An overview framework of welding process selection, current state and expectatives

O Bohórquez¹, A Pertuz², and M Rincón-Ortíz¹

¹ Grupo de Investigacion de Energía y Medio Ambiente, Universidad Industrial de Santander, Bucaramanga, Colombia
² Grupo de Investigacion en Corrosión, Universidad Industrial de Santander, Bucaramanga, Colombia

E-mail: obohorbe@correo.uis.edu.co, apertuze@uis.edu.co

Abstract. In the application of welding processes, various factors have a decisive influence on the result. In most manufacturing processes the designer in charge assigns the methods and procedures to be followed, according to his experience or the quantitative influence he can establish of the factors. Throughout the development of manufacturing, different models have been proposed to implement a selection model for welding processes, which can include in a weighted way the affectation or benefits in quality, costs or skills to optimize the development of the application. This work compiled chronologically the works and systematically grouped them in the most relevant methods presented, generating a brief description of each one of them and grouping the authors, also analyzing some bibliographic factors that allow estimating the level of impact that these scientific productions have generated from indicators such as the number of citations or the publisher of application. Finally, this work shows a proposal for future research which, being already on the way to its development, anticipates new approaches and impacts in the chosen research area.

1. Introduction
Permanent or removable mechanical assembly systems are part of the daily life of industrial development [1], static or structural models, and dynamic models are exposed to load conditions that vary with time or corrosion [2]. Within traditional schemes manufacturing, welding is presented as a joining system between two or more elements, which from the addition of heat, pressure or friction allows the fusion of the materials involved [3]. According to the American Welding Society (AWS), there are more than seventy-two welding processes available that develop this joining mechanism [4]. However, choosing the appropriate process option can be complicated by the variables involved. Multiple criteria taken into account include the cost of the weld, its failure rate, base metal, dimensions, shape, location, required standard, weld joint preparation, and so on [5].

For decades, some authors have recognized the importance of selecting the appropriate welding process to achieve the optimal parameters of a certain process [6,7], some essential variables such as cost or reduction of environmental damage [8,9], or to conclude specific applications of processes for repair or manufacturing models [10,11]. The use of computational tools [6,12] and numerical models [8,13,14] as well as decision algorithms [15] in which various criteria are included has generated that the selection of the welding process is an activity that meets different fields of knowledge.
This work presents a list of the different concepts that revolve around the selection process, a review of the techniques described by the authors who have studied this topic, and a chronological analysis associated with a citation index of the publications made in this regard. From this scenario, finally a research horizon towards what could deepen a more accurate knowledge of the techniques used or experimental tools of determination to facilitate the selection in the industrial scenario of welding application.

2. Influence factors in the welding process

Performing a welding process selection approach involves a comprehensive review of several criteria that cause a marked influence on the expected results, hence it is necessary to review the welding scenario. Figure 1 presents a generic evolution process in three steps of consideration, all of which are along with the cost factor.

Each criterion shown in Figure 1 represents a set of conditions that can alter the final result of the welding process, inherently the analysis of each element of these lists can represent a greater or lesser influence, as well as a degree of complexity in its optimized obtaining or cost, this iteration process for the established criteria, has formed what is recognized as a welding process selection model.

![Figure 1. Influence criteria in generic welding process.](image)

3. Models of welding process selection

For this review, four fundamental models that have been used in many types of research studies were considered, the models were presented, and examples of validation were developed.

3.1. Knowledge base system or personal computer based expert system

This method aims to establish detailed lists of the parameters included in the lists presented in Figure 1, which will be included in a priority matrix system, and to which certain values are attributed, finally it is possible to establish an algorithm where the variables are located and the system, based on the responses of the interface user, can make its decision through the results offered by the algorithm. Figure 2 shows the Boolean decision system. Some authors have developed analyses based on this method [5], with the inclusion of weighting matrices and listing up to thirty welding processes simultaneously [15].

3.2. Fuzzy logic

The fuzzy logic system promotes the numerical weighting of criteria within a range of acceptance or denial of its value, generating that the decision takes into account subjective elements with less or more weighting in the application of a selection model. This objective is achieved from the application of operations that allow locating the weighting in mathematical functions that describe geometric elements that correlate with other selection criteria; by applying Boolean conditions, it allows the decision to take into account several parameters simultaneously [16].
Fuzzy logic proposes the following scheme of equations to narrow down the connection between the uncertainty and subjectivity of two possible selection criteria. Let a selection variable $A$ be represented by a triangular fuzzy number TFN $\tilde{A}$, with components $(a_1, a_2, a_3)$, its membership function to the selection set will be represented as shown in Equation (1).

$$
\mu_\lambda(x) = \begin{cases} 
  x=a_1, & a_1 \leq x \leq a_2 \\
  a_2-x, & a_1 \leq x \leq a_3 \\
  a_3-x, & a_2 \leq x \leq a_3, \\
  0 & \text{otherwise} 
\end{cases}
$$

(1)

where $a_2$ is the most possible value of the TFN $\tilde{A}$, and $a_1$, and $a_3$ are the lower and upper bounds, and they are used to show the edges of this variable as a function for the selection process and it can be linked with other variables through operations like sum, product, quotient, and Euler distance. Figure 3 shows how two variables $A$ and $B$ interact to quantify their relevance in the decision process.

**Figure 2.** Algorithms for the expert system model: (a) welding process algorithm, (b) general algorithm [15].

**Figure 3.** Two variables interacting using the fuzzy logic method [6].
3.3. Multicriteria decision model
In this process it is necessary to list the attributes that can influence the performance of the welding procedure, and apply values that classify their relevance, it will be usual to apply normalization procedures and develop matrices that operate the total of affection to result in a decision value from that weighting.

The value assignment scheme will depend on the level of strength or weakness provided by each variable and the information that usually comes from experimental models or scientific literature. Logically, this method will cast subjectivity on the decision model. However, it is viable for direct variables such as materials, gas flows, input transfer systems, and also for indirect variables such as costs, labor personnel, operator skill, environmental impact, and others. In Table 1 is presented a matrix example for this method in the processes shielded metal arc welding (SMAW), gas metal arc welding (SMAW), Flux cored arc welding (FCAW), and gas tungsten arc welding (GTAW).

| Table 1. Example of multicriteria decision model (MCDM) matrix. |
|---|---|---|---|
| Process | Weld quality (WQ) | Operator skills (OS) | Consumables costs (CC) | Surface cleaning (SC) |
| SMAW | k | 0.3 | 0.1 | 0.3 |
| GMAW | 0.7 | 0.2 | 0.5 | 0.5 |
| FCAW | 0.4 | 0.4 | 0.4 | 0.3 |
| GTAW | 0.8 | 0.6 | 0.7 | 0.6 |

3.4. Analysis hierarchic of process
The main advantage over other techniques for welding process selection lies in the numerical inclusion and blending of quantitative and qualitative factors, unified in a weighted ranked matrix that reviews the permutation of all variables to measure their level of influence. The algorithm to apply an analysis hierarchic of process (AHP) is as follows.

- Select the variables to control for the process and list them.
- Classify the variables as intrinsic or extrinsic, in such a way that they represent the influence on the outcome.
- Draw a graph linking the problem and the alternatives according to the proposed objective, and generating the hierarchy of influence at each level.
- Make comparisons in pairs and based on this assign a value to each alternative.
- Apply a normalized priority for each alternative, this is, sum all the values per column, then divide the value assigned to each alternative in the column total, finally, calculate the average horizontally for all values in this direction.
- Repeat step four, with a matrix that contains the welding process and then a new matrix with results from criteria matrix and welding process, make combinations and calculate products from normalized priorities matrices, the best results are the proper decision of welding process.

Table 2 shows a normalized priority matrix with previous variables analyzed in other methods. Additionally, Figure 4 shows the graph for linked variables.

| Table 2. Example of AHP normalized priority matrix. |
|---|---|---|---|---|---|
| Variable | WQ | OS | CC | SC | Priority weight |
| WQ | 1 (0.091) | 1/5 (0.032) | 1/2 (0.086) | 1/3 (0.057) | 0.266 |
| OS | 5 (0.455) | 1 (0.161) | 1/3 (0.057) | 1/2 (0.086) | 0.759 |
| CC | 2 (0.182) | 3 (0.484) | 1 (0.171) | 4 (0.686) | 1.523 |
| SC | 3 (0.273) | 2 (0.323) | 4 (0.686) | 1 (0.171) | 1.453 |
| Total | 11 | 6.2 | 5.833 | 5.833 | 1 |
3.5. **Technique for order of preference by similarity to ideal solution**

This model can be comparable to the AHP method, but the normalized priority matrix has a different calculation model. Let $Y = (y_{ij})$ the decision matrix, then it can get normalized priority matrix $R = (r_{ij})$ with the following Equation (2).

$$r_{ij} = \frac{y_{ij}}{\sum_{i=1}^{n} y_{ij}}$$

(2)

The technique for order of preference by similarity to ideal solution (TOPSIS) method also measures the differential value between the proposed ideal solution and the distance state of the non-ideal solution. Through Equation (3) to approach the ideal solution and Equation (4) to measure the distance from the neglected point.

$$d^+ = \frac{\sqrt{\sum_{i=1}^{m} (r_{ij} - r^+_j)^2}}{\sqrt{\sum_{j=1}^{n} y_{ij}}}$$

(3)

$$d^- = \frac{\sqrt{\sum_{i=1}^{m} (r_{ij} - r^-_j)^2}}{\sqrt{\sum_{j=1}^{n} y_{ij}}}$$

(4)

where $d^+$ and $d^-$ represent the distance mentioned above.

4. **Overview**

Several methods have been described for the selection of a welding process, based on mathematical techniques or subjective choice models that aim to order the relevant concepts that must be taken into account in a multiphysics process such as welding. Table 3 presents a summary of the methods and authors who have developed scientific knowledge on the subject, together with the year of their publications in chronological order and a citation index as a reflection of the quality of their work.

5. **Suggestions for future researches**

The authors wish to mention that the focus of this review is to formulate new research that will increase the level of knowledge on the subject, as well as to present the following suggestions for future researches.
➢ Selection of welding processes based on the affectations to the mechanical properties of the intervened materials. It is presented as a research option by proposing a material durability approach.

➢ Modeling of welding processes to formulate numerical simulation schemes that project the state of the materials affected by the welding processes. Welding process selection based on Select the variables to control for the process and list them.

**Table 3. Summary of scientific publications on welding process selection.**

| Method     | Author                  | Publication year | Citation index - source |
|------------|-------------------------|------------------|-------------------------|
| Expert system | Lovegrove [5]           | 1989             | 4 – Google scholar (GS)  |
|            | Darwish [15]            | 1997             | 31 – GS/Scopus          |
| Fuzzy logic | Jafarian [6]            | 2012             | 838 – GS/Scopus         |
|            | Wisnu [17]              | 2020             | 2 – GS                 |
| MCDM       | Badhesia [18]           | 1997             | 29 – GS                |
|            | Yeo [9]                 | 1998             | 45 – GS/Scopus          |
|            | Silva [19]              | 2000             | 32 – GS/Scielo         |
|            | Brown [20]              | 2002             | 10 – GS                |
|            | Rao [21]                | 2007             | 953 – GS               |
|            | Correia [14]            | 2007             | 22 – GS/Scopus         |
|            | Araque [22]             | 2012             | 17 – GS/Conicyt        |
|            | Lazić [7]               | 2012             | 19 – GS/Scopus         |
|            | Sproesser [8]           | 2016             | 13 – GS/Scopus         |
|            | Thakur [23]             | 2019             | 6 – GS                 |
| AHP        | Balasubramanian [24]    | 2000             | 2 – GS                 |
|            | Ravisankar [10]         | 2009             | 67 – GS/ Springer       |
|            | Jayant [13]             | 2015             | 33 – GS                |
| TOPSIS     | Mirhedyatian [12]       | 2013             | 69 – GS/Scopus         |
|            | Capraz [11]             | 2015             | 13 – GS                |
|            | Omar [25]               | 2019             | 1 – GS/ Springer        |

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