 

# SELECTING OF THE MOST SUITABLE NON-CONVENTIONAL WELDING PROCESS: A STUDY CASE

Oana Dodun[1], Andreea Istrate[2], Mihaela Nicolau[3], Vasile Merticaru[4] and Gheorghe Nagîț[5]
[1] "Gheorghe Asachi" Technical University of Iaşi, Romania, oana.dodun-des-perrieres@academic.tuiasi.ro
[2] "Gheorghe Asachi" Technical University of Iaşi, Romania, mihaela.nicolau@student.tuiasi.ro
[3] "Gheorghe Asachi" Technical University of Iaşi, Romania, andreea.cretu@student.tuiasi.ro
[4] "Gheorghe Asachi" Technical University of Iaşi, Romania, vasile.merticaru@academic.tuiasi.ro
[5] "Gheorghe Asachi" Technical University of Iaşi, Romania, gheorghe.nagit@academic.tuiasi.ro

ABSTRACT: In recent years, non-conventional welding processes have gained significant traction across various industries due to their unique advantages. However, selecting the most appropriate welding method for a specific application remains a complex and challenging task. This complexity arises from the need to consider numerous criteria that often conflict with one another, making the decision-making process intricate. This study addresses this challenge by employing the Analytical Hierarchy Process (AHP) methodology to evaluate and determine the most suitable non-conventional welding process for a particular case study. The findings of this research provide valuable insights and practical guidance that can be directly applied to various industrial applications, facilitating more informed and effective process selection.

KEY WORDS: multi-criteria decision making, welding, non-conventional welding processes, Analytical Hierarchy Process.

## 1. INTRODUCTION

Conventional welding processes refer to the traditional methods used to permanently join parts, primarily metals parts, by the application of heat, pressure, or both, and with or without added metal for formation of metallic bond. Although, it is possible to join a variety of materials, including metallic alloys, polymers, composites, and even biological tissues. These processes are well-established in various industries (electronics, aerospace, automotive, construction, healthcare, energy, etc.) and are characterized by their reliance on melting or solidifying materials to create strong joints.

Although traditional welding technologies are widely used and highly relevant, these processes fall short of meeting the stringent requirements of certain industries. This has prompting significant research into non-conventional welding techniques.

Non-conventional welding processes, also referred to as non-traditional or advanced welding techniques, encompass a variety of innovative methods that enhance the efficiency and effectiveness of joining materials. These innovative techniques can be defined as those welding processes that utilize different forms of energy to obtain the adhesion of materials or/and by combining multiple processes. Those processes are particularly useful for materials that are difficult to weld using conventional methods or the required characteristics of the joint are special.

Welding is a critical manufacturing method, widely used across nearly all industrial sectors. One of the main avenues for advancing welding technology is the development of hybrid welding processes. These processes combine two conventional welding methods, leveraging the benefits of each to enhance process stability and efficiency. Moreover, the use of advanced welding technology goes beyond traditional manufacturing industries, reaching into emerging fields like additive manufacturing and robotics.

In additive manufacturing, welding-based techniques such as direct energy deposition and laser metal deposition are facilitating the production of complex metal components with improved geometric precision and material properties [1, 2].

[3] presents a novel hybrid welding process combining submerged arc welding techniques and laser beam. The integration of these methods enhances the efficiency and quality of welds in steel applications. The study explores the process parameters, benefits, and potential industrial applications, demonstrating significant improvements in weld penetration and mechanical properties compared to traditional methods.

A classification of the methods of welding materials is difficult to achieve due to the fact that the processes are very different. A classification is possible that takes into account the energy source used. The welding processes can also be classified on the core approaches utilized for material deposition in joint formation. [4, 5, 6]

Figure 1 shows the categories of known welding processes. In blue bold italic font are the welding processes that are considered to be part of the category of non-conventional processes due to the energy used or the hybrid characteristic of the process [5, 6, 7].

The standard ISO 4063:2023 [7] has recognized 78 different types of welding processes, the categories are as follows: metal arc welding without gas protection, submerged arc welding, gas-shielded metal arc welding, gas-shielded arc welding with non-consumable tungsten electrode, plasma arc welding, other arc welding processes, resistance spot welding, resistance seam welding, projection welding, flash welding, resistance butt welding, HF resistance welding, oxyfuel gas welding, ultrasonic welding, friction welding, friction stir welding, impact welding (or shock welding), diffusion welding, oxyfuel gas pressure welding, cold pressure welding, hot pressure welding, beam welding, laser welding, resistive implant welding, radio frequency welding, solvent welding, hot gas welding, heat sealing, heated tool welding, flash-free welding, other plastics-specific welding processes, aluminothermic welding (or thermite welding), electroslag welding, electrogas welding, induction welding, light radiation welding, arc stud welding.

The welding process input factors are established by considering the type and chemical composition of the workpiece material and the filler material type, the joint design and fit-up, the thickness of the parts, the electrical parameters (current, voltage, polarity), the heat input factors, welding speed, the shielding gas, the composition and its flow rate, welding position, operator skill and technique, etc.

In order to be used effectively, it is crucial for the welding automated systems to have a high level of confidence in predicting weld parameters to achieve the desired mechanical strength or shape in welded joints. Many researchers developed mathematical models [8, 9, 10] that can accurately forecast weld strength for input into automated welding systems has therefore become increasingly important.

In summary, non-conventional welding processes represent a significant advancement in joining technologies. By employing innovative techniques that utilize different forms of energy and combining multiple processes, these methods offer enhanced capabilities for modern manufacturing challenges.

## 2. DIFFERENT USE AND ADVANTAGES OF NON-TRADITIONAL WELDING PROCESSES

Kalpakjian [11] identifies the three primary types of joining processes which are mechanical fastening, adhesive bonding, and welding. The first one uses standard fasteners like bolts, nuts, and rivets.

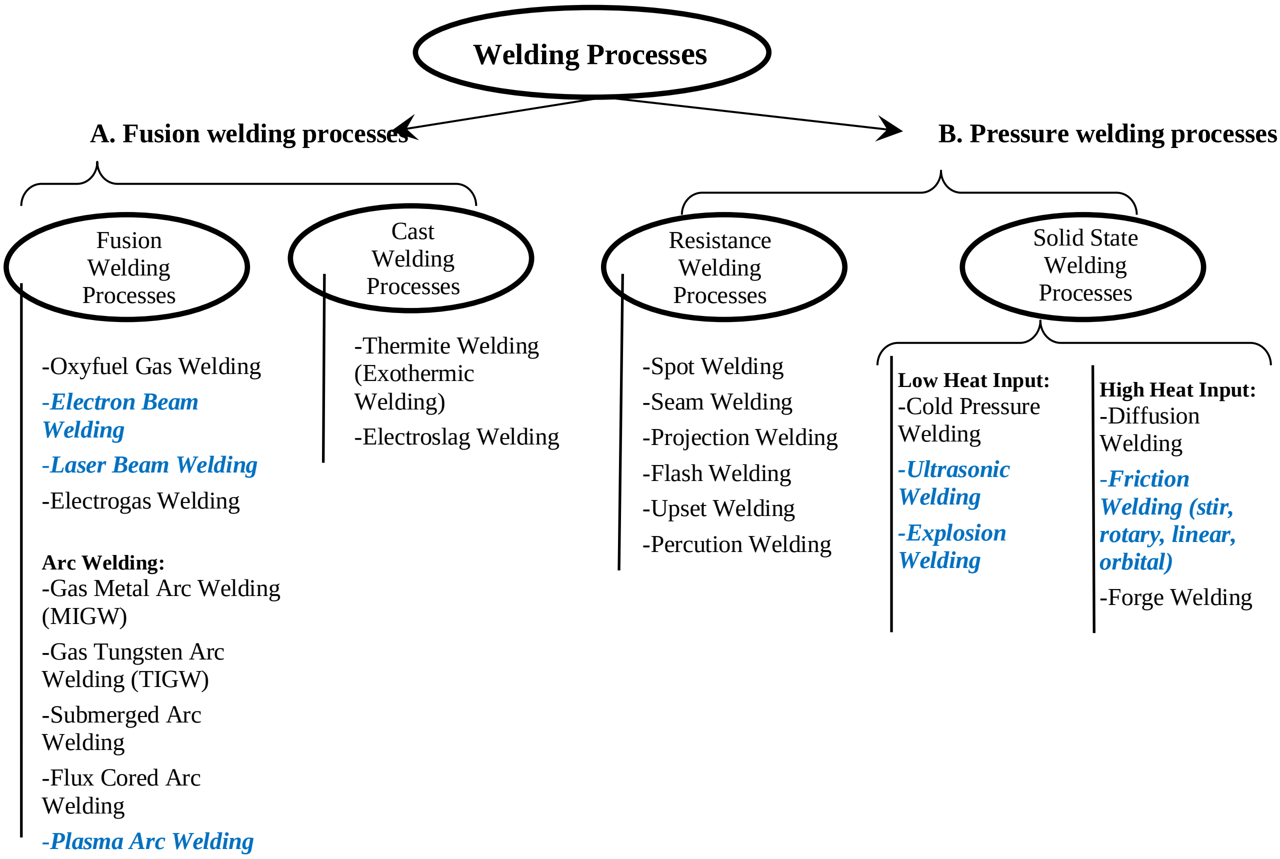


**Figure 1.** Classification of the different methods for welding

Adhesive bonding, by contrast, is applied to provide strength, sealing, thermal and electrical insulation, vibration dampening, and corrosion resistance, particularly between dissimilar materials. Welding is the most economical method, making it a frequently preferred choice. Advantages of welding include creating strong and tight joints, cost-effectiveness, ease of designing welded structures, and the potential for welding processes to be mechanized and automated. However, disadvantages of welding involve internal stresses, distortions, and changes in microstructure within the weld area, as well as exposure to harmful effects such as intense light, ultraviolet radiation, fumes, and high temperatures.

Unlike the other joining processes, welding requires supervision of the working environment in terms of process sustainability, the working environment and the minimization of the effects of welding processes on the environment.

Each welding method has distinct advantages and applications, varying in complexity and suitability depending on the part materials and shapes involved. Some emerging specialized methods are tailored for niche applications within specific industries.

Researchers emphasize that resistance welding produces high-quality welds quickly and is often automated through robotic systems.

Gas tungsten arc welding (GTAW) is used for martensitic stainless steel and offers high precision by independently controlling arc heat and filler metal additions, although it operates at a slower pace.

Friction stir welding (FSW) has proven effective for joining difficult-to-weld metals and varying thicknesses, including dissimilar materials like aluminium, magnesium, titanium alloys, and metal-matrix composites.

Plasma arc welding (PAW) uses a tungsten electrode that is not consumed during the process and shielding gas, such as argon, delivering high-power density comparable to laser welding but with lower cost. PAW’s key advantage lies in its ability to weld without filler metal in most cases. Additionally, it has a high tolerance for variations in torch-to-plate distance and better thermal efficiency than laser welding, making it an efficient option for fusion welds.

Laser beam welding (LBW) has gained widespread industrial use for producing high-quality welds with minimal shrinkage. The process requires high welding speeds, as laser beams vaporize the base material, producing fumes.

Electron beam welding (EBW) stands out for its versatility, capable of welding nearly all metals across a range of thicknesses, from foil to heavy plates. With electron beam guns reaching up to 100 kW, EBW accommodates varying welding speeds while achieving deep welds up to 300 mm, deep penetration, minimal weld size, and a narrow heat-affected zone, creating clean, efficient welding results and exceptionally fine welds, as small as 20 μm.

Ultrasonic welding (USW) is a rapid, cost-effective, and sustainable method that converts friction into heat to melt materials, particularly effective for plastics, thermoplastics, synthetic fabrics, and films. This process is notable for being eco-friendly, as it eliminates the need for adhesives or solvents.

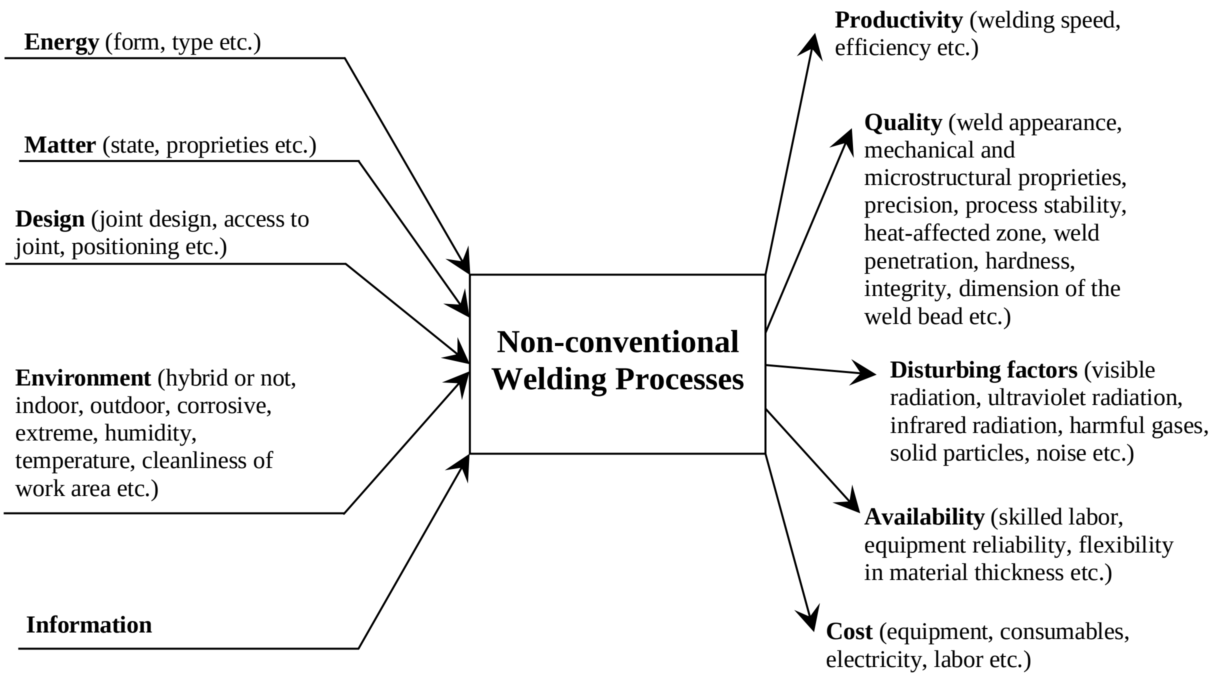


**Figure 2.** Use of the systemic analysis method in the case of the non-conventional welding processes

Ultrasonic welding also offers low energy consumption, can weld large areas at a low cost, and is particularly effective in removing surface oxides and contaminants, resulting in clean welds that are ideal for a various modern application.

Systemic analysis is an analytical method that views the process or assembly under investigation as a system. This system has multiple input factors and corresponding output parameters, with the output values influenced by both the input values and the relationships between these inputs and outputs. A more performant analysis of the process is conducted if the input and output parameters are highlighted. Figure 2 present a systemic analysis for the non-conventional welding processes.

The choice of welding technology depends on various factors, including material thickness, joint design, required strength and weld quality, cost considerations and production speed. Each method has its strengths and weaknesses that make it suitable for specific applications within industries such as automotive, construction, aerospace, and manufacturing. Understanding these technologies is essential for achieving strong and durable welded joints.

## 3. METHODS OF SELECTING THE MOST SUITABLE SOLUTION

In general, to solve a problem, the concept of optimization implies choosing the most convenient solution from various options available. This paper presents the findings of the research aiming to establish the most suitable welding process for a specific steel part by using the AHP method were presented.

Whether it is about the detailed design of some parts, whether it is about choosing a manufacturing process for a specific part, the choice of the most suitable solution can be made through different methods. Multicriteria optimization is used most of the time to obtain an appropriate solution. Most of the time, companies tend to develop two or three ideas from one end to the other and finally choose the most suitable solution. In order to reduce constructive or technological design costs, multi-criteria decision-making (MCDM) methods were developed such as: Choosing by Advantages decision-making, Analytical Hierarchy Process (AHP) method, Weighting Rating Calculating [12], Technique for Order of Preference by Similarity to Ideal Solution, Best Value Selection [12], Elimination and Choice Expressing Reality, Fuzzy MCDM, Multi-Attribute Utility Theory etc.

## 4. APPLYING AHP METHOD FOR SELECTING THE WELDING PROCESS

Analytic Hierarchy Process (AHP) propose a methodology to obtain a decision when there are multiple alternatives and criteria to be considered. AHP is a decision-making technique which necessitates four steps as follows [13]:

- Define the problem and gather relevant information;

- Build a decision hierarchy, starting with the primary goal, followed by broad criteria and sub-criteria, down to the alternatives;

- Create pairwise comparison matrices, comparing each criterion and alternative based on the level above;

- Use the priorities from these comparisons to calculate overall priorities for each alternative.

In [14] it is explored a model example to demonstrates how AHP can effectively prioritize and evaluate complex criteria, providing a systematic approach for decision-making in varied applications, emphasizing also its flexibility and adaptability in real-world scenarios.

**Table 1**. Decision matrix, the corresponding weightings, and ranks based on the principal eigenvector of the matrix.

| Criterion | *C1* | *C2* | *C3* | *C4* | *C5* | *C6* | Priority | Rank |
|---|---|---|---|---|---|---|---|---|
| *Column no. 1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
| ***C1-***_Speed_ | 1 | 0.50 | 1.00 | 0.50 | 0.33 | 0.50 | 9.1 % | 5 |
| ***C2-***_Precision_ | 2.00 | 1 | 0.33 | 0.33 | 0.50 | 0.33 | 8.7 % | 6 |
| ***C3-***_Appearance_ | 1.00 | 3.00 | 1 | 1.00 | 1.00 | 0.25 | 13.7 % | 4 |
| ***C4-***_Strenght and integrity_ | 2.00 | 3.00 | 1.00 | 1 | 1.00 | 0.33 | 15.6 % | 2 |
| ***C5-***_Skill labor_ | 3.00 | 2.00 | 1.00 | 1.00 | 1 | 0.25 | 15.2 % | 3 |
| ***C6-***_Cost_ | 2.00 | 3.00 | 4.00 | 3.00 | 4.00 | 1 | 37.7 % | 1 |

The total number of comparisons is 15, with a consistency ratio of 7.9%.
The principal eigenvalue is calculated as 6.496.
The eigenvector solution was achieved in six iterations, with a delta value of $1.4 \times 10^{-8}$

**Table 2.** Results of comparing the 5 proposed alternatives in regard of the criterion *C1 -Speed.*

| Alternative | *EBW* | *LBW* | *PAW* | *USW* | *FRW* | Priority | Rank |
|---|---|---|---|---|---|---|---|
| ***EBW*** | 1 | 1.00 | 3.00 | 5.00 | 1.00 | 27.2% | 2 |
| ***LBW*** | 1.00 | 1 | 4.00 | 6.00 | 2.00 | 34.7% | 1 |
| ***PAW*** | 0.33 | 0.25 | 1 | 3.00 | 0.33 | 4.7% | 5 |
| ***USW*** | 0.20 | 0.17 | 0.33 | 1 | 0.20 | 9.7% | 4 |
| ***FRW*** | 1.00 | 0.5 | 3.00 | 5.00 | 1 | 23.8% | 3 |

The total number of comparisons is 10, with a consistency ratio of 2.0%.
The principal eigenvalue is calculated as 5.088.
The eigenvector solution was achieved in six iterations, with a delta value of $2.5 \times 10^{-8}$

**Table 3.** Results of comparing the 5 proposed alternatives in regard of the criterion *C2 -Precision.*

| Alternative | *EBW* | *LBW* | *PAW* | *USW* | *FRW* | Priority | Rank |
|---|---|---|---|---|---|---|---|
| ***EBW*** | 1 | 3.00 | 5.00 | 7.00 | 3.00 | 45.7% | 1 |
| ***LBW*** | 0.33 | 1 | 5.00 | 5.00 | 5.00 | 30.4% | 2 |
| ***PAW*** | 0.20 | 0.20 | 1 | 3.00 | 0.5 | 8.4% | 4 |
| ***USW*** | 0.14 | 0.20 | | 1 | 1.00 | 5.7% | 5 |
| ***FRW*** | 0.33 | 0.20 | 2.00 | 1.00 | 1 | 9.9% | 3 |

The total number of comparisons is 10, with a consistency ratio of 9.7%.
The principal eigenvalue is calculated as 5.438.
The eigenvector solution was achieved in six iterations, with a delta value of $9.2 \times 10^{-9}$

**Table 4.** Results of comparing the 5 5 proposed alternatives in regard of the criterion *C4 -Strength and integrity.*

| Alternative | *EBW* | *LBW* | *PAW* | *USW* | *FRW* | Priority | Rank |
|---|---|---|---|---|---|---|---|
| ***EBW*** | 1 | 2.00 | 6.00 | 4.00 | 4.00 | 44.2% | 1 |
| ***LBW*** | 0.5 | 1 | 6.00 | 3.00 | 1.00 | 24.0% | 2 |
| ***PAW*** | 0.17 | 0.17 | 1 | 0.33 | 0.25 | 4.6% | 5 |
| ***USW*** | 0.25 | 0.33 | 3.00 | 1 | 1.00 | 11.6% | 4 |
| ***FRW*** | 0.25 | 1.00 | 4.00 | 1.00 | 1 | 15.6% | 3 |

The total number of comparisons is 10, with a consistency ratio of 3.8%.
The principal eigenvalue is calculated as 5.170.
The eigenvector solution was achieved in six iterations, with a delta value of $9.0 \times 10^{-9}$

**Table 5.** Results of comparing the 5 proposed alternatives in regard of the criterion *C6 -Cost.*

| Alternative | *EBW* | *LBW* | *PAW* | *USW* | *FRW* | Priority | Rank |
|---|---|---|---|---|---|---|---|
| ***EBW*** | 1 | 0.50 | 0.25 | 0.20 | 0.11 | 4.3% | 5 |
| ***LBW*** | 2.00 | 1 | 0.50 | 0.25 | 0.17 | 7.3% | 4 |
| ***PAW*** | 4.00 | 2.00 | 1 | 0.50 | 0.25 | 13.8% | 3 |
| ***USW*** | 5.00 | 4.00 | 2.00 | 1 | 0.33 | 23.4% | 2 |
| ***FRW*** | 9.00 | 6.00 | 4.00 | 3.00 | 1 | 51.1% | 1 |
| | | | | | | | |

The total number of comparisons is 10, with a consistency ratio of 1.7%.
The principal eigenvalue is calculated as 5.074.
The eigenvector solution was achieved in six iterations, with a delta value of $5.3 \times 10^{-9}$

**Table 6**. Assessment of each alternative based on the specified criteria.

| Criterion | ***C1-*** *Speed* | ***C2-*** *Precision* | ***C3-*** *Appearance* | ***C4-*** *Strenght& integrity* | ***C5-*** *Skill labor* | ***C6-*** *Cost* | Priority | Rank |
|---|---|---|---|---|---|---|---|---|
| ***Criterion weight*** | ***9.1%*** | ***8.7%*** | ***13.7%*** | ***15.6%*** | ***15.2%*** | ***37.7%*** | | |
| ***Column no. 1*** | ***2*** | ***3*** | ***4*** | ***5*** | ***6*** | ***7*** | ***8*** | ***9*** |
| *EBW* | 27.2% | 45.7% | 40.5% | 44.2% | 36.9% | 4.30% | 28.5 % | **1** |
| *LBW* | 34.7% | 30.4% | 39.8% | 24.0% | 32% | 7.30% | 24.3 % | **2** |
| *PAW* | 4.7% | 8.4% | 5.3% | 4.6% | 10% | 13.8% | 10.8 % | **5** |
| *USW* | 9.7% | 5.7% | 7.9% | 11.6% | 16% | 23.4% | 16.8 % | **4** |
| *FRW* | 23.8% | 9.9% | 6.5% | 15.6% | 5.1% | 51.1% | 19.6 % | **3** |
| Sum = | 100% | 100% | 100% | 100% | 100% | 100% | 100 % | |

The objective of this paper is to determine the most suitable process for welding a butt joint from specific materials. The hierarchical relationships are built with the help of the criteria that are taken into account: ***C1**-speed of welding, **C2**-precision of the process, **C3**-appearance of the weld bead, **C4**-Strength, **C5**-Skill labor necessary for carrying out the process, **C6**-Cost of the process* as well as of the considered alternatives: *Electron Beam Welding (**EBW**), Laser Beam Welding (**LBW**), Plasma Arc Welding (**PAW**), Ultrasonic Welding (**USW**), Friction Stir Welding (**FSW**)*.

In a further step of the AHP method, each solution is compared pairwise, considering each evaluation criterion. This approach reveals the priority weightings and ranks of all criteria. The resulting priority weightings and ranks are shown in Tables 2. The on-line system from [15] were used for all performed calculations.

Tables 2-5 provides an overview of criteria weightings and highlight the significance of each alternative when a particular criterion is applied. By using the values in Table 6, the overall composite weighting is calculated by summing the products of each criterion's weighting with the corresponding values for each alternative process. Based on these values, the final ranking of alternatives was determined, showing that, using the AHP method and under these specific criteria, the EBW is the most favourable process.

## 5. CONCLUSIONS

One method commonly used to address multicriteria decision-making problems is the analytic hierarchy process. This approach helps in selecting the optimal alternative from several available options, based on pre-established evaluation criteria. It was employed in the selection of the most suitable welding process for two specific steel components. By considering the general composite weight values assigned to each alternative, the best available solution was identified.

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