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A Study on Effect of Preheating and Post Weld Heat Treatment (PWHT) of Grade P91 Steel

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Abstract—*In the present study, bead-on-plate welds were carried out on P91 steel plates using Gas Tungsten Arc Welding (GTAW). Experiment is carried out on three control input process parameters (current, travel speed and gas flow rate) with pure argon gas, without any filler material using autogenous fusion arc welding(GTAW) to investigate the effect of preheating and post weld heat treatment (PWHT) on 6mm thick plate of grade P91 steel plates was used. The responses, weld bead geometry (in terms of bead width(BW), depth of penetration(DOP)), weld area(WA), and width of Heat Affected Zone (HAZ) width have been measured with Adobe Acrobat 9.0 Pro software. The measured weld quality in the form of weld bead geometry which played an important role in determining the input process parameters to analysis the weld structure and size of weld bead geometry. It has been found that the pre-heat and post weld heat treatment effects the microstructure and micro-hardness of welded specimen.*

Keywords*: Preheat, PWHT, microstructure, micro-hardness.*

1. INTRODUCTION

Grade P91 steel, basically is a Creep Strength – Enhanced Ferritic Steel (CSEF) known as the modified 9Cr-1Mo-V, designated as P91 steel for Plate (A 387/A387M) its Standard Specification for Pressure Vessel Plates, Alloy Steel, Chromium – Molybdenum [1]. Modified 9Cr-1Mo-V (P91) steel is widely used in different high temperature components of power- generating applications such as steam header, steam pipes, Superheater, Pressure Vessel Plates, reheater and in process vessels of chemical industries[2]. An advantage of using P91steel is low thermal expansion, high thermal conductivity, good stream corrosion resistance and excellent creep resistance [3-4]. The modified 9Cr-1Mo-V steel plates extremely hardenable material. However, welded P91 grade steel components required proper application of heat treatment because in power- generating industries P91 steels components are used at a higher steam temperature more than 600^0C and a steam pressure greater than 35 MPa[5]. Components are reported to show premature creep failure in the temperature range 600- 650^0C. Failures occur in the inter critical heat affected zone (ICHAZ) and coarse grain region of HAZ (CGHAZ) of weld joints, generally known as Type IV cracking of weld[6]. Research attempts have been made to understand and minimize its susceptibility to such cracking regarding that Pre-heat (at 200^0C) and Post Weld Heat Treatment (at 760^0C for 2 hrs.) is required to ensure that desired hardness and microstructure are obtained. Heat treatment operations are necessary to avoid hydrogen retention cracking problems in this extremely hardenable P91 steel material [7-8]. The present study shows that heat treatment is not an optional operation in welding of A 387 Grade - P91 (plates). It is necessary as it improves the welding properties as well as the microstructures of different weld bead zones. The study helps to understand and minimize its susceptibility to cracking after proper heat treatment operations. An autogenous (TIG) welding process on bead on plate welding was performed without the use of filler material.

2. EXPERIMENTS

Bead on plate welding experiment was performed on Grade P-91 steel plates on 6 mm thick plate by Tungsten Inert Gas (TIG) welding. TIG welding process is generally used to produce high quality weld joints of 9Cr-1Mo steel [9]. The chemical composition of Grade P-91 steel plate's material is shown in Table 1.

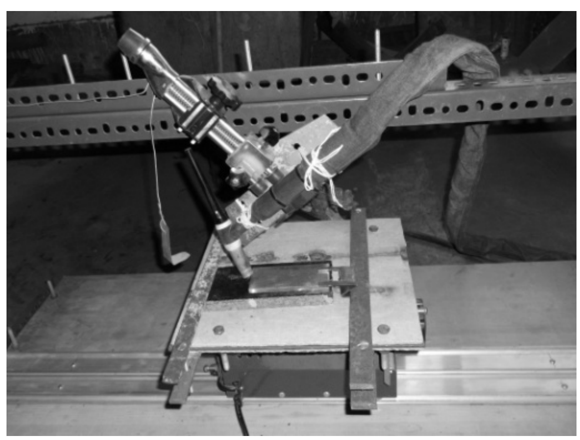


Fig. 1: TIG welding experimental setup

Experiment is carried out on three control input process parameters(i.e. current, travel speed and gas flow rate) is shown in Table 2. For welding, the specimen P91 steel plate material was cut into size of 100mm x 50mm x 6mm by abrasive cutter with blade of thickness 1.5 mm was used to cut the specimens at 1500 rpm.

Two types of welding have been performed on P91 steel plate. First - Before welding preheating. Second - after welding post weld heat treatment (PWHT). In both welding's the torch fixed and workpiece is controlled by travel-speed machine has been fabricated to avoid human errors during welding which shown in Fig. (1).

After welding, the specimens were cut by abrasive cutter then grinded. After that polished and etched, using 5% Nital solution, to reveal the bead geometry on the cross section. The etched specimens were then photographed using a digital camera, shown in Fig. 2 and 3 which were later used for dimension measurement.

Table 1: The chemical composition of material used

	Cr %	Mo %	V %	N2 %	C %	Si %	Mn %	P %	S %	Ni %	Al %
P91 Steel Plate (6 mm Thickness)	8.81	0.97	0.24	0.046	0.093	0.32	0.44	0.018	0.007	0.15	0.015

Table 2: The Control Input Process Parameters

Sample No.	Welding Current (A)	Welding Time (cm/min)	Gas flow rate (l/min)
1	150	15	8
2	200	17.5	10
3	250	25	12

3. RESULTS AND DISCUSSION

To recognize the weld bead geometry, the welded specimens were cut by abrasive cutter then grinded, polished and etched to reveal the bead geometry on the cross section. Photographed taken from a digital camera. To recognize the digital camera pixel intensity and image capture distance of specimens, we pasted the (1 cm) scale on the specimen to measure accurate dimension. The responses, dimensions measurement of weld bead geometry (in terms of bead width, depth of penetration), weld area, and width of Heat Affected Zone (HAZ) have been measured with the help of Adobe Acrobat 9.0 Pro software. Measured data is shown in Table (3& 4) and Bar-graph shown in Fig. (3&4)

3.1 Pre-Heat and PWHT Welding's

In Table (3-4) show the measured dimensions of weld bead geometries and bar-graph is also shown in Fig. (3&4) to analysis the weld bead geometry of Pre-Heat and PWHT welded dimensions. Fig.3 shows Pre-Heat before welding, the specimen C2S2G2 as the heights dimensions at bead welds (BW), weld area (WA) and width of Heat Affected Zone (HAZ). When current increases penetration dimension is decreases toward C1S1G1 to C3S3G3.

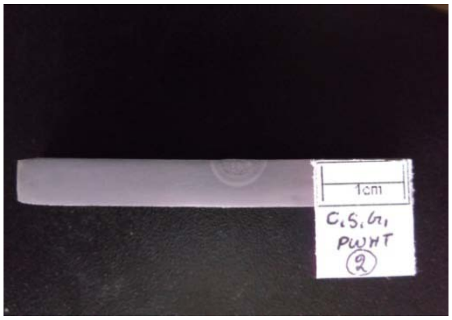
Fig.4 shows the PWHT after welding, in this welding we observed that when current increases WB and WA dimensions is increases toward C1S1G1 to C3S3G3 and the heights penetration dimensions is found at specimen C2S2G2. In both the weld processes, it can be clearly seen from the Fig. (3 and 4) width of the heat affected zones has approximately equal dimensions observed at both the specimens C1S1G1 and C2S2G2.

(C1S1G1)

(C2S2G2)

(C3S3G3)

Fig. 2: Etched cross-section of pre-heat welding showing bead geometry



(C1S1G1)

(C2S2G2)

(C3S3G3)

Fig. 3: Etched cross-section PWHT welding showing bead geometry

Table 3: Measured Data of Pre-Heat Welding

Sample Number	Measured Data Of Pre-Heat Welding			
	Width	Penetration	Area	Width HAZ
	(cm)	(cm)	(cm2)	(cm)
C1S1G1	0.634	0.261	0.1164	0.118
C2S2G2	0.769	0.247	0.133	0.119
C3S3G3	0.661	0.183	0.090	0.109

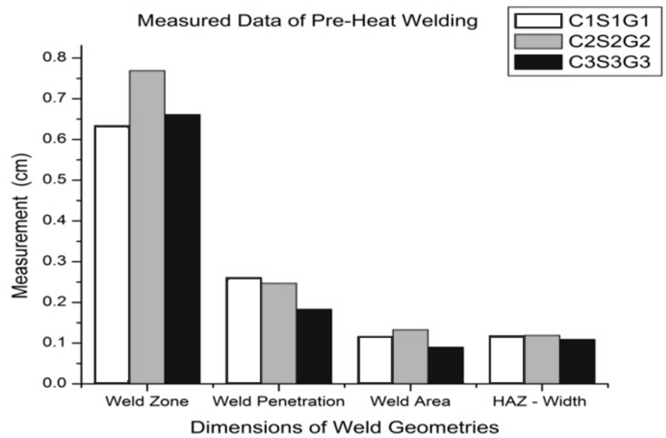


Fig. 3: Show the measured data of Pre-Heat Welding

Table 4: Measured Data of PWHT Welding

Sample Number	Measured Data of PWHT Welding			
	Width	Penetration	Area	Width HAZ
	(cm)	(cm)	(cm2)	(cm)
C1S1G1	0.469	0.220	0.076	0.097
C2S2G2	0.513	0.286	0.113	0.095
C3S3G3	0.715	0.237	0.119	0.042

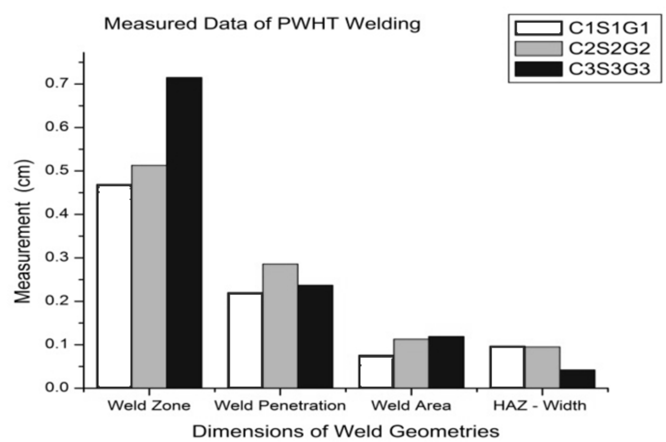


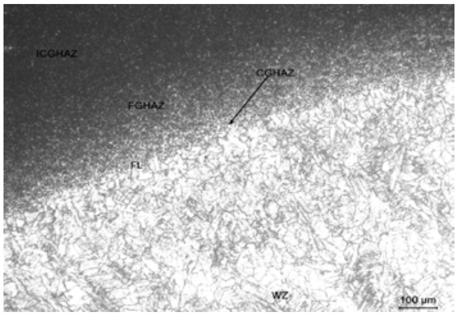
Fig. 4: Show the measured data of PWHT Welding

3.2 Microstructures after TIG Welding

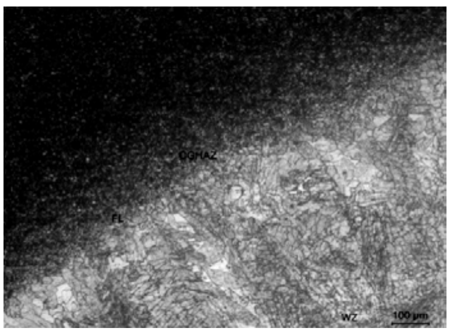
The microstructures of weld bead geometry and Heat Affected Zone (HAZ) have been analysis by optical microscope (Lieca Qwin software). The microstructures of Pre-Heat and PWHT welding are shown in the Figures. (5-6).

Fig.(5) shows the microstructure of Pre-Heat welding(200^{O}C) in which all the welds show ferrite as well as fresh-martensite like structures observed in weld zone. The microstructure of coarse grain zone, grain size is larger than the fine grain zone. Fig. (6) Shows the overall microstructure of P91 steel in which all the welds show at weld zone we observed delta-ferrite like structure after PWHT (760^{O}C for 2hrs.). HAZ- including coarse grain zone and fine grain zone. The microstructure of coarse grain zone shows martensite like structure [10-12].

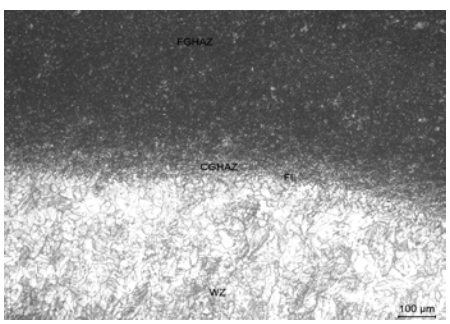
The specific microstructure depends on the related thermal profile generated by a particular welding condition [13].



(a)



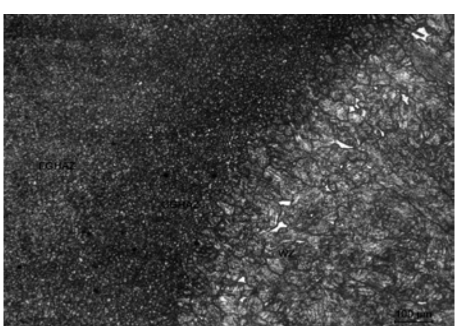
(b)



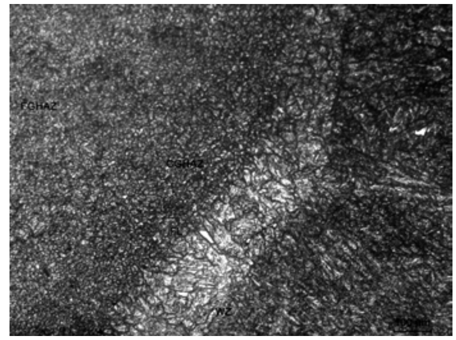
(c)

Fig. 5: The microstructures of Pre-Heat weld:

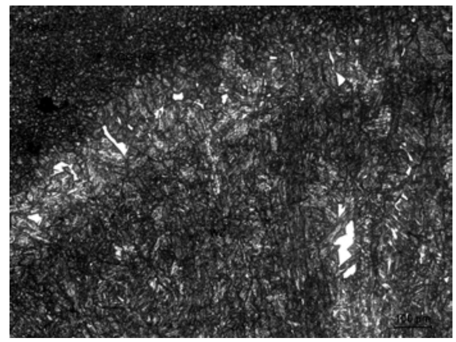
(a) C1S1G1, (b) C2S2G2 and (c) C3S3G3



(a)



(b)



(c)

Fig. 4: The microstructures of PWHT weld:

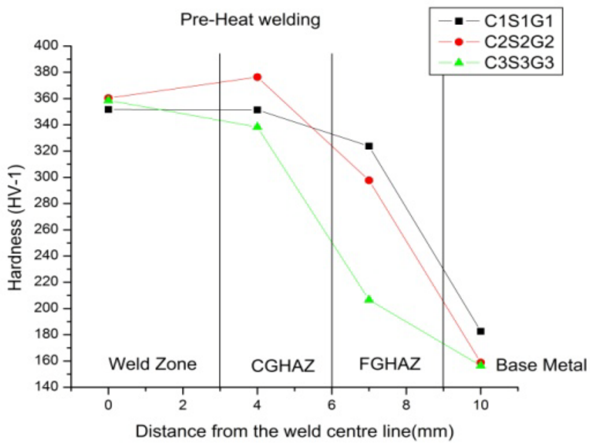
(a) C1S1G1, (b) C2S2G2 and (c) C3S3G3

After performing the basic operation of welding image measurement and microstructure the specimen is further used for micro-hardness to analysis the mechanical properties of welding parameter and process used.

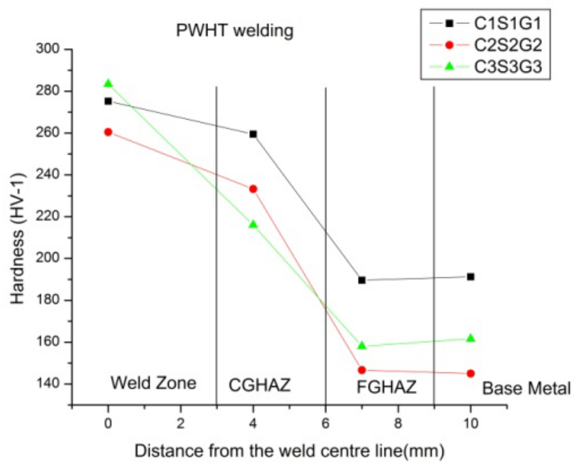
3.3 Hardening Behaviour

Hardness is the property of a material to resist the plastic deformation. For hardness measurement - specimen P91 steel plate material was cut into size of 50mm x 5mm x 6mm by abrasive cutter with blade then grinded, polished and etched, using 5% Nital, to reveal the bead geometry on the cross section. Hardness testing was carried out in a straight line 2 mm below and parallel to surface of the base plate with a constant load of 1 Kg and dwell time 10 sec. Reading were taken 0.5 steps through the WZ, HAZ and the part of the base material. Hardness testing was carried out according to ASTM designation: E384 – 11, Standard Test Method for Knoop and Vickers Hardness of Materials [14].

Fig. 7(a) shows hardness profiles across the entire Pre-heat (200^{O}C) welded specimens. Hardness is taken from weld centre line distances(mm). In pre-heat welding we observed that hardness suddenly increases from weld zone toward CGHAZ where all specimens have higher hardness value and then decreases toward base metal. Fig. 7(b) shows hardness profiles across the PWHT (760^{O}C for 2hrs.) weld. Hardness is higher at weld zone (WZ) region in all specimens and hardness decrease toward the FGHAZ and then slightly increases toward base metal[15-17].



(a)



(b)

Fig. 7: (a) shows the Pre-Heat welding (200^{O}C) and (b) PWHT welding (760^{O}C for 2hrs.)

4. CONCLUSION

The effect of Pre-Heat (200^{O}C) and PWHT at 760^{O}C for 2 hours on microstructures, hardness and weld bead geometries with respect to process parameter of TIG weldment without using filler metal was studied. The effect of variation in welding parameters on hardness of the weld is pronouncedly visible when welding is done with Pre-Heat and PWHT. In both autogenous TIG welding processes mentioned above, hardness is higher in Pre-Heat welding than PWHT welding. It is found that PWHT could drastically reduce the hardness but side by side increases other properties of material. Grade P91 steel materials have higher hardenability and components are used at a higher steam temperature more than 600^{0}C and a steam pressure greater than 35 MPa that why heat treatment operations are necessary to avoid hydrogen retention cracking problems or we call Type IV cracking of weld [16]. The more effect of heat treatments of P91 steel is investigated in a future study.

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