Advanced Materials Research Vols. 1025-1026 (2014) pp 310-316
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doi:10.4028/www.scientific.net/AMR.1025-1026.310

Submitted: 26.06.2014
Revised: 08.07.2014
Accepted: 14.07.2014

Study of Weld Hardness of Pipes at Elevated Temperature Application in Power Plants

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Keywords: P91Pipes, TIG Welding, Hardness, DoE, Regression

Abstract. This study aims to identify the parameters that affect the quality of weld in achieving the required weld quality in terms of hardness and to establish the relationship between different factors that affect the weld quality. The focus is to study and explore the Welding input parameters for Gas Tungsten Arc Welding (GTAW) of elevated temperature piping used in Power Plants and to predict the Weld's Hardness on construction sites. The study is based on Design of Experiment (DoE) taking the important parameters into account and analyzing each of them. The data generated through experiments has been validated for the hardness based on input process parameters (welding current, welding voltage, travel speed, welding rod diameter) and the findings from the study revealed that the most important factor influencing the hardness of a Creep-Strength Enhanced Ferritic (CSEF) material welds is the Voltage while other factors have minimum or the least influence for the studied ranges and factors.

Introduction

In any welding process the input parameters have an influence on joint's mechanical properties. By varying the input process parameter's combinations, the output would be different welded joints with significant variation in their mechanical properties. Quality of a welded joint is generally evaluated by different parameters such as weld size, bead geometry, deposition rate, hardness, strength etc. [1] These characteristics are controlled by welding input parameters like welding current, voltage, welding speed, size and type of consumable, electrode stick out, shielding gas, etc.[2]

S.P.Gadewar (2010)[3] investigated the effect of process parameters of TIG welding like weld current, gas flow rate, work piece thickness on the bead geometry of SS304 and noted that the increase in weld current and gas flow results in change in Bead Geometry of the welded joint which dominates the weld characteristics. The variations in the process parameters affect the mechanical properties with great extent.

R.Sathish, et al. (2012) [4] optimized parameters for Dissimilar Pipe Joints Using GTAW while R Sudhakaran, V Vel-Murugan and P S Sivasakthivel (2012) [5] investigated effects of Process Parameters on Depth of Penetration in Gas Tungsten Arc Welded (GTAW) on 202 Grades Stainless Steel Plates. Chandresh. N. Patel, S. J. Chaudhary (2013) [6] optimized parameter for weld strength of metal inert gas welding and tungsten inert gas welding.

Ahmed Khalid Hussain, et al. (2010) [7] investigated the effect of welding speed on the tensile strength of the welded joint. Experiments are conducted on specimens of single v butt joint having different bevel angle and bevel heights. The material selected for preparing the test specimen is Aluminum AA6351 Alloy plate. The strength of the welded joint is tested by a universal tensile testing machine and the results are evaluated.

All these studies have been confined to controlled experiments while the common problem that has been faced on the construction sites is the control of the process input parameters to obtain a good welded joint with the required strength of weld having minimal detrimental residual stresses and distortion. Unfortunately, the review studies are not addressing the construction site practices.

The Creep-Strength Enhanced Ferritic (CSEF) materials used for noncorrosive high-temperature application with very high strength at elevated temperatures, such as for Steam Piping, Super-heater

Headers, Boiler Tubes, Boiler Drum, Pressure Vessel etc. in Power Plants, has not been explored much and the factors effecting the weld quality has not much been investigated. Such materials do require special attention and consideration as the cost of repair is normally considered as more than three times the original work cost.

From the analysis of about 12 projects of Power Plant construction around the world (8 Combined Cycle PP, 03 Coal and one Nuclear PP), it is noted that several CSEF materials are used among which alloy steel 9Cr-1Mo, Grades 91 has been used widely due to its improved and exceptional properties compared to other materials with same diameter and thickness. Nearly 2:1 reduction in thickness and an increase of 44 to 170% in allowable strength in the 510-570 ^{o}C temperature range is noted when compared to P (T) 22 material.

The objective of this study is to explore Welding input parameters with Design of Experiments, identify the input parameters/factors that affect the quality of weld on construction site and to achieve required hardness and to establish the relationship between different factors that affect the weld quality in terms of efficiency and economics. This study is focused on the TIG welded alloy steel pipes welds (Alloy Steel-A335 P91) on construction sites

Methodology

The steps involved in this investigation are as follows:

Step 1: Collection and compilation of data from the field
Step 2: Analysis of compiled data
Step 3: Application of DOE approach & ANOVA on the data

Experimental Procedure and Selection of Process Parameters

The main criterion adopted for material selection is based on the composition of the material. The material composition for 9Cr-1Mo, Grades 91 (SA/A 335 Grade P91) pipes having the chemical composition as per Table 1. Among these elements Cr, Mo and Mn are the most important and influencing the weld properties. These elements are based on the material test certificate produced by the mill and are cross checked by the Positive Material Identification (PMI) on site.

Table 1 Chemical Composition of Base (SA/A 335 Grade P91) and Filler material

Element	C	Mn	P, S, max	Si	Cr	Mo	V	N	Ni	Al	Nb	Ti
% by weight	0.08-0.12	0.30-0.60	0.020-0.010	0.20-0.50	8.00-9.50	0.85-1.05	0.18-0.25	0.03-0.07	0.40 max	0.02 max	0.06-0.10	0.01 max

Selection of Process Parameters

Deep studies of all the affective and available factors on the site as well as per the industrial practice are made, and then some important ones are selected for detailed investigation. Properly qualified welders as per applicable welding procedure specification (WPS) were used to carry out the welding works.

A record of about 62000 pressure piping joints on one Power plant site revealed that the majority of joints are butt and follow the same joint configuration and geometry during fit-up prior to welding. Keeping the same fact in view, and due to its importance on the construction site, the type of joint selected for this study is a Single Vee Butt as per Fig. 1

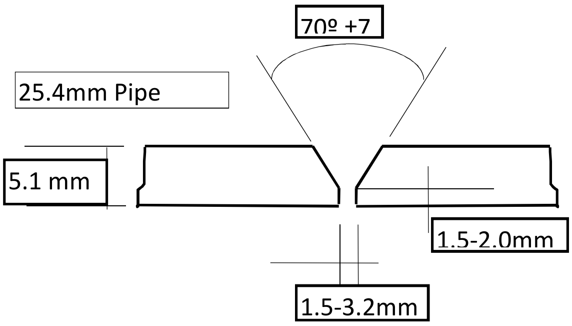

Fig. 1 Actual Joint Design for the welding of P91 Pipe

As per the geometry of joint, further corresponding configuration and position are set is as per below Table 2. [1]

Table 2 Joint Design & Position

Joint Design	Single Vee Butt
Backing	No
Backing Material	N/A
Root Face	1.5-2.0mm
Root Gap	1.5-2.0mm
Thickness	1.6 mm-10.02 mm
Pipe Diameter	25.4mm & above
Position Of Groove	6G (All)
Welding Progression	Uphill
Position(s) of Fillet	All

The Filler Metal and the shielding gas play vital role in the welding joint and it must conform to all the requirements of the latest edition of applicable Codes and Standards. [1, 13]
The Filler metal and the shielding gas selected for this study were as per Table 3 & Table 4

Table 3 Filler Metals (Welding Rod: ER 90S-B9 for GTAW)

F. No. / A. No	6 / 5
Specification No (SFA)	5.28
AWS No (Class)	ER 90S-G
Size Of Filler Metals	2.4mm & 3.2mm

Table 4 Gas for GTAW (Shielding & Purging / Backing Gas)

Shield Gas(es)	Argon
Percent Composition	99.9 % Argon
Flow Rate	8 - 12 Liter/Min
Gas Backing	None
Trailing Shielding Gas	N.A.

In order to allow enough hydrogen to diffuse out of the joint and to avoid cold cracking, preheating of this P91 material is a must. As per the standard industrial practice and recommendation of ASME, the weld joints were preheated as per Table 5

Table 5 Preheat requirements for P91 material

Preheat Temperature (Min)	200 - 250°C
Inter pass Temperature (Max)	350°C
Preheat Maintenance	>225°C

Since the change in technique, changes the weld properties a lot, for this study, the Technique used for GTAW welding was as per Table 6.

Table 6 Technique – GTAW for welding of P91 Pipe

String Or Weave Bead	String
Orifice Or Gas Cup Size	10 -12mm Dia
Initial And Inter pass Clean	Wire Brushing & Grinding
Method Of Back Gouging	N.A.
Oscillation	10 mm
Contact Tube To Work Distance	6-10 mm
Multiple Or Single Pass (Per Side)	Single
Multiple Or Single Electrodes	Single
Travel Speed (Range)	3-5 cm/Min
Tungsten Electrode Seize & Type	2.4 mm Dia. & 2% Thoriated Tungsten

The electrical characteristics are considered as the main and influencing factors for weld properties. During the welding works, the electrical characteristics were maintained as per Table 7.

Table 7 Electrical Characteristics

Current - Amps (Range)	100-125
Voltage - Volts (Range)	10-13 & 13-15
Polarity	DC Straight

As P91 material is considered as Creep-Strength Enhanced Ferritic (CSEF) alloy whose creep strength is enhanced by the creation of precise conditions of microstructure. To have the required microstructure of the weld metal for adequate strength and ductility, the PWHT condition are critical and are required to be maintained. Here the post weld heat treatment was carried out as per Table 8

Table 8 Post Weld Heat Treatment

Temperature Range	700°C -765°C
Time Range	1hr/In 15 (Minutes)
Heating Rate	100-150°C/hr.
Cooling Rate	150-200°C/hr., below 400°C still air cooling

Results and Discussions

The base material selected meets the requirement of SA/A 335 Grade P91 with Cr, Mo and Mn in the specified limits. All the other factors were controlled and maintained per requirements. The study has identified the 4-factors having 2-levels with 8 experiment runs. The most important parameters having greater influence on the weld hardness (HB) are considered as welding current(I), welding voltage(V), travel speed(S), welding rod diameter(D). Several trials were conducted by varying one of the process parameters and keeping the others constant, and the results were recorded in Table 9 & Table 10.

Table 9 Factors and Levels of Process Parameters

FACTORS	NAME	LEVEL 1	LEVEL 2
A	Current	100 Amp	125 Amp
B	Voltage	10 V	13 V
C	Travel Speed	30 mm/min	50 mm/min
D	Dia. of Filler Metal	2.4 mm	3.2 mm

Table 10 L8 Orthogonal Array for GTAW for P91Pipe welding Experiments

DESIGN ORDER	**EXP RUN ORDER**	Current (I) A	Voltage (V) B	Travel Speed (S) C	Dia. of Filler Metal (D) D	Hardness Value **HB**
1	1	100 Amp	10 V	30 mm/min	2.4 mm	**228**
2	2	125 Amp	10 V	30 mm/min	3.2 mm	**233**
3	3	100 Amp	13 V	30 mm/min	3.2 mm	**235**
4	4	125 Amp	13 V	30 mm/min	2.4 mm	**237**
5	5	100 Amp	10 V	50 mm/min	3.2 mm	**227**
6	6	125 Amp	10 V	50 mm/min	2.4 mm	**231**
7	7	100 Amp	13 V	50 mm/min	2.4 mm	**233**
8	8	125 Amp	13 V	50 mm/min	3.2 mm	**236**

Graphs of the each factor and interaction sets are plotted. These plots are only valid if a factor is significant in the Final ANOVA analysis. If significant, we choose the best level average and the corresponding setting for this factor. Non-Significant factors will be set at the lowest cost setting. The impacts and the relationships of all the selected parameters were studied,

Linear Regression by Least Square Criterion for individual factors are obtained as per below equations 1, 2, 3 & 4.

- Hardness(HB) Vs. Current(I) » $HB = 0.132I + 217.700$ (1)
- Hardness(HB) Vs. Voltage(V) » $HB = 1.833V + 211.47$ (2)
- Hardness(HB) Vs. Travel Speed(S) » $HB = -0.095S + 236.35$ (3)
- Hardness(HB) Vs. Rod Dia(D) » $HB = 0.375D + 231.50$ (4)

The statistical analysis of variance (ANOVA) carried out on these factors revealed the contribution of each factor influencing the hardness of weld joint. The tests were conducted to see the individual impacts

Current and Voltage relationship was studied, graphs were prepared for individual factor as shown below in Fig. 2 & 3. The current is not so significantly affecting the hardness of the welded joint.

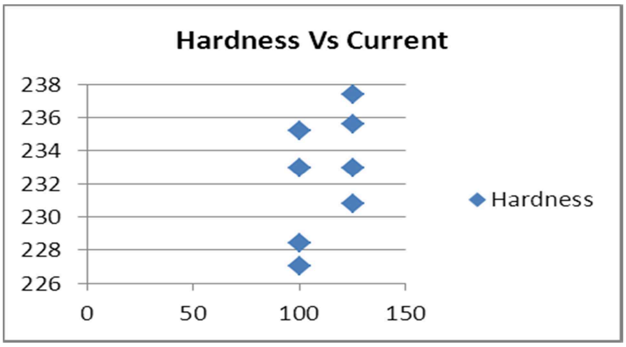

Fig. 2 Main effect plot for Hardness Vs. Current with R Square = 0.238

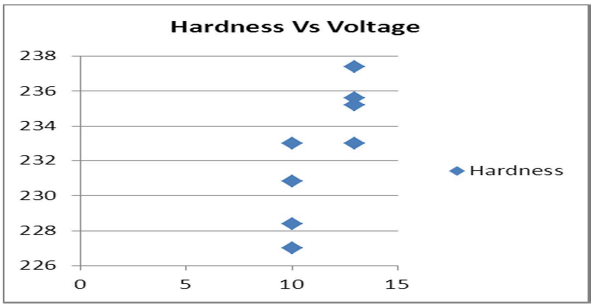

Fig. 3 Main effect plot for Hardness Vs. Voltage with R Square = 0.662

The Voltage is significantly affecting the hardness of the welded joint and varying the Voltage will impact the weld hardness notably.
Further ANOVA study shows that Travel Speed and Welding Rod Diameter are not so significantly affecting the hardness of the welded joints, refer to Fig. 4 & 5.

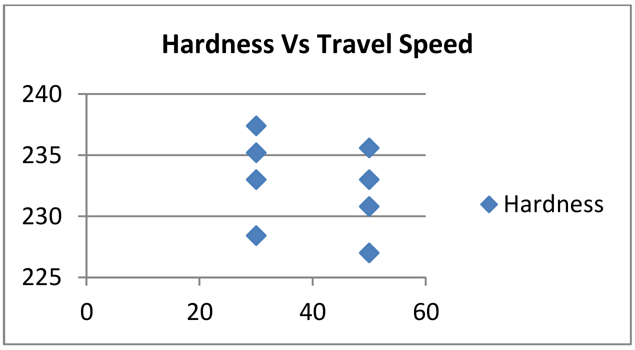

Fig. 4 Main effect plot for Hardness Vs. Travel Speed with R Square = 0.079

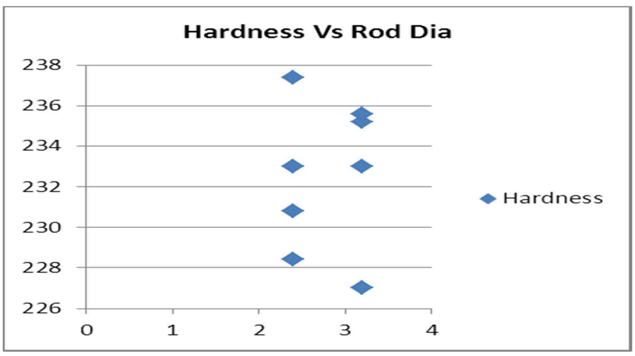

Fig. 5 Main effect plot for Hardness Vs. Rod Dia with R Square = 0.002

Conclusion

From the studies, it is found out that the Voltage has significant influence on the weld hardness of Alloy Steel-A335 P91 Pipes. The other studied parameters namely Current, Travel Speed and Welding Rod Diameter have least significant influence. However these findings are covering only the selected Voltage ranging from 10 to 15Volts, Current from 100 to 125Amp, the Travel Speed 3 to 5cm/Min, for 2.4 & 3.2 mm Diameter Welding Rods.
For future studies, the voltage, current, travel speed, welding rod diameter and other factors should be varied and investigated in detail to cover wider span.

Acknowledgement

The authors would like to acknowledge the support of Universiti Teknologi PETRONAS for this study.

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