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Research Article

SELECTION OF PROCESS PARAMETERS FOR WELDING P91 STEEL PIPES USING THE ANALYTIC HIERARCHY PROCESS

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Abstract: Many new materials have been developed to render efficient service in power utilities under increased duty conditions. In this work, optimal parameters for welding P91 steel pipes are tried to find out. Welding tests are performed utilizing varying processes and process steps. First, gas tungsten arc welding (GTAW) process is used to make root welding and to fill the weld zone. Next, shielded metal arc welding (SMAW) is done. In each of these processes, process parameters are optimised using the Anal\ytic Hierarchy Process (AHP). It is observed that at the welding voltage of 15 Volt, welding current of 110 Amp and 40.5 mm/min weld speed, GTAW gives sound weld, while at a welding voltage of 24 Volt, 85 Amp welding current and 35 mm/min weld speed, flawless welding is obtained with SMAW process for P91 steel pipes.

Key words: *Welding, pipe welding, P91 steel, GTAW, SMAW, AHP, Analytic Hierarchy Process*

1. Introduction

Materials used for boilers and pressure vessels are subject to high temperature and pressure. Hence, properties expected of a material to be used for this service are high temperature strength, and resistance to corrosion/ oxidation by flue gases on its outer surface, and by water/ steam on its inside surface [1]. In 1977, development of 9% Cr steel with improved strength and toughness was reported. In 1983, ASTM approved modified 9Cr 1Mo under designation A213 T91. Since this time, T91 becomes commercially applicable for pressure tube service. In 1984, ASTM approved modified 9Cr 1Mo was included in ASME code for use in piping and headers in standard A 335 as P91 steel [2]. These steels are being used in power plants since last two decades as an alternative to stainless steels.

The need for incorporating higher operating pressure and temperature to improve thermal efficiency of the system demands employment of superior materials such as chromium-molybdenum steels. Fabrication of these steels are usually done using SMAW [3], short circuit GMAW (GMAW-S) and GTAW [4] processes. The GTAW is employed in the fabrication process of chromium-molybdenum steels depending on the size and shape of different jobs, parameters can be changed in this process as required. However, if parameters are not selected properly, sound weld may not be obtained [4]. Newell [5] discussed briefly the processes to use for sound welding of P91 steels and also recommended the necessary post weld heat treatment method.

The Analytic Hierarchy Process (AHP) was introduced by Saaty [6], and this simple tool was widely applied in the decision making and optimising process for different applications [7-13]. The AHP was also applied to optimise welding processes successfully [14,15].

In this work, experiments with different parameters of gas tungsten arc welding (GTAW) process are performed first. To find out appropriate combination of process parameters, the Analytic Hierarchy Process (AHP) is employed based on experimental results. Next, the applicability of shielded metal arc welding (SMAW) process is explored in welding P91 steel pipes, and process parameters of SMAW are also optimised using the AHP within the experimental domain.

2. Experimental Details

There are number of parameters that can affect the GTAW process. Out of them, only welding current is varied in the present investigation for welding P91 steel pipes. Four levels of welding current are selected for the GTAW process; they are 110, 120, 130 and 140 Amp, keeping weld voltage constant at 15 Volt and welding speed remaining at 40.5 mm/min. In these tests, filler used is having AWS specification No. ER90S and is of 1.6 mm filler diameter (ESAB make). The GTAW is done under 100% argon gas shield under DCEP.

For SMAW process, welding current chosen are 78, 80, 82 and 85 Amp. Welding Voltage of 24 Volt is set for SMAW process with the welding speed maintained at 35 mm/min. The consumable electrode

(ESAB make) used is of 2.5 mm diameter having the AWS specification of E9018-B9 with DCEP. The welding rectifier used is Quality make (model: QTW-400) 22 kVA machine.

In this work, pipe welding is done on ¾ inch P91 steel pipes at a root gap of 1.5 mm with welding torch angle of 75^0 with the horizontal plane. No preheating or post-heating is done. V type edge is prepared for the weld. Before initial welding and between successive passes, the work parts are cleaned through brushing, chipping and/or grinding. After welding is complete, excess spill over weld metals are removed through grinding. To check soundness of the weld, visual inspection, dye penetration (DP) test, and observation of penetration are carried out. The weld portion including HAZ is cut off using an abrasive cutting off machine, and then sequentially belt ground/polished, disc ground and polished with alumina paste (buffing). Subsequently, the sample is etched using 2% nital solution. Under the Metzer-make inverted metallurgical microscope, depth of penetration of the sample is observed.

3. Results Obtained through Visual Inspection and DP Test

Experimental observation obtained from gas tungsten arc welding (GTAW) of P91 steel pipes show that corresponding to the welding current of 110 Amp, welding voltage of 15 Volt and weld speed of 40.5 mm/min, uniform, thick weld metal deposition with very less spatter, less under cut, no blow hole and good penetration is observed indicating good weld quality (sample S_1). Other conditions show medium to good weld penetration. The observation from the first weld sample (S_1) indicates the welding to be sound, and comparable with the usual practice of making the root weld with GTAW and subsequent passes using SMAW. Visual inspection of weld samples made using SMAW process shows that for sample S_8, corresponding to welding current of 85 Amp, weld voltage of 24 Volt and weld speed of 35 mm/min, spatter and under cut is very less, no blow hole is there, and penetration is good. At this condition, uniform, thick metal deposition is also observed. For other samples, discontinuous metal deposition is found.

Results observed through dye penetration test show that samples S_1 and S_4 have no weld defects during GTAW. On the other hand, weld samples S_5 through S_7, made out of SMAW process, are so defective that no DP test could be performed. SMAW sample No. S_8 shows almost no weld defects, thus can be considered an acceptable weld. This process condition may also be applied successfully as it shows comparable results using root weld by GTAW and gap filling by SMAW process.

4. Optimisation of P91 Steel Welding Using the Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a very simple and widely used decision- making tool, and can solve complex discrete type multi-criteria decision-making problem hierarchically [6]. There are wide ranges of applications where the AHP was employed [7-13]. First, the objective or goal, different criteria and available alternatives are structured hierarchically as shown in Fig. 1 [6]. Different priority weights are then assigned to various criteria and alternatives locally. Finally the global weight for each alternative is calculated and the decision is made. In the present work, using the information got from the experiment, the optimal parametric condition for welding P91 steel pipes using GTAW and SMAW processes are found out by using the AHP.

In the AHP, pair wise comparison matrices are constructed by comparing an element with the elements of the next higher level. This is to find out local priority weights [6][9]. A typical pair wise comparison matrix (A) is shown in Equation (1) [6]. Here, a_{ij} (for i,j = 1, 2,

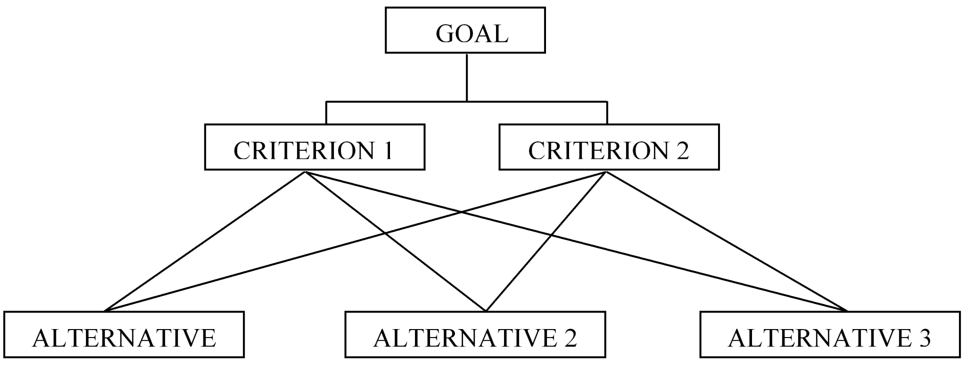

Fig.1: Typical hierarchy structure of the AHP

3,…. n) are the strengths of preferences of the alternative E_i over E_j corresponding to the criterion (C), $a_{ji}=1/a_{ij}$ and $a_{ii}=1$ for all values of i and j. The numerical values of a_{ij} are taken from the ratio scale (Table 1) to construct pairwise comparison matrices for criteria and alternatives. When all the elements of the matrix are selected, consistency of the entries of the matrix is checked.

$$A = \begin{array}{c|cccc} C & A_1 & A_2 & \dots & A_n \\ \hline A_1 & a_{11} & a_{12} & \dots & a_{1n} \\ A_2 & a_{21} & a_{22} & \dots & a_{2n} \\ A_{3..} & a_{31} & a_{32} & \dots & a_{3n} \\ . & . & . & . & . \\ A_n & a_{n1} & a_{n2} & \dots & a_{nn} \end{array} \quad \dots\dots\dots\dots \textbf{(1)}$$

Table 1: Ratio scale of comparison matrix

Preferential Judgment	Rating
Extremely preferred	9
Very strongly to extremely preferred	8
Very strongly preferred	7
Strongly to Very strongly preferred	6
Strongly preferred	5
Moderately to strongly preferred	4
Moderately preferred	3
Equally to moderately preferred	2
Equally preferred	1

For an inconsistent matrix, the degree of inconsistency is measured by the consistency index (CI) = $(\lambda_m – n)/(n – 1)$, when λ_m is the largest eigen value of the matrix A, and n is the number of row/ column elements in the matrix. A random index (RI) is also calculated which is the consistency index of a matrix with the elements randomly selected from (1/9, 1/8, 1/7, …1,…,7, 8, 9) scale. The ratio (CI/RI) is known as consistency ratio (CR). A consistency ratio of 10% or less is generally accepted [6]. For details of the AHP, references [6,9,15] may be referred.

The maximum value of the global weight is generally considered the optimum value and the corresponding alternative is selected for the optimum decision.

5. The AHP to Optimize the GTAW and SMAW Conditions

In this study, the best condition for GTAW of P91 steel pipes is found out first. Four alternatives are considered as shown in Table 2 based on four criteria such as blow hole (C_1), penetration (C_2), undercut (C_3) and uniformity (C_4). The pair wise comparison matrix for criteria for this case is given in Table 3.

Table 2: Alternative conditions for GTAW

Alterna-tive No.	Speed (mm/min)	Voltage (Volts)	Current (Amp)
E_1	40.5	15	110
E_2	40.5	15	120
E_3	40.5	15	130
E_4	40.5	15	140

The pair wise comparison matrices for alternatives for this problem are given in Table 4 through Table 7. These tables show the preferences for selection of a condition compared with different criteria, such as blow hole, penetration, under cut, uniformity of Weld.

Table 3: Pair-wise comparison matrix for criteria for GTAW and SMAW

S	C_1	C_2	C_3	C_4
C_1	1	¼	2	¼
C_2	4	1	3	1
C_3	1/2	1/3	1	¼
C_4	4	1	4	1

λ_m= 4.097; CR = 0.008

Table 4: Pair-wise comparison matrix for alternatives for criterion 1 (Blow hole) in GTAW

C_1	E_1	E_2	E_3	E_4
E_1	1	1	1	1
E_2	1	1	1	1
E_3	1	1	1	1
E_4	1	1	1	1

λ_m= 4.000; CR = 0.000

Table 5: Pair-wise comparison matrix for alternatives for criterion 2 (Penetration) in GTAW

C_2	E_1	E_2	E_3	E_4
E_1	1	2	3	3
E_2	1/2	1	2	2
E_3	1/3	½	1	1
E_4	1/3	½	1	1

λ_m= 4.010; CR= 0.001

Table 6: Pair-wise comparison matrix for alternatives for criterion 3 (Under cut) in GTAW

C_3	E_1	E_2	E_3	E_4
E_1	1	1	2	2
E_2	1	1	2	2
E_3	1/2	½	1	1
E_4	1/2	½	1	1

λ_m= 4.000; CR= 0.000

Table 7: Pair-wise comparison matrix for alternatives for criterion 4 (Uniformity) in GTAW

C_4	E_1	E_2	E_3	E_4
E_1	1	2	3	3
E_2	½	1	2	2
E_3	1/3	½	1	1
E_4	1/3	½	1	1

λ_m= 4.010; CR= 0.008

Table 8: Global weights for alternatives of GTAW

Alternatives	Global weights
E_1	0.419
E_2	0.268
E_3	0.157
E_4	0.157

It is found from the above Table 8 that the weight of E_1 is the maximum. So, it can be concluded that the condition (40.5 mm/min speed, 15 Volt voltage and 110 Amp current) is the best condition for GTAW of P91 Steel pipe.

In this experiment based work, the best condition for SMAW of a particular material is also found out. Four alternatives considered are shown in Table 9 on the basis of four criteria as detailed in the case of GTAW. The pair wise comparison matrix for criteria is given in Table 3. This table shows the preferences for selection of a condition (S) compared with different criteria. The pair wise comparison matrix for alternatives with respect to each criterion for this problem is given in Table 10-Table 13.

Table 9: Alternative conditions of SMAW

Alternative No.	Speed (mm/min)	Voltage (Volts)	Current (Amp)
E_1	35	24	78
E_2	35	24	80
E_3	35	24	82
E_4	35	24	85

Table 10: Pair-wise comparison matrix for alternatives for criterion 1 (Blow hole) in SMAW

C_1	E_1	E_2	E_3	E_4
E_1	1	1	½	½
E_2	1	1	½	½
E_3	2	2	1	1
E_4	2	2	1	1

λ_m = 4.000; CR = 0.000

Table 11: Pair-wise comparison matrix for alternatives for criterion 2 (Penetration) in SMAW

C_2	E_1	E_2	E_3	E_4
E_1	1	1	1/2	1/3
E_2	1	1	1/2	1/3
E_3	2	2	1	½
E_4	3	3	2	1

λ_m= 4.010; CR= 0.001

Table 12: Pair-wise comparison matrix for alternatives for criterion 3 (Under cut) in SMAW

C_3	E_1	E_2	E_3	E_4
E_1	1	1	1/2	1/3
E_2	1	1	1/2	1/3
E_3	2	2	1	½
E_4	3	3	2	1

λ_m= 4.010; CR= 0.001

Table 13: Pair-wise comparison matrix for alternatives for criterion 4 (Uniformity of weld) in SMAW

C_4	E_1	E_2	E_3	E_4
E_1	1	1	1/2	1/3
E_2	1	1	1/2	1/3
E_3	2	2	1	½
E_4	3	3	2	1

λ_m= 4.010; CR= 0.001

Table 14: Global weights for alternatives of SMAW

Alternatives	Global weights
E_1	0.144
E_2	0.144
E_3	0.271
E_4	0.440

Global weights are found next using the AHP procedure and listed in Table 14. It is found from the table that the weight of E_4 is the maximum. So, the condition with 35 mm/min welding speed, 24 Volt welding voltage and 85 Amp welding current is the best choice for SMAW of P91 steel pipe within this experimental domain.

These results are in conformity with the observation made by visual inspection and through dye penetration test. Therefore, it can be stated that the optimum condition for GTAW and SMAW for a particular material can be obtained successfully using the AHP. Optimum parameters selected for GTAW and SMAW processes show comparable results as that of usual practice with root welding by GTAW and gap filling by SMAW.

6. Conclusions

The experimental investigation on P91 pipe welding conducted in this study reveals the following observations;

- Flawless welding can be obtained for P91 steel pipes by GTAW process at welding voltage of 15 Volt, current of 110 Amp and 40.5 mm/min weld speed.
- At 24 Volt voltage, 85 Amp current and 35 mm/min speed, good weld can also be obtained for P91 steel pipe by SMAW process.
- Hence, these parameter combinations can be used easily in practice as these welds show comparable results with the conventional practice of root welding using GTAW and gap filling with SMAW.

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