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Interrelationship Modeling Among Weld Strength Improvement by Parametric Approach in TIG Welding using DEMATEL Software

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Abstract: Tungsten Inert Gas (TIG) welding is an important and versatile welding technique used across the globe to join ferrous materials such as mild steel and nonferrous materials like stainless steel, aluminum alloys, and copper alloys. TIG welding technique has various parameters like current type, depth of penetration, length of the arc, welding speed, inert gas flow rate, and much more. These parameters are essential in obtaining a weld with desired strength and properties. By controlling these parameters, a sound and strong weld joint can be obtained. In this paper, five important parameters are selected, and a cause and effect diagram is plotted using DEMATEL (Decision Making Trail and Evaluation Laboratory) software. Then the degree of importance is calculated to find which of the five parameters are causes and which of the given parameters are effects. Further, a sensitivity test is done to check whether the results obtained from the used approach are feasible or not.

Keywords: TIG Welding, DEMATEL, Degree of Importance, Welding Parameters, Weld Strength

1. Introduction

Various industries widely use arc welding techniques to join different materials of different compositions and thicknesses. In perfect TIG welding, no electrode will be consumed because in TIG welding, a non-consumable electrode (Tungsten Electrode) is used.[1)] The welding process takes place under the high-pressure inert gas shield to protect it from oxidation due to atmospheric air. In TIG welding, there are various parameters that should be under sight during the welding process. AC and DC (DCEP/DCEN) current can be used to weld various materials. DCEN can be used, which gives high melting, but the arc is unstable in nature.[2)]

Further, nonferrous materials like aluminum alloys, magnesium alloys, and stainless steel, when welded in the presence of argon or argon and helium gas mixture, gives sound weld quality, and copper gives sound weld in the presence of nitrogen. If the torch speed or weld speed is reduced, it gives deep penetration but increases the weld time and cooling time, which further affects the weld quality.

Further, conventional TIG welding was replaced with fluxed-based TIG welding to improve weld strength and to get a sound weld joint. In this paper, five major parameters current type, depth of penetration, welding speed, plate material, and gas flow rate are selected. Using DEMATEL software, a cause and effect diagram is plotted to determine the degree of importance, which helps in finding cause and effect parameters.

The tensile strength of the specimen varies with the change in gas flow rate in TIG welding. An increase in the gas flow rate between the workpiece and electrode increases the tensile strength.[1)] The main limitation in TIG welding is the maximum depth of penetration in a single pass which leads to joining thick sections with multi passes.[3)]

In TIG, welding fluxes are not used because of the formation of slag, causing corrosion on weld metals. Further welding current is another factor affecting the weld joint. Lack of power supply can affect the fusion and weld joints. Conventional TIG welding does not use Flux, but now a day, fluxes are used in TIG welding.[4)] Depth of penetration in TIG welding can be improved by Activated flux tungsten inert gas welding (ATIG), Flux bounded tungsten inert gas welding (FBTIG), and Pulsed current tungsten inert gas welding (PCTIG).[5] DCEN welding is an ideal method to weld aluminum alloys. It stabilizes the arc, induces excessive heat in the base material, increases the depth of penetration, and reduces welding current.[6] To increase the depth of penetration in TIG welding speed of welding should be reduced, but it causes reduction in productivity.[7]

If ATIG welding is used, weld bead width reduces, but ATIG welding is ineffective at a low current level. ATIG welding improves the depth of penetration.[8] In DCEN (direct current straight polarity), 30% of heat is liberated at the electrode; therefore, deep penetration is obtained. In DCEP (direct current reverse polarity), 70% heat is liberated at the electrode, causing a decrease in depth of penetration.[9] In TIG welding, if the gas flow rate increases, the total heat input into the workpiece increases. The gas mixture also affects other welding parameters.[10]

Weld strength can be improved with the pulsed current in TIG welding.[11] With the help of activated flux in TIG welding, melt metal flows deep inside the molten pool, improving the weld strength.[12] Even if a non-consumable electrode is used in TIG welding, some part of the electrode is consumed; that's why automatic wire feeding can also be done in TIG welding.[13] Higher tensile strength can be obtained with low weld speed[14] filler material and electrode type can also affect weld strength.[15] Generally, forehead welding is preferred for stainless steel.[16] Tensile strength in TIG welding decreases with an increase in the impulse frequency because of the shortening of the time interval between two adjacent peaks of impulse current.[17]

Welding speed is most important parameter to achieve welding strength [18] in TIG welding, factors like thermal expansion, the specific heat of base material, density and Resistance plays an essential role in welding strength[19] now a day highly efficient thermocouples are used to measure temperature in heat affected zone during welding[20] artificial neural networks can be used to get optimize weld strength[21] with DEMATEL, TOPSIS method can be used to develop an interrelationship between welding variables with sensitivity test.[22]

Fuzzy expert system can also be applied to create a relation between strength and other variables.[23] It is difficult to join thick plates with TIG welding so hybrid TIG – Laser welding is used now a day.[24] Porosity in weld is a problem in TIG welding, such type of defects can be detected by using genetic algorithm.[25]

TIG, as well as other welding processes, has many variables, which may be physical variables like the structure of base material, chemical variables like the chemical composition of base material and electrodes, or process variables like torch angle and torch speed. It is hard to consider all parameters simultaneously in weld strength improvement. Thus a condition-based selection of variables is taken, and the goal is to attain optimum weld strength by considering condition-based parameters. From the literature review and discussion with experts, it is observed that weld strength improvement optimization in TIG welding has significantly less research work. Multi-criteria decision-making approach is also not much applied in this area of research.

The study done in this paper is focused on weld strength improvement using the TIG welding technique. Here a product is not made using this study in this paper. Here out of the known twelve parameters, mainly five parameters are taken. Studies in the future can be done by including the remaining seven parameters and other possible parameters. Here in this study, process variables are taken.

Further chemical composition, thermal conductivity, thermal expansion, and the density of the mother material and electrode can be considered in the study. To the best knowledge, very few research works are available that focus on the improvement of weld strength in TIG welding or other welding processes by using a multi-criteria decision-making tool. Here DEMATEL software is used to make a parametric interrelationship. Other software and theories like fuzzy and TOPSIS can be applied. TIG weld properties can also be enhanced by using an automated process by controlling torch speed and electrode feed rate through automation. The study can also be done by making welds by automation, and new parameters can be obtained.

2. Methodology

In this phase, various research databases are used to identify the papers related to TIG welding and a modern approach to improve the TIG welding technique. The string used were "welding technique," "TIG welding," and "DEMATEL" "2011-2021". Further 50 papers were selected. After critical review of these papers, twelve parameters were taken, and after consulting with institution experts and industrial experts, the five mostly used parameters (current type, depth of penetration, gas flow rate, joint type and plate material) were taken out of twelve parameters.

DEMATEL software is used in this paper, where the most important parameters are identified to improve weld strength in the tungsten inert gas welding process. By taking expert opinion and from the literature review cause and effect diagram is plotted using DEMATEL software (Fig.1).[12]

3. Result and analysis

Here DEMATEL approach is used, a multi-criteria decision-making tool that provides interrelationships between the factors used in the problem to convert and give a quantitative analysis from qualitative design. The steps used in this DEMATEL approach are as follows.

STEP 1: Make a direct relation matrix

First, a matrix was filled by the experts showing the degree of influence each factor exerts on another factor, shown as b_{ij}. The influence scale used by the expert has the lowest value of 0 (no effect) and highest value of 4 (very high effect); by using these matrices, a direct relation matrix is constructed. The average matrix B is shown below.

$$B = \begin{bmatrix} b_{11} & \cdots & b_{1j} & \cdots & b_{1n} \\ \vdots & 0 & \vdots & 0 & \vdots \\ b_{i1} & \cdots & b_{ij} & \cdots & b_{in} \\ \vdots & 0 & \vdots & 0 & \vdots \\ b_{n1} & \cdots & b_{nj} & \cdots & b_{nn} \end{bmatrix}$$

This study includes the opinion of 20 people from north India, including people from companies, and faculty from college, with experience of a minimum of five years in either the industrial or education fields. Here in the table 2, the current is represented as P1, depth of cut as P2, gas flow rate as P3, current type as P4, and plate material as P5.

Table 1: Rating scale

Scale Variable	Scale Value
No effect	0
Very low effect	1
Low effect	2
High effect	3
Very high effect	4

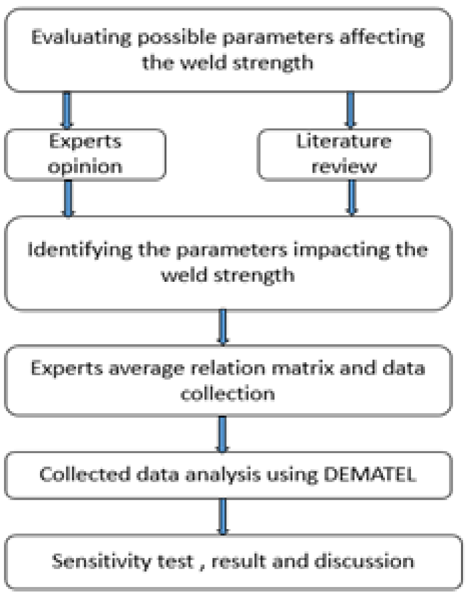

Fig.1: Flowchart to identify the cause and effect parameter[12)]

Table 2: Direct relation matrix (expert 1)

Parameters	P1	P2	P3	P4	P5
P1	0	4	2	2	3
P2	3	0	1	2	3
P3	1	2	0	1	1
P4	2	2	1	0	3
P5	2	3	1	2	0

Before collecting data, the motive and objective of the research, with its benefits and usefulness, were appropriately explained to each expert. After getting the response from the experts, a direct relation matrix (also called the average relation matrix, table 3 was made.[12)]

Table 3: Average relation matrix

Parameters	P1	P2	P3	P4	P5
P1	0	3.6	1.4	1.4	2.2
P2	3.2	0	1	1.6	2.6
P3	1	1.4	0	1.2	0.6
P4	2	2.2	0.8	0	2.4
P5	2.4	2.6	1.2	2.4	0

STEP 2: normalized matrix calculation It is also called initial influence matrix. $Y = [y_{ij}]_{n\times n}$ is obtained by normalizing direct relation matrix A where all the principle diagonal elements are zero.

Table 4: The normalized matrix

Parameters	P1	P2	P3	P4	P5
P1	0	0.419	0.163	0.163	0.256
P2	0.372	0	0.116	0.186	0.302
P3	0.116	0.163	0	0.14	0.07
P4	0.233	0.256	0.093	0	0.279
P5	0.279	0.302	0.14	0.279	0

Step 3: the direct-indirect matrix

The decrement of the indirect effects of a problem can be obtained by formula

Y = z × B

Where

$$z = \left\{ \frac{1}{max_{1\le i\le n}\sum_j^n a_{ij}}, \frac{1}{max_{1\le j\le n}\sum_i^n a_{ij}} \right\}$$

And

$$lim_{h\to\infty} Y^h = [0]_{n\times n}, 0 \le Y_{ij} \le 1$$

Step 4: the influence matrix

The formula for total influence matrix is given by

$Y (I - Y)^{-1}$.

Table 5: The influence matrix

Parameters	P1	P2	P3	P4	P5
P1	2.225	2.72	1.328	1.846	2.255
P2	2.489	2.416	1.293	1.857	2.278
P3	1.255	1.388	0.617	1.005	1.134
P4	2.183	2.375	1.155	1.535	2.064
P5	2.437	2.648	1.309	1.924	2.052

After making of total relation matrix, a threshold matrix is formed. in threshold matrix all values from the relation matrix which are less than threshold value 1.831 are taken zero. Here welding speed and depth of penetration have maximum effects on other parameters.

here d_i = direct-indirect effects sum of one obstacle on other barriers

r_j = direct-indirect effects sum that an obstacle has received.

$d_i + r_j$ = the index of strength of influences

$d_i - r_j$ = the net effect that parameter gives to the problem. When $d_i - r_j$ is positive then obstacle affects other parameters, if it is negative, then a factor is impacted by other parameters.

Table 6: Threshold matrix

Para meters	P1	P2	P3	P4	P5
P1	2.225	2.72		1.846	2.255
P2	2.489	2.416		1.857	2.278
P3					
P4	2.183	2.375			
P5	2.437	2.648		1.924	2.052

Table 7: The influences sum which are given and received on criteria

Parameter	d_i	r_i	$d_i+ r_i$	$d_i- r_i$
Welding speed	10.589	10.373	20.962	- 0.216
Depth of penetration	11.547	10.332	21.879	- 1.215
Gas flow rate	5.703	5.399	11.102	- 0.303
Current type	8.165	9.312	17.478	1.147
Plate material	9.783	10.371	20.154	0.587

Table 8: The prominence vector

Rank	Parameter	$d_i+ r_i$
1	Depth of penetration	21.879
2	Welding speed	20.962
3	Plate material	20.154
4	Current type	17.478
5	Gas flow rate	11.102

Increasing application of TIG welding process by studying various process and design parameters. TIG welding uses various process and design parameters so it is not easy to identify specific parameters to improve the process.

Weld strength is affected by various process variables and design parameters but the work done in this field is very low in this study DEMATEL software is used to make the interrelationship between 5 parameters affecting the weld strength. In this study two relative vectors group are taken namely cause table and effect table. The cause table include two parameters current type (P4) and plate material (P5) and effect table includes welding speed (P1), depth of penetration (P2) and gas flow rate (P3).

Table 9: Resulted vectors

Rank	Cause parameters	$d_i+ r_i$
1	Current type	1.147
2	Plate material	0.587
Rank	**Effect parameters**	**d_i-r_i**
1	Welding speed	-0.216
2	Gas flow rate	-0.303
3	Depth of penetration	1.215

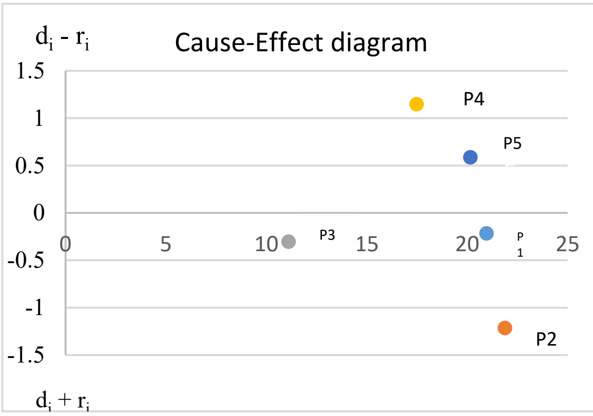

Fig. 2: The causal-effect plot (ref. DEMATEL software

From the cause-effect plot (figure 2) it can be seen that current type and plate material are most influencing parameters for TIG welding process, as it is known that cause criteria more dominantly affecting the overall set target. here d_i and r_j shows degree of influencing impact (d_i-r_j) shows each parameter's relative importance, so high value of it gives most influencing parameters and low value gives least influencing parameters. It can be seen in table 6 that $d_i+ r_i$ is maximum for depth of penetration welding speed and plate material and here positive value of $d_i- r_i$ indicates that d_i is greater than r_j highest values of current type and plate material in cause diagram result that we need to focus more on the current type and plate material to improve the weld strength.

3.1 Sensitivity analysis

Here to validate the results sensitivity test in which different weights are given to the expert's opinion. The first expert opinion is taken with the highest weight, and the other expert's opinion is taken with equal weight.

Table 7 gives the rank of the parameters before and after the sensitivity test. It can be seen that the rank of the first two parameters before and after sensitivity analysis remains the same. It implies that "depth of penetration" and "welding speed" are the most significant parameters.

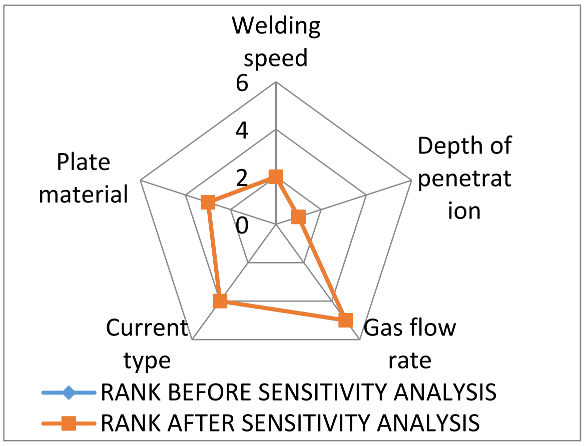

Fig. 3: Spider web diagram for sensitivity test

Parameter		Rank Before (Sensitivity Test)	Rank After (Sensitivity Test)
P1	Welding speed	2	2
P2	Depth of penetration	1	1
P3	Gas flow rate	5	5
P4	Current type	4	4
P5	Plate material	3	3

Conclusions

Industries across the globe are working to enhance weld strength by using different approaches and using various modern technologies to fulfill the need of customers. Industries like automobiles and aerospace play an essential role in a country's economy. These industries are using multiple TIG welding techniques with a modern approach to getting weld strength as required. Various parameters which affect the weld strength can be material, process, or product related. This study targets to identify the parameters that play an important role in weld strength improvement by TIG welding, which is important from the point of view of the customer as well as the company. This study considers north India's local companies which are using conventional TIG welding as well as modern TIG welding approaches.

After getting the expert's opinion, the DEMATEL (a multi-criteria decision-making approach) software is used which helps to get quality data from quantitative values to identify parametric relationships. Further, it concludes that companies using the TIG welding process have a major focus on the type of joint and plate material. After study most influencing parameters manufacturers trying to use TIG welding can concentrate specifically on two welding parameters in strength improvement. This will not only improve the weld strength but also reduce the chances of weld joint failure.

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