SELECTION OF APPROPRIATE PROCESS PARAMETERS FOR GAS METAL ARC WELDING OF MEDIUM CARBON STEEL SPECIMENS

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ABSTRACT

Gas Metal Arc Welding (GMAW) is a semi-automated process used widely for accurate welding in the fabrication industry. The selection of appropriate process parameters of GMAW is essential to obtain the desired weld quality. In the past, much work has been done investigating a variety of workpiece and electrode material combinations. In the present work, an Analytical Hierarchy Process (AHP) based parametric optimization is tried in gas metal arc welding of C45 medium carbon steel specimens using carbon dioxide as the gas shield. The experiments were performed by varying three process parameters, weld speed, weld voltage and weld current. The AHP facilitates the selection of suitable process parameters to obtain a sound weld. In the present experimental domain, optimal conditions are evaluated to be at a weld voltage of 30 V, weld current of 160 A with a weld speed of 475.75 mm/min.

Keywords: AHP, welding, GMAW, MAG, parametric optimization

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1. Introduction

The Analytic Hierarchy Process (AHP) is a simple, widely used decision making tool that can effectively solve a variety of complex multi-criteria problems hierarchically (Saaty, 1977; Saaty, 1980; Vargas et al., 1990). The AHP was and is being employed to solve several managerial, manufacturing and production related decision making problems. This has also been utilized for the optimum selection of process parameters in different welding processes. In a recent work, Saaty (2009) discussed a method of taking a judgment in decision-making process in contrast to that used in usual science experiments.

Gas metal arc welding (GMAW) utilizes an arc maintained between the workpiece and an automatically fed wire electrode. Argon, helium or a mixture of the two is usually used for welding different metals, and primarily nonferrous metals. When welding steel, some oxygen or carbon dioxide is usually added to improve the arc stability and reduce weld spatter. Less costly CO_2 can be used alone when welding steel, provided that a deoxidizing electrode wire is employed in this process of GMAW known as MAG (Metal Active Gas) welding (Khanna, 1995; Nadkarni, 1996). The GMAW process can be easily mechanized to guarantee high productivity while maintaining good quality. However, to achieve good results, process variables of GMAW need be selected appropriately.

Nadkarni (1996) reported the relationship of mechanical properties of a welded joint with the degree of compositions of base material, and the effect of main process parameters of welding on the quality of the weld. Detailed investigation of the effect of the chemistry of base material on the softening of HAZ was made by Mohandas et al. (1999). Hardness and microstructure were compared with the variation of the chemistry of the parent metal and the welding process to gain an understanding of the influence of the alloy chemistry, and the effect of different welding processes on the same low alloy steel. In another work, Zumelzu et al. (1999) observed the effect of post-weld heat-treatment and external cooling on the GMAW product. They investigated the quality of the joining of 316L stainless steel specimens under varying conditions through the analysis of microstructure observation. Kim and Basu (1998) employed mathematical models of the GMAW process to select welding process parameters for obtaining the required weld-bead geometry. All these works reported some success in the respective electrode-workpiece material combinations under variations of the welding processes.

In other works, Modensi et al. (1999) evaluated the influence of small differences in wire characteristics on operational conditions of CO_2 gas shielded GMAW. Data were evaluated using factorial analysis and graphical techniques to assess the effect of different wire characteristics on the weldment. The results showed that differences in wire diameter produced varying quality of a welded joint. An abductive polynomial network model of the GMAW process was established by Simpson and Hughes (2006). This network model enabled establishing the relationship between GMAW process parameters such as wire diameter, gas flow rate, welding speed, arc current and welding voltage on the weld bead penetration. The estimated value of weld bead penetration derived from network training was compared with the measured value. Jones et al. (1992) observed a relationship between power input to the arc in GMAW, metal transfer process and base plate heating. Optimized parameters evolved within the respective experimental domain in other investigations by Sabiruddin and Das (2005) and Jaubari et al. (2007) involving MAG welding of different steels under varying conditions. Jaubari et al. (2007) recommended a gas mixture of argon, CO_2 and oxygen for the GMAW process to obtain substantial cost savings with a good control of spatter.

In order to discover appropriate process parameters for desired weld quality, a number of works were also done employing the Analytical Hierarchy Process (AHP) for optimal selection of process variables. Ravisankar et al. (2006) and Sabiruddin et al. (2009) tried to obtain quality butt joints of aluminium alloys and steels respectively through the selection of a suitable welding process and corresponding process parameters applying the AHP. The selection of appropriate process parameters was also successfully carried out by Lai et al. (2009) by applying the AHP for resistance spot welding, and choosing typical edge preparation for obtaining sound welding was tried by Liu et al. (2011) using the AHP that could have long fatigue life. In all these works involving the AHP, appropriate process conditions could be achieved to apply in practice.

Because the optimal process parameters are vital to the quality of the weldment, in this work, a number of experiments have been conducted to determine these parameters. Using the AHP, different parameters of CO_2 gas shielded GMAW process were varied in order to find out an appropriate combination of process parameters.

2. Details of experiments

In this experimental work, gas metal arc welding of medium carbon steel flats is carried out on an ESAB India Ltd. made GMAW set up with an AUTOK 400 model. An indigenously developed system is used to move the welding torch along a straight path along the gap between the two steel flats to weld with a set speed to have weld deposition under a carbon dioxide gas shield. Although there are many factors that influence a weld, we have chosen three main factors that determine heat input to the weld to investigate in this work. These factors are welding current, welding voltage and welding speed. Heat input (Q) is quite important in welding, and during the GMAW process, heat input is calculated by:

$$Q = 0.8\ V\ I\ /\ S$$

when V is weld voltage, I is weld current, and S is weld speed.

Based on the trial tests, a welding current of 140 A, 150 A and 160 A, a welding voltage of 25 V and 30 V, and a welding speed of 370.5 mm/min and 475.75 mm/min are chosen for the present experimental work on joining C45 medium carbon steel specimens as detailed in Table 1.

Twelve experiments are carried out, and the parameters corresponding to each experiment are shown in Table 1. Without any preheating, specimens (size: 120 mm x 50 mm x 5 mm) are joined by a double-butt joint (in which both sides of the joint are welded) with a root gap of 1.5 mm. The weldment is brought to room temperature by air cooling. The joint is made in a horizontal position with the torch angle of 75° with the horizontal, using a low carbon steel wire electrode of 1.2 mm diameter.

The weldments are visually inspected and tested through dye penetration. The presence of a visible crack, a blow hole, and the extent of spatter and uniformity of weld metal deposition is discovered through visual inspection. At some experimental conditions, bubbles of molten metal are scattered around the weld resulting in less penetration and reducing the aesthetic look of the weldment. Penetration of weld metal is the depth of penetration of the weld metal going into the gap between two specimens being joined, and is observed through polishing a cut section of the weldment along its cross section. A bend test is done on a universal testing machine (Fine Spavy Associates & Engineers Pvt. Ltd., Miraj, India, model- TUN 200: 97/333) that observes the bending strength of the weldment. In this test, the butt welded specimen is placed on two supports, and a downward load is placed onto it at its middle and around the weld region. The bend test is continued up to a bend angle of 45^0, or when any crack is formed in the weldment, and the corresponding bending load is noted. These observed results are utilized to design the AHP model that will be used to discover the appropriate process parameters.

Table 1
Experimental conditions (alternatives) for welding medium carbon steel flats

Sl. No. (Alternatives)	Weld speed (mm/min)	Weld voltage (V)	Weld current (A)	Heat input (kJ/mm)
A_1	370.5	25	140	0.45
A_2	370.5	25	150	0.49
A_3	370.5	25	160	0.52
A_4	370.5	30	140	0.54
A_5	370.5	30	150	0.58
A_6	370.5	30	160	0.62
A_7	475.75	25	140	0.35
A_8	475.75	25	150	0.38
A_9	475.75	25	160	0.40
A_{10}	475.75	30	140	0.42
A_{11}	475.75	30	150	0.45
A_{12}	475.75	30	160	0.48

3. Discussion of experimental results

The experimental results that were obtained are given in Table 2. Observation of weld quality, such as spatter, blow holes, penetration at the joint, uniformity of weld, and presence of surface cracks are shown in tabular form against each experiment. Bending load obtained through the bend test, is also included in Table 2.

At a low travel speed of 370.5 mm/min with an weld voltage of 25 V and weld current of 140 A (experiment 1), large spatter and blow holes are found with less penetration; transverse and longitudinal surface cracks are also observed indicating quite poor weld quality. The bending load for this case is moderate. When weld current is set at 150 A in experiment 2, less spatter and thin welds are noticed. Although good penetration is achieved, a few blow holes and apparent toe cracks are found. However, the weld joint appears to be good as it sustains a high bending load of 15.8 kN up to a bend angle of 45^o without fracturing. At a weld current of 160 A (experiment 3), spatter and blow holes are present less, and good penetration is observed. The presence of transverse and longitudinal cracks limits the bending load when the weld gets fractured.

When weld voltage is increased to 30 V in experiments 4-6, increase in weld current also causes an increase in heat input from 0.54 kJ/mm to 0.62 kJ/mm. This results in deep penetration of the weld metal inside the joint. However, this high heat input to the weld caused non-uniform contraction upon cooling leading to different types of cracks detected in the weld (see Table 2). This gives low bending load of the weld.

Table 2
Experimental observation of the weldment

Sl. No.	Weld Speed (mm/ min)	Weld Voltage (V)	Weld Current (A)	Spatter	Pene tration	Blow Hole	Uniformity of Weld Deposition	Observed crack	Bend ing Load (kN)
A1	370.5	25	140	Large	Less	Large	Poor weld deposition	Transverse, longitudinal under-bead crack	8.8
A2	370.5	25	150	Less	Good	Less	Thin weld deposition	Toe crack	15.8
A3	370.5	25	160	Less	Good	Less	Thin weld deposition	Transverse, longitudinal crack	9.2
A4	370.5	30	140	No	Very good	Very less	Good, continuous deposition	Longitudinal crack	7.8
A5	370.5	30	150	No	Very good	Very less	Good, continuous deposition	At HAZ	9
A6	370.5	30	160	No	Good	No	Good, continuous deposition	Transverse crack	10.2
A7	475.75	25	140	Some	Less	Medium	Disconti nuous deposition	Toe crack	7
A8	475.75	25	150	Little	Less	Medium	Not a smooth deposition	Transverse, longitudinal, under-bead crack	7.8
A9	475.75	25	160	No	Medium	No	Good deposition	Transverse, longitudinal, root crack	6.5
A10	475.75	30	140	No	Good	No	Good deposition	No crack	13
A11	475.75	30	150	No	Good	No	Good deposition	No crack	13.4
A12	475.75	30	160	No	Good	No	Good deposition	No crack	16

In experiments 7-9 with a welding speed of 475.75 mm/min, heat input is less (0.35 kJ/mm to 0.4 kJ/mm) leading to less penetration and a poor weld joint. This resulted in a considerably less bending load and indicated the presence of different types of cracks. On the other hand, at the weld speed of 475.75 mm/min, an acceptable quality of weld was observed corresponding to a weld voltage of 30 V at all the weld currents selected (experiments 10-12) having good bending strength. No crack, blow hole or spatter was detected in the weld portion or in the HAZ (see Table 2). In these cases of 475.75 mm/min weld speed and weld voltage of 30 V, increase in heat input from 0.42 to 0.48 kJ/mm resulted in an increased of bending load.

4. Optimal selection of process parameters

The Analytic Hierarchy Process (AHP) was introduced by Saaty (1977). The hierarchy structure used in this work is shown in Figure 1. The goal or objective of the decision-making process is placed at the top level of the hierarchy. The goal or objective of the AHP in this work is the selection of optimum process parameter combination. The criteria and decision alternatives come in the subsequent descending levels. Six criteria, as detailed in Table 3, are considered in order to determine the best alternative out of a total of 12 alternatives listed in Table 1. Each alternative corresponds to a typical parametric combination for welding test corresponding to a typical experimental run. In this way, at two levels of weld speed and two levels of weld voltage, weld current is varied at three levels, and hence, twelve (2x2x3 = 12) experimental runs are performed. From these runs, the set of process parameters giving the best quality weld will be selected.

The pair wise comparison matrices are formed by comparing an element with the elements of the next higher level. This determines the local priority weights. A typical pair wise comparison matrix (A) is shown in Equation (1). Here, a_{ij} (for i, j = 1,2,3,…….n) is the strength of preference of the alternative A_i over A_j corresponding to the criterion, C, $a_{ji} = 1 / a_{ij}$ and $a_{ii} = 1$ for all values of i and j.

$$A = \begin{array}{c|c} C & A_1 \;\; A_2 \;\ldots\; A_n \\ \hline A_1 & a_{11} \;\; a_{12} \ldots \; a_{1n} \\ A_2 & a_{21} \;\; a_{22} \ldots \; a_{2n} \\ A_3 & a_{31} \;\; a_{32} \ldots \; a_{3n} \\ . & . \quad . \quad\; . \\ . & . \quad . \quad\; . \\ A_n & a_{n1} \;\; a_{n2} \ldots \; a_{nn} \end{array} \qquad \text{(Equation 1)}$$

The numerical values of a_{ij} are taken from the ratio scale (Table 4). When all the elements of the matrix are selected, consistency of the entries of the matrix needs be checked. A comparison matrix is said to be consistent if,

$$a_{ij}\ a_{jk} = a_{ik} \text{ for all values of i, j and k} \qquad \text{(Equation 2)}$$

For a consistent matrix,

$$a_{ij} = w_i / w_j \text{ for all values of i and j} \qquad \text{(Equation 3)}$$

where, w is the priority weight.

Usually, matrix A is rarely consistent, that is, $a_{ij} \neq a_{ik}\, a_{kj}$ for some elements of the matrix. Then, a priority weight can be evaluated solving Equation 4;

$$Aw = \lambda_m w \qquad \text{(Equation 4)}$$

where, $w = (w_1, w_2, w_3, ..)^T$, $\lambda_m \geq n$, and λ_m is the largest eigen value of the matrix A.

On the other hand, for a consistent matrix, Equation 4 becomes;

$$Aw = nw \qquad \text{(Equation 5)}$$

For an inconsistent matrix, the degree of inconsistency is measured by consistency index (CI).

$$CI = (\lambda_m - n) / (n - 1) \qquad \text{(Equation 6)}$$

A random index (RI) is computed through evaluating the consistency index of a matrix with the elements randomly generated from the range of ratio scale (1/9, 1/8, 1/7, …1, …, 7, 8, 9). The consistency ratio (CR = CI/RI) is then calculated, and a consistency ratio of up to 10% is considered acceptable.

Table 3
Criteria selected for judging a sound weld

Criterion No.	Criterion
C_1	No spatter
C_2	Good penetration
C_3	No blow hole
C_4	Good weld deposition
C_5	No surface crack
C_6	Good bending load

Local weights, w_i of a comparison matrix for a criterion or an alternative are next determined by solving the Equation 7.

$$w_i = \sum_{j=1}^{n} (a_{ij}\, w_i)/\lambda_m,\ i=1,2,3,\ldots\ldots.,n \qquad \text{(Equation 7)}$$

if P_j (j =1, 2, 3, …, m) are the priority weights of n alternatives with respect to the jth criterion, and if q_{ij} are the priority weights of the criteria, then global weights (r_i) of alternatives are calculated as

$$r_i = \sum_{j=1}^{m} (P_j\, q_{ij}),\ i =1,2,3,\ \ldots\ldots\ldots,n \qquad \text{(Equation 8)}$$

The largest global weight thus obtained is the optimum one, and a corresponding alternative is recommended as the optimum solution after Saaty (1977), Saaty (1980), Vargas (1990) and Das et al. (2003).

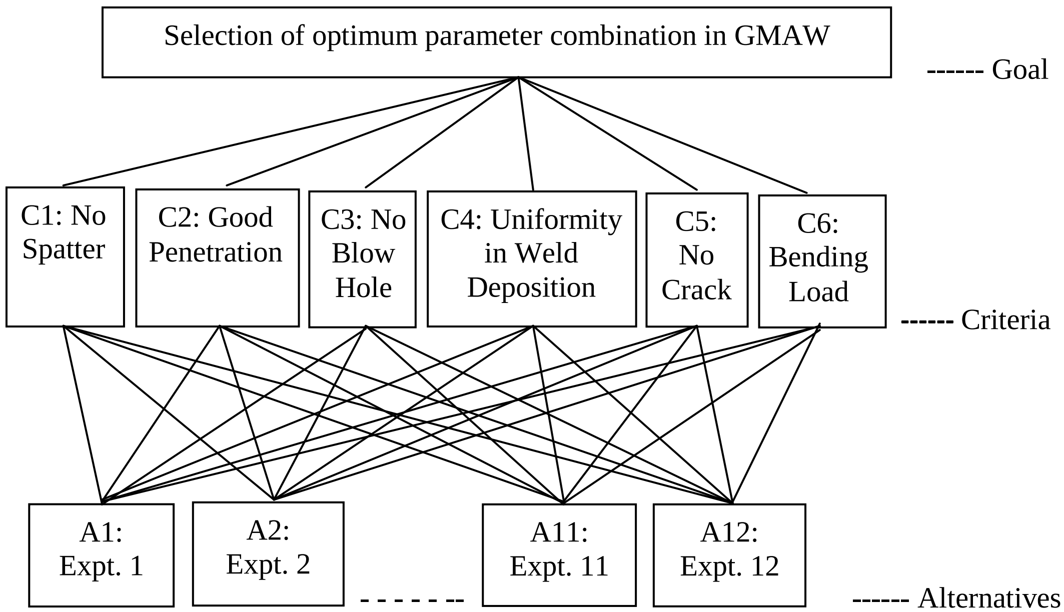

Figure 1. Hierarchy structure of the AHP used

Table 4
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

The pair wise comparison matrix for criteria is constructed to solve the present problem of the selection of optimum parametric combination, and is given in Table 5. This table shows preferences for selection of a criterion compared with the other criterion to judge a quality weld. Good penetration and good bending load are more highly preferred than spatter, as a high bending load indicates good load sustaining capability of the weld. Good weld penetration facilitates this. These weights of preferences have been introduced based on the experiences from different welding tests. Good, uniform weld deposition has slightly less preference compared to penetration and bending load, as it has less influence than the other factors when determining a good weld. The presence of cracks and blow holes is next in order of preference. Even if there is an apparent presence of a crack and blow hole in a weld, if there is high bending strength along with deep penetration, the weld may still be usable. If a crack cannot propagate, and it is arrested summarily, it may not cause any failure in the component. A blow hole presents some discontinuity; however, if bending strength of the weld is good in spite of presence of a blow hole, the weld may be acceptable. With these considerations, priority weights of the criteria matrix are chosen, and the consistency ratio (CR) of the matrix comes out to be less than 10% which signifies consistency of the chosen values.

In this work, no commercial software was used for calculations. The local weight is not calculated raising the powers to the pairwise comparison matrix; however, it is calculated using a computer programme written by the authors in C++ language in the following manner:

i) First, the elements of each column are normalized by dividing each element of a column by the arithmetic sum of elements of that column.
ii) Local weight of a row is then calculated by arithmetic mean of the normalized row elements.

Table 5
The criteria matrix

Optimum Quality Weld	C1	C2	C3	C4	C5	C6	Local Weight
C1	1	1/7	1/3	1/6	¼	1/8	0.0317
C2	7	1	3	1	4	½	0.2295
C3	3	1/3	1	1/3	½	1/5	0.0716
C4	6	1	3	1	3	½	0.2107
C5	4	¼	2	1/3	1	1/4	0.0958
C6	8	2	5	2	4	1	0.3606

Principal eigen value, λ_{max} = 6.1521, CR = 0.004469

For each criterion (C), preferences of the alternatives (A) are tabulated in Table 6 through Table 11. Table 6 shows the relative priorities within any two alternatives (experiments) considering the occurrence of no spatter (criteria, C1). As A1 alternative (experiment 1) has large spatter, and alternatives A4, A5, A6, A10, A11 and A12 show no spatter, compared to A1 alternative, these six alternatives are assigned a ‘very strong preference’ (a preferential strength of 7). On the other hand, presence of low spatter in A2 and A3 compared to that of A1 alternative, results in assigning the preferential rating of 4 (that is, moderately to strongly preferred).

Table 7 shows the pair-wise comparison matrix for alternatives with respect to criterion, C2 which is good penetration. Compared to less penetration observed in A1 alternative, A7 and A8 alternatives have similar less penetration, and hence, are assigned a value of equal preference (that is 1). Similarly, alternative A6 shows good penetration and has astrength of preference of 5 which signifies ‘strongly preferred’ compared with alternative A1.

Table 6
Pair-wise comparison matrix for alternatives for criterion 1 (no spatter)

C1	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	Local weight
A1	1	1/4	¼	1/7	1/7	1/7	1/5	1/6	1/6	1/7	1/7	1/7	0.0133
A2	4	1	1	1/5	1/5	1/5	½	1/3	1/3	1/5	1/5	1/5	0.0266
A3	4	1	1	1/5	1/5	1/5	½	1/3	1/3	1/5	1/5	1/5	0.0266
A4	7	5	5	1	1	1	4	2	2	1	1	1	0.1263
A5	7	5	5	1	1	1	4	2	2	1	1	1	0.1263
A6	7	5	5	1	1	1	4	2	2	1	1	1	0.1263
A7	5	2	2	¼	1/4	¼	1	½	½	¼	1/4	1/4	0.0387
A8	6	3	3	½	1/2	½	2	1	1	2	2	2	0.103
A9	6	3	3	½	1/2	½	2	1	1	2	2	2	0.103
A10	7	5	5	1	1	1	4	½	½	1	1	1	0.103
A11	7	5	5	1	1	1	4	½	½	1	1	1	0.103
A12	7	5	5	1	1	1	4	½	½	1	1	1	0.103

Principal eigen value, λ_{max} = 12.689, CR = 0.0039

Table 7
Pair-wise comparison matrix for alternatives for criterion 2 (good penetration)

C2	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	Local weight
A1	1	1/3	1/3	1/4	1/4	1/5	1	1	1/3	1/3	1/3	¼	0.0263
A2	3	1	1	1/3	1/3	1/4	3	3	1	1	1	1/3	0.0592
A3	3	1	1	1/3	1/3	1/4	3	3	1	1	1	1/3	0.0592
A4	4	3	3	1	1	1/3	4	4	3	3	3	1	0.1329
A5	4	3	3	1	1	1/3	4	4	3	3	3	1	0.1329
A6	5	4	4	3	3	1	5	5	4	4	4	3	0.2354
A7	1	1/3	1/3	1/4	1/4	1/5	1	1	1/3	1/3	1/3	¼	0.0263
A8	1	1/3	1/3	1/4	1/4	1/5	1	1	1/3	1/3	1/3	¼	0.0263
A9	3	1	1	1/3	1/3	1/4	3	3	1	1	1	½	0.0608
A10	3	1	1	1/3	1/3	1/4	3	3	1	1	1	½	0.0608
A11	3	1	1	1/3	1/3	¼	3	3	1	1	1	½	0.0608
A12	4	3	3	1	1	1/3	4	4	2	2	2	1	0.1190

Principal eigen value, λ_{max} = 12.3832, CR = 0.0019

Table 8 illustrates the pair-wise comparison matrix for alternatives with respect to the criterion C3, that is, lack of a blow hole. Compared to presence of large blow holes in experiment 1 (alternative A1), occurrence of less or no blow hole is assigned a priority ratio of moderately to strongly preferred (3 to 5). Similarly, Table 9, 10 and 11 are constructed for pair-wise comparison matrix of alternatives with respect to criteria C4 (uniformity of weld deposition), C5 (no crack) and C6 (bending load).

Table 8
Pair-wise comparison matrix for alternatives for criterion 3 (no blow hole)

C3	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	Local weight
A1	1	1/3	1/3	1/4	1/4	1/5	1	1	1/3	1/3	1/3	¼	0.0188
A2	3	1	1	1/3	1/3	1/4	3	3	1	1	1	1/3	0.0188
A3	3	1	1	1/3	1/3	1/4	3	3	1	1	1	1/3	0.0371
A4	4	3	3	1	1	1/3	4	4	3	3	3	1	0.0685
A5	4	3	3	1	1	1/3	4	4	3	3	3	1	0.0685
A6	5	4	4	3	3	1	5	5	4	4	4	3	0.1429
A7	1	1/3	1/3	1/4	1/4	1/5	1	1	1/3	1/3	1/3	¼	0.0371
A8	1	1/3	1/3	1/4	1/4	1/5	1	1	1/3	1/3	1/3	¼	0.0371
A9	3	1	1	1/3	1/3	1/4	3	3	1	1	1	½	0.1429
A10	3	1	1	1/3	1/3	1/4	3	3	1	1	1	½	0.1429
A11	3	1	1	1/3	1/3	1/4	3	3	1	1	1	½	0.1429
A12	4	3	3	1	1	1/3	4	4	2	2	2	1	0.1429

Principal eigen value, λ_{max} = 12.3832, CR = 0.0017

Table 9
Pair-wise comparison matrix for alternatives for criterion 4 (good weld deposition)

C4	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	Local weight
A1	1	1	1	1/3	1/3	1/4	1	1	1/2	1/6	1/5	1/5	0.0285
A2	1	1	1	1/3	1/3	1/4	1	1	1/2	1/6	1/5	1/5	0.0285
A3	1	1	1	1/3	1/3	1/4	1	1	1/2	1/6	1/5	1/5	0.0285
A4	3	3	3	1	1	1/3	3	3	2	1/5	1/3	1/3	0.0708
A5	3	3	3	1	1	1/3	3	3	2	1/5	1/3	1/3	0.0708
A6	4	4	4	3	3	1	4	4	3	1/3	1/2	1/2	0.1185
A7	1	1	1	1/3	1/3	1/4	1	1	1/2	1/6	1/5	1/5	0.0285
A8	1	1	1	1/3	1/3	1/4	1	1	1/2	1/6	1/5	1/5	0.0285
A9	2	2	2	1/2	1/2	1/3	2	2	1	1/4	1/3	1/3	0.0506
A10	6	6	6	5	5	3	6	6	4	1	2	2	0.2354
A11	5	5	5	3	3	2	5	5	3	1/2	1	1	0.1557
A12	5	5	5	3	3	2	5	5	3	1/2	1	1	0.1557

Principal eigen value, λ_{max} = 12.2903, CR = 0.0015

Table 10
Pair-wise comparison matrix for alternatives for criterion 5 (no surface crack)

C5	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	Local weight
A1	1	1/5	1/3	1/5	1/5	1/5	1/5	1/2	1/2	1/7	1/7	1/7	0.0148
A2	5	1	3	1	1	1	1	4	4	1/3	1/3	1/3	0.0866
A3	3	1/3	1	1/3	1/3	1/3	1/3	2	2	1/4	1/4	1/4	0.0410
A4	5	1	3	1	1	1	1	4	4	1/3	1/3	1/3	0.0866
A5	5	1	3	1	1	1	1	4	4	1/3	1/3	1/3	0.0866
A6	5	1	3	1	1	1	1	4	4	1/3	1/3	1/3	0.0866
A7	5	1	3	1	1	1	1	4	4	1/3	1/3	1/3	0.0866
A8	2	1/4	½	1/4	1/4	1/4	¼	1	1	1/5	1/5	1/5	0.0250
A9	2	1/4	½	1/4	1/4	1/4	¼	1	1	1/5	1/5	1/5	0.0250
A10	7	3	4	3	3	3	3	5	5	1	1	1	0.1536
A11	7	3	4	3	3	3	3	5	5	1	1	1	0.1536
A12	7	3	4	3	3	3	3	5	5	1	1	1	0.1536

Principal eigen value, λ_{max} = 12.404, CR = 0.0019

Table 11
Pair-wise comparison matrix for alternatives for criterion 6 (good bending load)

C6	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	Local weight
A1	1	1/5	1	2	1	1	2	1	2	1/4	1/4	1/5	0.444
A2	5	1	5	6	5	5	6	5	6	2	2	1	0.2074
A3	1	1/5	1	2	1	1	2	1	2	1/4	1/4	1/5	0.4532
A4	½	1/6	1/2	1	1	½	1	1/2	1	1/5	1/5	1/6	0.2758
A5	1	1/5	1	1	1	½	1	1/2	1	1/5	1/5	1/6	0.3167
A6	1	1/5	1	2	2	1	2	1	2	1/4	1/4	1/5	0.4709
A7	½	1/6	1/2	1	1	½	1	1/2	1	1/5	1/5	1/6	0.2758
A8	1	1/5	1	2	2	1	2	1	2	1/4	1/4	1/5	0.4709
A9	½	1/6	1/2	1	1	½	1	1/2	1	1/5	1/5	1/6	0.0307
A10	4	1/2	4	5	5	4	5	4	5	1	1	1/2	0.1384
A11	4	1/2	4	5	5	4	5	4	5	1	1	1/2	0.1464
A12	5	1	5	6	6	5	6	5	6	2	2	1	0.2065

Principal eigen value, λ_{max} = 12.1907, CR = 0.0010

Combining the pair-wise comparison matrix for criteria and that for alternatives, a global matrix is found as shown in Table 12. In the present work, a computer programme is developed by the authors using C++ computer programme that takes the input of the element data of all matrices, and computes the consistency ratio and global weight following the same steps as that of manual calculations.

Table 12
Global weights for alternatives

Alternatives	Weld Speed (mm/min)	Weld Voltage (V)	Weld Current (A)	Global Weight
A_1	370.5	25	140	0.0314
A_2	370.5	25	150	0.103
A_3	370.5	25	160	0.0425
A_4	370.5	30	140	0.0715
A_5	370.5	30	150	0.073
A_6	370.5	30	160	0.1174
A_7	475.75	25	140	0.0331
A_8	475.75	25	150	0.0372
A_9	475.75	25	160	0.0505
A_{10}	475.75	30	140	0.1459
A_{11}	475.75	30	150	0.1292
A_{12}	475.75	30	160	0.1655

5. Discussion of AHP results

Many process parameters influence GMAW or MAG performance, and three main parameters are selected for the present investigation. The results, as detailed in Table 2, show that the relationship among parameters chosen is not simple enough to draw a clear conclusion. Therefore, the AHP is used in this work to discover the appropriate combination of process variables to obtain sound welding. Experimental observations made in GMAW show that at a welding voltage of 30 V, 140-160 A welding current and 475.75 mm/min speed condition, a good quality weld is obtained. At a lower weld voltage, weldments begin to exhibit a number of weld defects. The AHP is used to find out the optimized process conditions by choosing suitable weights in the criteria matrix and the alternative matrices, and finally combining these weights to find the global matrix as shown in Table 12. The expertise of the authors is utilized to choose the pair-wise comparison ratio, and these are comparable with some other published articles by Sabiruddin et al. (2009) and Muralidharan et al. (1999).

If global weights against each alternative are arranged in descending order, the same appears to be: A12 > A10 > A11 > A6 > A2 > A5 > A4 > A9 > A3 > A8 > A7 > A1. Therefore, the AHP indicates that the A12 alternative be chosen for GMAW for joining C45 medium carbon steel specimens. This corresponds to a setting of a weld voltage of 30 V, welding current of 160 A and 475.75 mm/min speed of the welding torch. Although, a weld voltage of 30 V with 140-160 A weld current at 475.75 mm/min speed condition (experiments A10 and A11) have been found experimentally to be somewhat good for having a sound weld, the AHP refines the experimental results further to give the optimum welding process parameters within the domain of conditions considered in this work. Conditions for experiments 6 and 2 may also be considered since they show global weights slightly less than that obtained from experiments 12, 10 and 11.

6. Conclusion

The following conclusions may be drawn from the present investigation on joining C45 medium carbon steel specimens using gas metal arc welding employing 100% carbon di-oxide as the shielding gas, and to find out the optimal set of process parameters utilizing the AHP. Three process parameters, weld speed, weld voltage and weld current were varied to evaluate the best combination of process parameters corresponding to an experimental run within the domain of the present work. As these process parameters have varying influence on weld quality, the AHP was employed to discover the experimental run(s) giving the desired quality of weld. The AHP analysis considered six criteria for joining medium carbon steel specimens optimally, and a weld voltage of 30 V, weld current of 160 A, and welding speed of 475.75 mm/min were chosen for the selected electrode and workpiece. This result corresponded to the maximum global weight of the A_{12} alternative. This is also agreeable with the experimental results. At this condition, heat input is supposed to be quite favourable to facilitate good weld penetration, high bending strength, and lack of the presence of a crack, spatter and blow hole. Therefore, this condition may be recommended for implementation to obtain sound welding.

Hence, while gas metal arc welding of medium carbon steel workpieces is used, the AHP helps managerial decision-making so that the management may prepare the process sheet specifying the evaluated optimized process parameters to set in order to have a defect-free, good welded joint.

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