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Effect of Postweld Heat Treatment on Microstructures and Hardness of TIG Weldment between P22 and P91 Steels with Inconel 625 Filler Metal

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Abstract

This research aims at searching for the optimal postweld heat treatment condition of the TIG weld joint between P22 (2.25Cr) and P91 (9Cr) steels using Inconel 625 as filler metal. The postweld heat treatment at 750°C for 2, 4 and 6 hours was applied in order to reach the proper microstructure and hardness for high performance in mechanical properties at elevated temperatures. It is recommended that postweld heat treatment at 750°C for 2 hours is the proper condition to reduce the hardness of heat affected zone (HAZ) of P91 steel.

Key words: P22, P91, Post weld heat treatment, Microstructure, Hardness

Introduction

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 Inconel 625 as filler metal were used (1). After welding, high hardness values of the heat affected zone (HAZ) of those dissimilar weld joints were possibly obtained (1). This high hardness HAZ comes from the austenite transformation to martensite due to the high cooling rate. The improper postweld heat treatment (PWHT) can result in a considerable difference in hardness between P91 steel and weld metal leading to prior crack and failure during high temperature operation (1). There are many research works studying and evaluating the microstructures and hardness of the dissimilar weld joints between P22 steel and P91 steel (2-5). However, very few researchers dealt with the effect of PWHT conditions on the weldment microstructure using Inconel 625 as filler metal. Inconel 625 is a popular nickel base superalloy, and used for high temperature service (6-9). It is utilized as a filler metal in welding because of its high strength and toughness. The aim of this research work is to determine the suitable PWHT conditions, which provide the proper microstructure and hardness to avoid earlier component failure for long-term high temperature service.

Material and Experimental Procedures

The chemical compositions of P22 steel, P91 steel and Inconel 625 are exhibited in Tables 1, 2 and 3, respectively. Table 4 shows the TIG welding parameters used in this work. All section P22 steel samples were TIG welded with sectioned P91 steel samples using Inconel 625 as filler metal as shown in Figure 1, followed by PWHT at 750°C for 2, 4 and 6 hours. Subsequently, they were ground and polished using standard metallographic technique, and afterwards etched in a Nital 10% etchant. The microstructures of all samples except Inconel 625 were viewed using optical microscopy.

Table 1. Chemical composition of P22 (2.25Cr) steel.

Composition (wt%)						
C	Mn	Si	S	P	Cr	Mo
0.07	0.6	0.3	0.02	0.02	2.25	1.0

Table 2. Chemical composition of P91 (9Cr) steel.

Composition (wt%)										
C	Mn	Si	S	P	Cr	Ni	Mo	Nb	V	N
0.1	0.5	0.3	0.01	0.02	9.0	0.1	1.0	0.08	0.2	0.05

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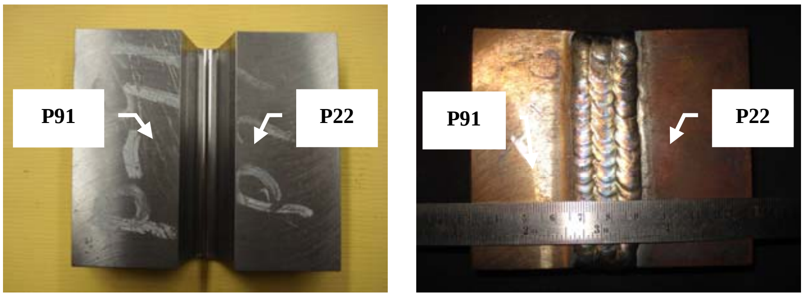
Table 3. Chemical composition of Inconel 625.

Composition (wt%)													
Ni	Cr	Fe	Co	Mo	W	Nb	Ti	Al	C	Mn	Si	B	Other
≥58.0	20.0-30.0	5.0	1.0	8.0-10.1	-	3.15-4.15	0.40	0.40	0.1	0.50	0.50	-	-

Table 4. TIG welding parameters.

Voltage	130-160 V
Current	11-13 A
Preheat Temperature	300°C
Interpass Temperature	330-350°C
Postweld Heat Treatment Temperature	750°C
Travel Speed	3-5 cm/min
Welding pass	10



(a) Before welding (b) After welding

Figure 1. Weld joint between P91 and P22 steels (a) Before welding (b) After welding.

Results and Discussion

Microstructure after TIG Welding

The microstructures of P91 steel after TIG welding are shown in Figures 2(a)-2(c). It is found that the base metal (Figure 2(a)) is temper martensite phase [(2, 3)]. This zone is far away from weld metal and no effect of welding heat was found in any way. Figure 2(b) shows HAZ microstructure, the matrix of which consists of martensite and retained austenite phases [(3)], which occurred due to phase transformation from martensite to austenite at higher temperature near welding zone. Figure 2(c) shows interface zone near Inconel 625 weld metal, which consists of bigger grain size structure than that of HAZ due to higher temperature conductivity of Inconel 625 [(6-9)]. This high temperature zone also assisted in carbide decomposition resulting in no carbide inhibiting grain growth [(3)].

The microstructures of P22 steel of TIG weldment are shown in Figures 2(d)-2(f). It is found that the base metal (Figure 2(d)) consists of ferrite phase and ferrite with carbide precipitation [(4, 5)]. This zone is far away from weld metal. No effect of welding heat was observed at all. Figures 2(e) and 2(f) show HAZ microstructure and P22 microstructure connected to weld metal. However, it was discovered that the bainite grain structure of the latter is more coarsening than that of HAZ, due to the difference in welding heat and cooling rate.

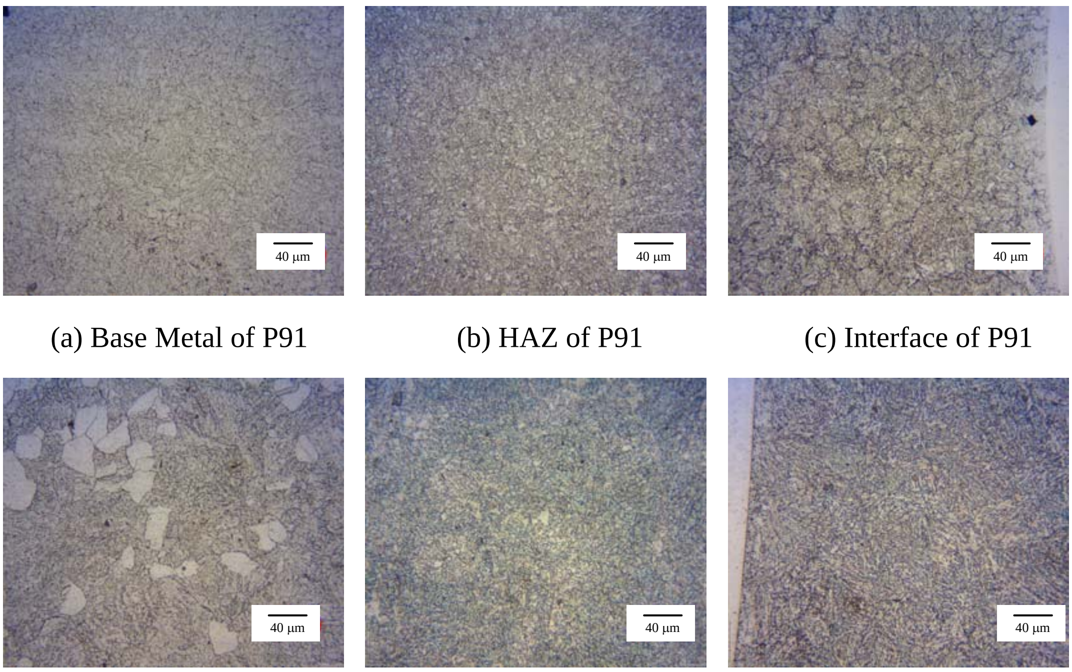
P91 Microstructure after Postweld Heat Treatment

Figures 3(a)-3(c) show microstructures of P91 base metal after obtaining post weld heat treatment at a temperature of 750°C for 2, 4 and 6 hours, respectively. No significant difference in microstructural characteristics was detected in these specimens. However, it should be noted that all received microstructures were temper martensite, which consists of carbide precipitation along grain boundaries [2, 3]. These similar characteristics were also found in HAZ after PWHT; see Figures 4(a)-4(c). However, temper martensite grain structures of postweld heat treated HAZ are finer than those of postweld heat treated base metal microstructures. Figures 5(a)-5(c) show postweld heat treated microstructures of interface zone adjacent to weld metal after heating at a temperature of 750°C for 2, 4 and 6 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. No significant differences in microstructure characteristics were observed. They are all temper martensite with carbide precipitation along grain boundaries.

P22 Microstructure after Postweld Heat Treatment

Figures 6(a)-6(c) show microstructures of P22 base metals after obtaining PWHT at a temperature of 750°C for 2, 4 and 6 hours, respectively. All these microstructures consist of ferrite and ferrite with carbides [4, 5]. No significant effect of different PWHT durations on the microstructure was found. Figures 7(a)-7(c) show HAZ microstructure after PWHT at 750°C for 2, 4 and 6 hours, respectively. These postweld heat treated HAZ microstructures are much fine than those of postweld heat treated base metals. Ferrite grains were found in these postweld heat treated HAZ. Carbide precipitation was found along grain boundaries.

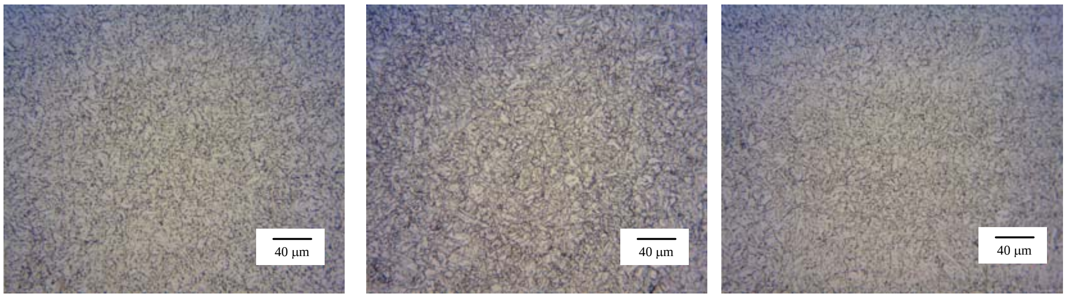
Figures 8(a)-8(b) show microstructures of P22 interface connecting to weld metal after PWHT was done at 750°C for 2, 4 and 6 hours, respectively. These obtained microstructures are different from those of P22 HAZ and base metal zones. In general, the microstructures consist of more coarsening grain structures 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 [4-5]. However, after applying PWHT, all microstructures would transform again to ferrite structure with carbide precipitation. HAZ microstructure after 6-hours PWHT consists of most coarsening ferrite grain structure.



(a) Base Metal of P91 (b) HAZ of P91 (c) Interface of P91

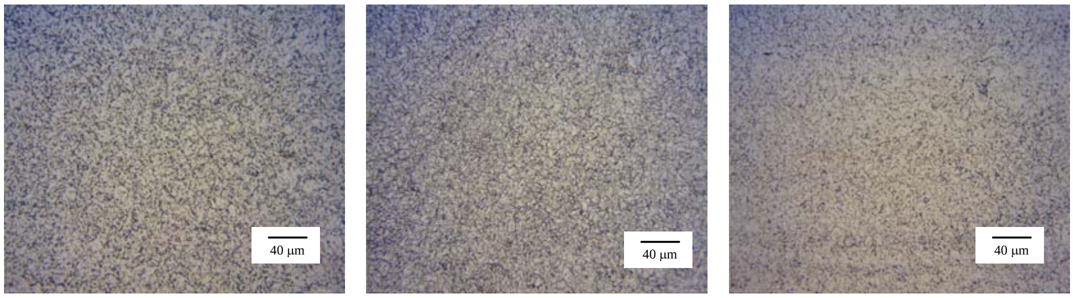
(d) Base Metal of P22 (e) HAZ of P22 (f) Interface of P22

Figure 2. Microstructures of TIG weldment between P91 and P22 steels with Inconel 625 filler metal.



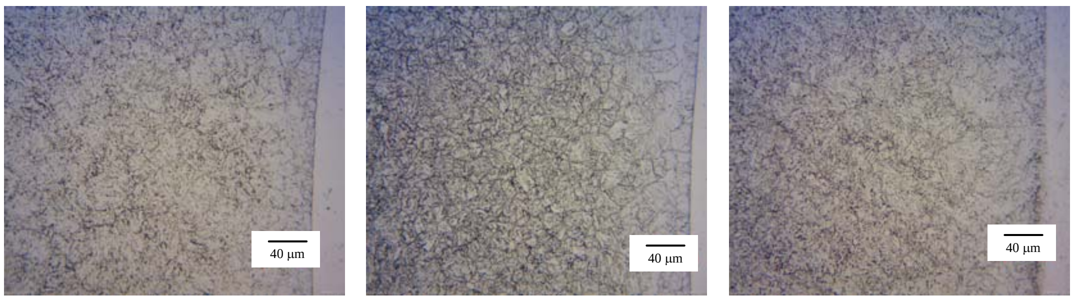
(a) 2 hours (b) 4 hours (c) 6 hours

Figure 3. Microstructures of P91 steel base metal after PWHT at 750°C.



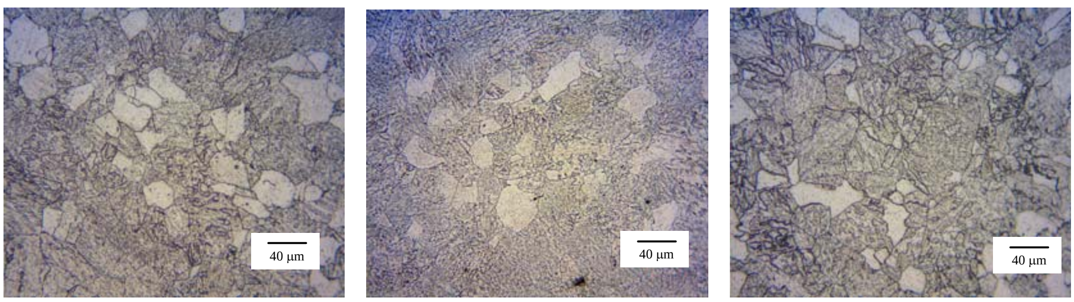
(a) 2 hours (b) 4 hours (c) 6 hours

Figure 4. Microstructures of P91 steel HAZ after PWHT at 750°C.



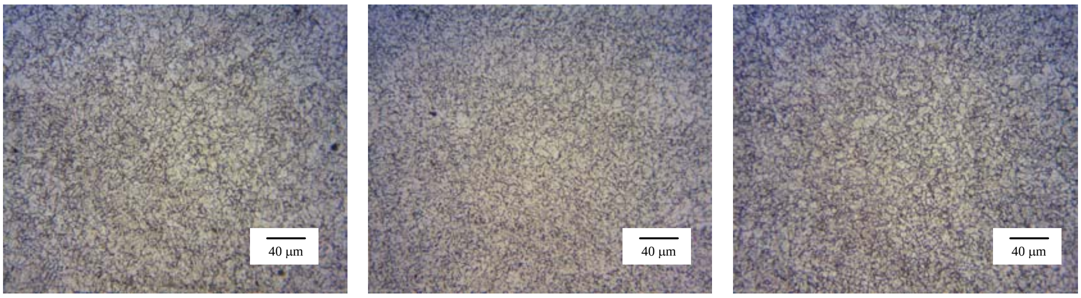
(a) 2 hours (b) 4 hours (c) 6 hours

Figure 5. Microstructures of P91 steel in the region of Interface P91 contact with Inconel 625 weld metal after PWHT at 750°C.



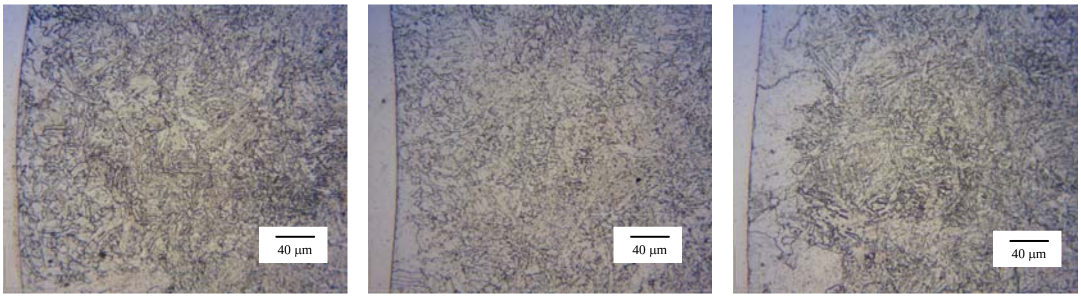
(a) 2 hours (b) 4 hours (c) 6 hours

Figure 6. Microstructures of P22 steel base metal after PWHT at 750°C.



(a) 2 hours (b) 4 hours (c) 6 hours

Figure 7. Microstructures of P22 steel HAZ after PWHT at 750°C.



(a) 2 hours (b) 4 hours (c) 6 hours

Figure 8. Microstructures of P22 steel in the region of Interface between P22 steel and Inconel 625 weld metal after PWHT at 750°C.

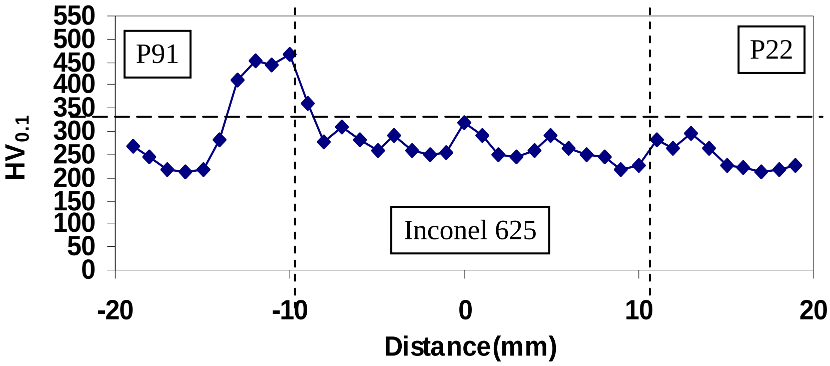


Figure 9. Hardness profile of dissimilar TIG weld joint between P91 and P22 steel with Inconel 625 filler metal.

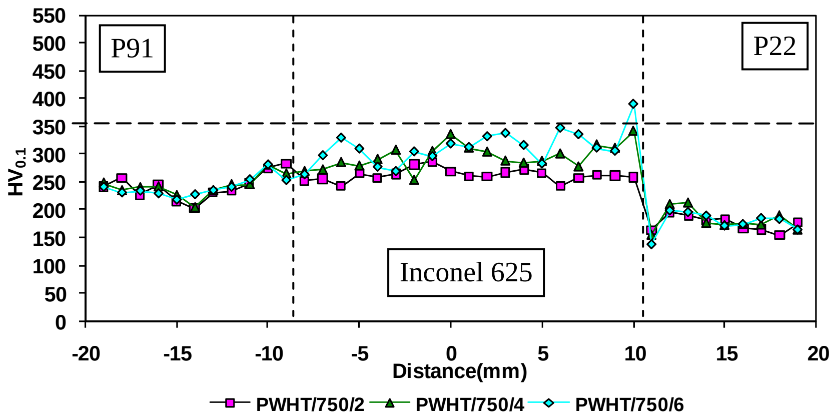


Figure 10. Hardness profiles of dissimilar TIG weld joint between P91 and P22 steels with Inconel 625 filler metal after PWHT for 2, 4 and 6 hours.

Hardness

Figure 9 shows hardness profile of welded specimen. The hardness values of HAZ of P91 steel are over 350 HV, which is a generally limited hardness of carbon steel HAZ [(10)]. This is due to the martensite microstructure as shown in Figure 1(b). However, the hardness value of the P22 HAZ was not higher than 350 HV. P91 HAZ has a higher hardness value than P22 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 induced cracking (HIC) [(10)]. Therefore, the postweld heat treatment is needed to reduce this high hardness HAZ.

Figure 10 shows hardness profiles of the welded samples after PWHT at 750˚C for 2, 4 and 6 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 ferrite as shown in Figures 3, 4 and 5. The hardness decrease was also found in the P22 zone due to phase transformation as well. The hardness results obtained in Inconel 625 filler metal zone are very similar. Therefore, the PWHT at 750˚C for 2 hours should be suggested to be the suitable condition in this work.

The hardness of Inconel 625 weld metal increases after PWHT at 750˚C for 2, 4 and 6 hours as seen in Figures 9 and 10. This is because the gamma prime (γ', Ni_3AlTi) precipitates in the matrix [(6-8)]. This precipitation obstructs the dislocation movement resulting in increase of strength and hardness.

Conclusions

The effect of postweld heat treatment at 750°C for 2, 4 and 6 hours on microstructures and hardness of TIG weldment between P22 and P91 steels using Inconel 625 as filler metal was studied. The following conclusions can be drawn.

1. Postweld 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 postweld heat treatment condition for these TIG weld joints is at 750˚C for 2 hours. This condition provides the minimum hardness of the weld zone between P91 steel and weld metal as well as minimum hardness difference between P1 and weld metal.

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