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Effect of Post Weld Heat Treatment Soaking Time on Mechanical Properties of TIG Welded Grade 91 Steel

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ABSTRACT

Grade 91 materials are widely used in the power generation industry for high-temperature components such as boiler tubes and steam line pipes. In this paper an attempt has been made to investigate the effort of post weld heat treatment (PWHT) soaking time on mechanical properties on the tungsten inert gas (TIG) welded joints of Grade 91 steel. Grade 91 plates of 13mm thick with preheat temperature of 220°C were used for welding. PWHT was conducted at 760°C for 2, 4 and 6 hours and examined the effect of PWHT duration on mechanical properties of the weldment. It was inferred from the present study that mechanical properties such as ultimate tensile strength and hardness of weldment decreases with increase in soaking time where as toughness increases with increase in soaking time. PWHT at 760°C for 2 hours soaking is adequate to get the desired mechanical properties of the weldment.

Keywords:— *PWHT, Soaking time, Mechanical Properties*

I. INTRODUCTION

The modified 9Cr-1Mo (Grade 91) is a structural steel used extensively in pressure vessels and steam generators for the next generation power plants because of its desirable properties like high creep rupture strength and toughness at elevated temperatures. The welded joints of Gr. 91 steel are generally subjected to post weld heat treatment to reduce residual stress and to improve the performance of the weld. If the PWHT is conducted at an appropriate temperature and time, the welded joint exhibits favorable mechanical properties. However, if the PWHT temperature is too low, the weld metal exhibits inadequate toughness due to insufficient tempering effect. On the other hand, if the PWHT temperature is too high, the tensile strength at ambient and elevated temperatures becomes insufficient due to excessive tempering effect. Samir et al. [1] reported that increasing number of cycle of PWHT does not give any significant benefit on mechanical properties of Grade 91 weld metal. Only PWHT cycle with appropriate soaking temperature and duration is sufficient and PWHT at 750°C is best suited for maintaining uniform hardness of base metal, heat affected zone (HAZ) and weld metal. It neither increases hardness of weld metal nor softness of base metal. Several researchers [2, 3] concluded that using filler metals ER90S-B9 for TIG, ER90S-B3 and ER9015-B9 for SMAW, PWHT at 750C for soaking time of 0.5, 1 hours gives desired mechanical properties of weldment. Pant et al. [4] studied the variation in mechanical properties of Grade 91 steel using different welding processes and concluded the PWHT importance for Grade 91 steel and final conclusion was drawn to justify the correct procedure for welding of 9Cr-1Mo-V alloy steel. Leijun et al. [5] analysed the effect of PWHT done at 760°C for 2 hours and evaluated mechanical properties of the as-welded and post welded heat treated Grade 91 steel. Nattaphon et al. [6] conducted PWHT of TIG Welded P91 Steel with using inconel 625 filler metal at 750°C for 2 hrs, 4 hrs, and 6 hrs and concluded that most suitable post weld heat treatment condition for TIG welded joints is at 750°C for 2 hrs and this condition provides the minimum hardness to the weld zone. Silwal et al. [7] investigated the impact toughness of the heat-affected zone (HAZ) for Grade 91 steel welds via measured thermal cycles, and microstructural evolution of various HAZ regions during post weld heat treatment has been investigated and used to explain the toughness changes. A 760°C for 2 hrs PWHT can significantly increase the cross-weld toughness of the HAZ. Devinder et al. [8] investigated the PWHT of the welded joints at 760°C for 3 hrs and 760°C for 6 hrs respectively. The effect of PWHT at different holding time was investigated on the heat affected zone (HAZ) of P-91 alloy steel and observed that as the PWHT duration time increases; there is a continual improvement in the impact toughness of the P-91 steel welds. Taniguchi et al. [9] have examined the effects of PWHT temperatures on the mechanical properties of TIG welded ASTM A335 Grade 91 steel and concluded that PWHT temperature of up to 7600Cis judged to be allowable to get desirable mechanical properties. Rahman et al. [10] has concluded that the tensile properties (strength, elongation, reduction of area) and the impact toughness are sensitive to heat treatment. Maridurai et al. [11] evaluated the effect of the tensile test temperature ranging from 4000C to 7000C on the tensile properties of the P91weldment. The fracture surfaces of the hot tensile & impact specimens were examined under Scanning electron microscope. Mosa et al. [12] have done the investigation on influence of PWHT on TIG welded Grade 91 weldment and indicated that PWHT at 750°C for 0.5 hour was the proper conditions to obtain optimum grain size and regular Hardness distribution of heat affected zone (HAZ).

From the literature review, it is found that PWHT is essential for grade 91 alloy steel. As we could see from Literature review, most of the research work done on the Grade 91 alloy steel by using combined welding process i.e., two different welding processes for root pass and subsequent pass for entire welding respectively. However there are certain research gaps in terms of TIG welding and PWHT soaking intervals 2 to 6 hours on Grade 91 alloy steel in practical usage of industrial purpose. Therefore an attempt has been made to investigate the effect of PWHT soaking time on Mechanical properties of TIG welded Grade 91 steel which is extremely used in BHEL Trichy.

II. Materials and Methods

2.1. Base metal and welding

The material selection in manufacturing process is most important as per process availability and customer's requirement. The material used to carry out experiment is ASME SA213 Grade 91 alloy steel. The chemical composition and mechanical properties of ASME SA213 Grade 91 alloy steel are shown in table 1 and 2 respectively.

The electrode material used for the work is ER90S-B9 having a diameter of 1.2mm. The chemical composition of the electrode is given in Table 3.

ASME SA213 Grade 91 alloy steel plates with the dimensions of 290×125×13 mm are prepared with the bevel heights of 10 mm, bevel angle of 22.5°. The groove was made on shaping machine tool. These specimens are then welded with a root gap distance of 2 mm. Figure 1 shows single V groove butt joint preparation.

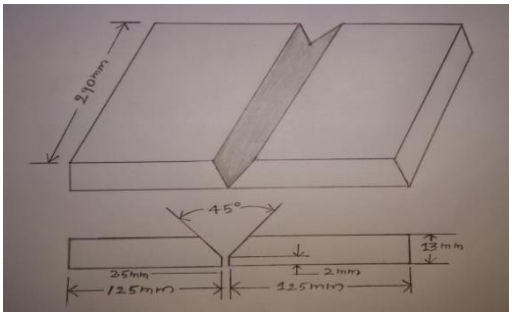


Figure 1: Geometry of work piece

Welding input parameters play a very significant role in determining the quality of weld joint. The optimum weld process parameters employed in this study is listed in table 4.

Table 1: Chemical composition of ASME SA213 Grade 91 Alloy steel

C	Mn	Si	P	Si	Cr	Mo	V	Nb	Ni	N	Al	Ti	Zr
0.07 -	0.03 -	0.2 -	max	max	8.0 -	0.85 -	0.18 -	0.06 -	max	0.03-	max	max	max
0.14	0.60	0.50	0.020	0.010	9.5	1.05	0.25	0.10	0.04	0.07	0.02	0.01	0.01

Table 2: Mechanical properties of Grade 91 base material plate at room temperature

Grade	Yield strength	Minimum elongation % in a gauge length of 50 mm	Tensile Strength (MPa)	Hardness (HV10)	Impact Energy (J)
ASME SA213 Grade 91 steel	560	25	630	210	220

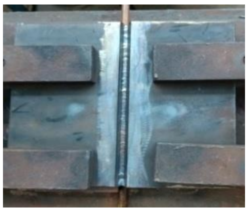
Table 3: Chemical composition of electrode ER90S-B9

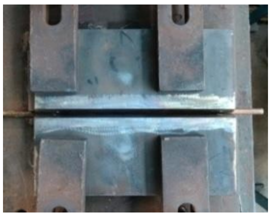
C	Mn	Si	P	S	Cr	Mo	V	Nb	Ni	N	Al	Cu
0.09	0.49	0.20	0.004	0.003	8.7	0.90	0.19	0.08	0.66	0.07	0.006	0.03

Table 4: Process Parameters of TIG Welding

Parameter	Range
Current type	DCEN
Welding Current	150 A
Voltage	12 V
Welding speed	1.16 mm/sec
Argon gas flow rate inner shield for weld bead	10 l/m
Argon gas flow rate outer shield for torch	5 l/m
Electrode Diameter	1.2 mm
Tip to surface distance	3 mm
Weld geometry	Single V-Groove Butt Joint

(a) *(b)*





(c) *(d)*

Figure 2: Stages Showing Welding Pass

The plates were pre-heated keeping in butt joint position up to 2200C. Using welding torch, the 1st layer having one bead, which is known as Root pass was welded. After that, 2nd layer having one bead which is known as Hot pass was welded. Next 3rd, 4th, 5th layers having two beads and 6th, 7th layers having three beads which are known as Filler pass were done. Finally, welding on back side of the plates having one bead which is known as Back pass was done.

The time taken to complete all these passes is shown in table 5 which gives total time for welding of one joint.

Table 5: Time Span for Welding Passes

S.No	Pass	No.of beads	Time taken per weld bead (min)
Plate-1	Root Pass	1	4.18
Plate-2	Hot Pass	1	4.20
Plate-3	Filler Pass	12	4.14
Plate-4	Back Pass	1	4.12

Average welding time per pass = 4.16 min

Heat input calculation

Welding speed = weld bead length (mm) / average weld time/pass (sec) = 290 / 249.6 = 1.16 mm/sec

Power (Watt) = Welding Current (A) × Voltage (V) = 150×12 = 1800W

Heat input (J/mm) = Power (Watt)/ Welding speed (mm/sec) = 1800/1.16 = 1551.724J/ mm

After welding these four butt welded plates were sent for radiography testing (RT) in order to ensure the quality of welding. After RT, post weld heat treatment done for 3 plates by using fixed furnace method and another plate kept remains as-weld condition only. The PWHT conditions employed for the experimentation is shown in table 6. After PWHT plates are marked for cutting and the plates were cut in samples by horizontal band saw machine.

Table 6: Post Weld Heat Treatment Conditions

Sl No.	Description	Value
1.	Heating rate	150°C/Hr
2.	Soaking Temperature	760°C
3.	Soaking Time	2, 4, 6 Hours
4.	Cooling Rate	100°C/ Hour
5.	Unloading Temperature	Room Temperature

2.2. Mechanical Characterization

The welded samples were characterized to establish the mechanical properties by conducting various tests such as Tensile, Hardness, Impact and Bend Tests. The Tensile test was conducted as per AWS B4.0 standard at room temperature using UTE-60 Universal Testing Machine. Hardness measurements were conducted on Vickers Hardness Testing Machine – FV700 as per ASTM E92 standard. A load of HV10 98.07N was applied on the specimen for a specific time of 10s. The Impact Test was conducted on Tinius Olisen Equipment at room temperature as per AWS B4.0 standard. Bend test was conducted on bend testing machine – UTN60 as per AWS B4.0 standard at room temperature. The results obtained from various mechanical tests are outlined in detail in the following sections.

III. Results and Discussion

The effect of post weld heat treatment on mechanical properties like tensile strength, base metal hardness, HAZ hardness, weld hardnes and impact energy were analysed.

3.1. Tensile Test

The work piece is prepared for tensile test and size of the work piece is 250×40×10mm with a Gauge Length of 50 mm and width 20 mm. The Prepared work piece after machining is shown in Figure 3.

Figure 3:Test specimen

Figure 4: Specimens after Tensile test

Load is gradually applied on the sample and at particular load the given sample broken and the results are tabulated in Table 7. The specimens after testing are shown in Figure 4.

Table 7: Tensile strength value

Samples	No. of experiments	U.T.S (MPa)	Position of Fracture
As received un -welded base metal	1	630	Base Metal
As-welded	1	720	Base Metal
2 Hours PWHT	1	698	Base Metal
4 Hours PWHT	1	688	Base Metal
6 Hours PWHT	1	684	Base Metal

Based on the above experiment, results were plotted between UTS as ordinate and PWHT cycle as abscissa as showed in the below figure 5

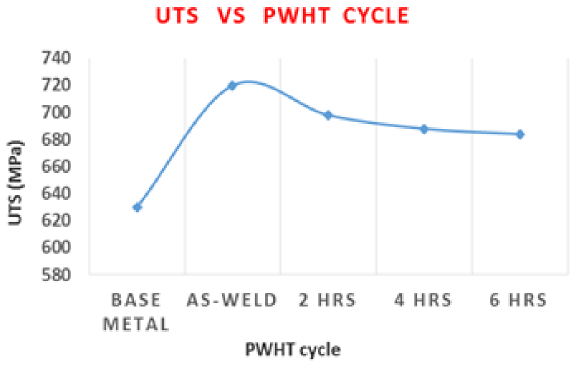


Figure 5: UTS vs PWHT at 760°C for various soaking time

It is analyzed that, slight decrease in Ultimate Tensile Strength with PWHT soaking time and minimum Ultimate Tensile Strength of weld specimen corresponding to 6 hours soaking time as compared to as-welded specimen. All the PWHT weld specimens found to fracture at base metal which ensures weld joint is strong.

3.2 Hardness Test

Work piece prepared for hardness test is of size 60 × 40 × 10 mm. Hardness values were measured in the base metal, weld zone, HAZ and results are tabulated in table 8.

Table 8: Average Vickers Hardness

	Average Vickers Hardness HV10				
Work Sample	As-weld	2 Hrs	4 Hrs	6 Hrs	As re-ceived
Base Metal	194	191	192	183	210
HAZ	262	220	214	181	
Weld Zone	322	242	227	213	

Based on the above experiment results, the graphs were plotted between Vickers Hardness HV10 as ordinate and distance between centre of weld as abscissa and average Vickers Hardness HV10 as ordinate PWHT cycle as abscissa as shown in figure 6.

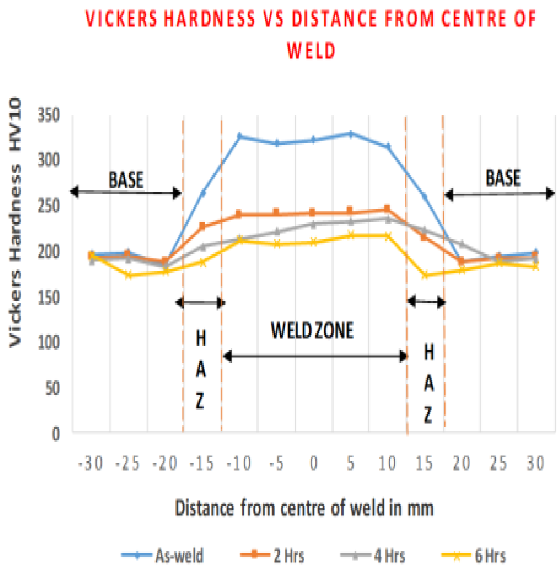
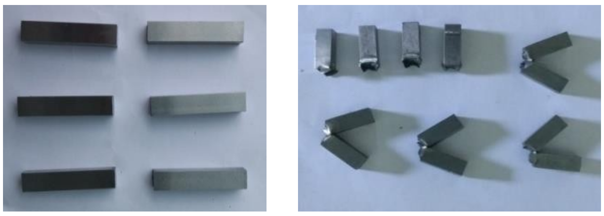


Figure 6: Avg. Hardness vs PWHT at 760°C for various soaking time.

It is observed that, there is no significant change in the base metal hardness with PWHT treatment soaking duration as compared to as-welded specimen. As PWHT soaking time increases, hardness in the HAZ and weld zone are found to drop and minimum hardness corresponding to 6 hours soaking time as compared to as-welded specimen.

3.3. Impact Test

The work piece is prepared for impact test and size of the work piece is taken as 55×10 × 10 mm. The samples before and after the impact test are shown in figure 7. The test sample with Charpy V-Notch 2 mm depth made at centre of the weld.



(a) *(b)*

Figure 7: Samples (a) before Impact test (b) after Impact test

Table 9: Impact energy value of an experiment

Samples	No. of experi-ments	Impact Energy les) (in Jou	**Average Impact Energy (in Joules)**
As-welded	1	79	102
	2	89	
	3	105	
	4	134	
2 Hrs PWHT	1	162	200
	2	185	
	3	212	
	4	238	
4 Hrs PWHT	1	198	214
	2	202	
	3	206	
	4	250	
6 Hrs PWHT	1	216	225
	2	222	
	3	229	
	4	233	
As received un-welded base metal	1	270	270

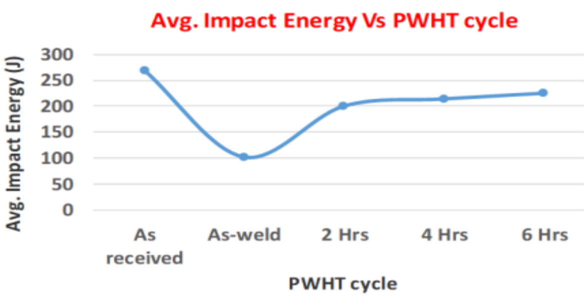


Figure 8: Impact Energy vs PWHT Cycle

It is analyzed that impact energy increases with increasing PWHT Soaking time and it is found that the maximum impact energy of weld specimen corresponding to 6 hours soaking time as compared to as-welded specimen.

3.4 Bend Test

The work piece is prepared for bend test and size of the work piece is 240×12×10 mm. The samples before and after the bend test are shown in Figure 9.

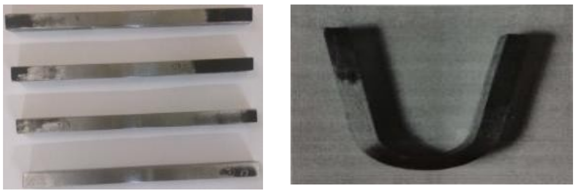


Figure 9: Samples before and after Bend Test

The Bending is done up to a max. 1800. The test is conducted using a plunger to force the specimen in to the die in order to produce the desired contour of the outside and inside surface of the specimen. The mandrel diameter is four times of the specimen thickness.

Table 10: Bend Test result

Samples	**No. of Experi-ments**	**Side Bend**	**Re-marks**
As-welded	1	No Open Dis-continuity	Passed
2 Hrs PWHT	1	No Open Dis-continuity	Passed
4 Hrs PWHT	1	No Open Dis-continuity	Passed
6 Hrs PWHT	1	No Open Discontinuity	Passed

It is analyzed that, there is no open discontinuity observed on the post weld heat treated as well as-welded specimens, which says there is a clear evidence of optimum ductility of welded joints and sound weld of all samples.

IV. Conclusions

The effect of post weld heat treatment at 760°C for 2, 4 and 6 hours soaking time on hardness, toughness and tensile strength of TIG welded Grade 91steel using ER90SB9 as filler metals was studied. The following conclusions can be drawn.

- Post weld heat treatment is necessary to improve mechanical properties of Grade 91 steel in weld metal and HAZ to avoid the premature failure. After welding, high hardness values in the heat affected zone (HAZ) and weld pool were obtained. After PWHT at temperature 760°C for hardness of weld joint is reduced. With increase in PWHT duration from 2 hours to 6 hours hardness of P91 weld metal and HAZ reduced.
- After increases the post weld heat treatment holding time from 2hrs to 6hrs, hardness level and the tensile strength of the P91 steel weldment were decreased and impact toughness was increased.
- The most suitable post weld heat treatment condition for TIG welded joint was 760°C for 2 hours soaking duration. PWHT at 760°C for 4 hrs is best suited for maintaining uniform hardness of base metal, HAZ and weld metal. But for reason of economy, the PWHT at 760ºC for 2 hrs is adequate to get the desired mechanical properties.

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