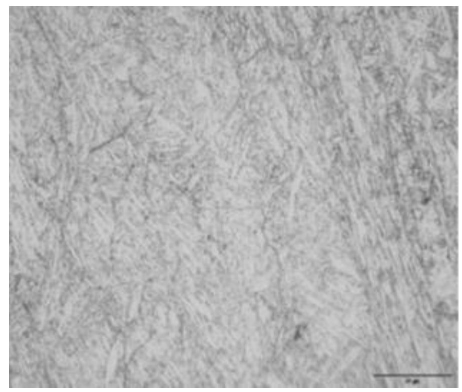


With immediate PWHT

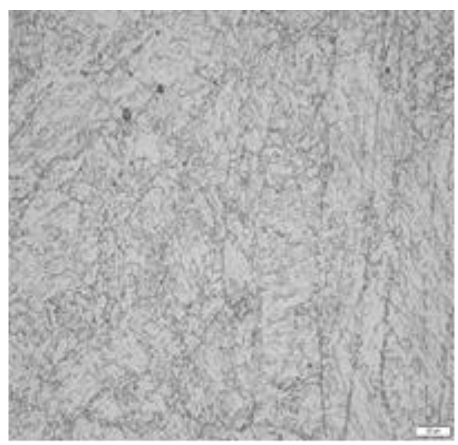


With Delayed PWHT

Fig. 6. (b) Welded sample HAZ, fusion line Micro Structure @ 500X



With immediate PWHT



With delayed PWHT

Fig. 6. (c) Welded sample Weld Metal Micro Structure @ 500X

C. *Mechanical & metallurgical testing*

To assess the mechanical properties of the weldments, tensile, bend, hardness and microstructure evaluation tests were performed on the weldment. The results of the tensile tests for the welding process were found to be satisfactory as seen in Table 3. Similarly, the face and root bend tests of the samples were found to be satisfactory.

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www.ijresm.com | ISSN (Online): 2581-5792

Fig. 7 (a). Tensile Test Specimens

Fig. 7 (b). Bend Test Specimens
Fig. 7. Test Samples for Mechanical Properties

D. Tensile test

Table 3
Tensile Test Result comparison

Process	UTS in MPa	Position of Fracture
With Immediate PWHT	676	Base Metal
	671	Base Metal
With Delayed PWHT	678	Base Metal
	677	Base Metal

E. Hardness Test

Table 4
Hardness Test Result

S. No.	With Immediate PWHT	With Delayed PWHT
01	189	186
02	187	183
03	185	182
04	225	218
05	260	254
06	255	248
07	263	253
08	259	251
09	242	238
10	205	201
11	180	178
12	189	184

The Vickers hardness values were measured across the weldment using a 10 kg load and the results are shown in Table 6 and Fig.10. The hardness values of delayed heat PWHT were found to be slightly lower for base material, Weld metal and Heat affected Zone. With delayed PWHT has exhibited higher peak hardness in the weld compared to base metal in both cases.

4. Conclusion

From the Previous research papers, different post weld heat treatment failures with affecting parameters of post weld heat treatment cracking studied. The effects of Mechanical and metallurgical properties using OHW –GTAW process on P91 pipes with a delayed post weld heat treatment was compared with the normal PWHT Specimen. The mechanical properties of delayed PWHT Process were found to be comparable with normal post treated job. Hardness test results shows a slightly lesser values compared to normal PWHT. Post weld heat treatment temperature and soaking time are the most significant input parameters for post weld heat treatment process.

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