No. 36 | 2026
ISSN Online 2007-9621
http://doi.org/10.15174/au.2026.4531

ACTA UNIVERSITARIA
Multidisciplinary Scientific Journal

Comparative analysis of welding processes using MCDM methods for the development of a component joining station

Análisis comparativo de los procesos de soldadura usando métodos MCDM para el desarrollo de una estación de unión de componentes

Alma Nayeli Balcázar-Terrones[1], Luis Alberto Rodríguez-Picón[1]*, Iván Juan Carlos Pérez-Olguín[1], Luis Carlos Méndez-González[1]

[1] Department of Industrial Engineering and Manufacturing, Engineering and Technology Institute, Autonomous University of Ciudad Juárez. CP. 32310.
al237863@alumnos.uacj.mx, luis.picon@uacj.mx, ivan.perez@uacj.mx, luis.mendez@uacj.mx
*Autor de correspondencia

Abstract

Keywords: AHP; TOPSIS; process control techniques.

Welding methods are common in production lines, which allows to join components with various properties that can impact quality, safety, and performance. There are techniques such as electric arc, induction, gas, GTAW, and GMAW, whose selection depends on the characteristics and needs of the process, which can be complex due to the multiple requirements to be met. This paper aimed to identify attributes of welding methods so as to weigh alternatives and, through a multi-criteria decision-making method, choose the most appropriate technology for a specific process. In particular, the AHP was used to weigh attributes found in the literature, and the TOPSIS method was applied to select the welding alternatives. At the end of the manuscript, the selection that best fitted the requirements of the joining station is provided.

Resumen

Palabras clave: AHP; TOPSIS; técnicas de control de procesos.

Los métodos de soldadura son comunes en las líneas de producción, lo que permite unir componentes con diversas propiedades que afectan la calidad, la seguridad y el rendimiento. Existen técnicas como el arco eléctrico, la inducción, el gas, el GTAW y el GMAW, cuya selección depende de las características y necesidades del proceso, lo cual puede ser complejo debido a los múltiples requisitos a cumplir. Este trabajo busca identificar los atributos de los métodos de soldadura con el fin de ponderar alternativas y, a través de un método de toma de decisiones multicriterio, elegir la tecnología más adecuada para un proceso específico. En particular, se usó el método AHP para la ponderación de criterios encontrados en la literatura y después se aplicó el método TOPSIS para seleccionar las alternativas consideradas. Al final del artículo, se muestra la mejor alternativa de acuerdo con los requerimientos de la estación de unión de componentes.

Recibido: 25 de febrero de 2025

Aceptado: 03 de octubre de 2025

Publicado: 25 de febrero de 2026

Cómo citar: Balcázar-Terrones, A. M.; Rodríguez-Picón, L. A.; Pérez-Olguín, I. J.; & Méndez-González, L. C. (2026). Comparative analysis of welding processes using MCDM methods for the development of a component joining station. *Acta Universitaria, 36*, e4531. doi. https://doi.org/10.15174/au.2026.4531

Introduction

Welding is a fundamental process in modern industry; it is used to bond materials effectively and durably. However, choosing the right welding method is crucial to ensure the quality of the work performed. Each welding technique has unique attributes that can influence the final product, going from the mechanical strength of the joint to compatibility with different materials (Weldero, 2024). Welding methods vary in terms of technique, type of energy used, and equipment requirements, which can complicate their selection for a specific process. For example, arc welding, gas metal arc welding (GMAW), and gas tungsten arc welding (GTAW) have distinctive characteristics that make them suitable depending on the type of material and the application conditions. Also, factors such as the working position, the thickness of the materials, and the desired properties of the joint must be considered (Leo, 2024).

Welding techniques are an integral part of various manufacturing applications, each tailored to meet specific requirements. The evolution of these techniques has expanded their applicability in various industries, improving the quality of joints and production efficiency. Some of the common welding techniques and their applications are exemplified as follows: induction welding, arc welding -such as GMAW and GTAW, widely used in construction and shipbuilding-, laser welding, friction welding, among others (Salvador, 2023a). Knowing the welding methods in the industry is crucial due to their impact on the quality, safety, and efficiency of metal joints. Welding is not only a metallurgical process, it is also a factor that influences the mechanical properties of materials, which is essential for various industrial applications.

These attributes must be evaluated to facilitate the selection of the appropriate welding method for specific processes, which can be done by performing a detailed analysis of factors, such as the nature of the material, the working conditions, and the requirements of the joint. In this way, professionals will not only be able to make informed decisions but also improve efficiency and safety in their welding operations.

Safety in welding processes is also crucial due to the associated risks, such as exposure to toxic fumes, ultraviolet radiation, and the handling of heavy equipment. In this sense, each type of welding (arc, GMAW, GTAW, or induction) presents unique challenges that require specific protective measures, for instance, the use of personal protective equipment (PPE), proper ventilation, and personnel training. Implementing safe practices not only protects the health of workers but also ensures the quality and effectiveness of the work performed.

The choice of a welding technique must consider the previously discussed factors (material properties, application requirements, and process capabilities) to ensure optimal weld quality and performance. Incorrect selection can lead to significant problems, such as structural failures and increased production costs.

Literature review about analytical methods

Selecting the right welding method is crucial in engineering and manufacturing, as it directly impacts on the quality, strength, and durability of metal joints. In this literature review, several factors that influence this choice are analyzed (*e.g.*, the type of materials to be joined, the required mechanical properties, safety, associated costs, and the availability of equipment). In addition, aspects such as production speed and the ease of automation are considered, which can determine the efficiency of the process. The exhaustive analysis of these elements seeks to offer a practical guide to facilitate decision-making in industrial applications. The literature review was filtered through the selection and systematic evaluation of relevant studies that consider the previously mentioned factors and technical aspects. The discussion of these elements is provided in the next section. Specifically, in this section, a review on analytical aspects is provided, and innovation in welding methods is discussed along with the use of machine learning algorithms.

Innovations in welding methods

Methods such as friction spot welding are increasingly used in the marine industry, allowing dissimilar materials to be joined with less energy and without toxic emissions. The evolution of welding techniques, such as shield metal arc welding (SMAW) makes it possible to optimize the formation of microstructures, improving resistance to cracking (Bhogendro *et al.*, 2020).

Despite its importance, some sectors still face challenges in implementing proper welding methods, which can compromise the quality and safety of joints. Knowledge of welding methods significantly improves efficiency in industrial processes through the integration of advanced technologies and optimized training systems.

Enhanced training and task assignment

The implementation of swarm intelligence algorithms and evolutionary modeling can optimize welder training, reducing training time by 20%-30% and minimizing welder defects (Zarovchatskaya *et al.*, 2024). Automated evaluation systems assess welders' performance, facilitating better task assignments based on individual skills and experience (Zarovchatskaya *et al.*, 2024).

Machine learning applications

Machine learning algorithms improve welding quality by automating parameter selection, reducing human error, and providing consistent estimations. Visual inspection processes are also improved through machine learning, enabling real-time quality assessment and predictive maintenance (Prasad *et al.*, 2023).

Hazards associated with welding methods

Welding involves a variety of hazards that can pose serious risks if it is not properly controlled. Usually, these hazards arise from the intense heat, electrical energy, radiation, and chemical by-products generated during the process, depending on the welding technique used. Some of these hazards are briefly described below.

- Toxic fumes and gases: Traditional welding methods often expose workers to noxious fumes, with concentrations of manganese and carbon monoxide reaching dangerous levels.

- Radiation and heat: Intense light radiation and extreme heat are inherent risks, leading to potential burns.

Safety measures and mitigation strategies

As previously described, welding operations involve inherent risks that require the implementation of effective safety measures and mitigation strategies to ensure safe working conditions. Some strategies that can be considered are:

- Engineering controls: The implementation of localized exhaust ventilation and advanced welding technologies can significantly reduce airborne contaminants.
- Personal protective equipment (PPE): The use of appropriate PPE is crucial to minimize exposure to hazards.
- Safety culture and training: A strong safety culture, supported by comprehensive training, empowers workers' attitudes toward safety, leading to better compliance with safety protocols (Belmoro & Gumasing, 2023).

While advances in welding technology and safety protocols are promising, continuous vigilance and adaptation to emerging risks remain essential to ensuring worker safety in the welding industry.

Description of the attributes relevant to welding processes

Attributes relevant to welding processes are essential characteristics that determine the quality, efficiency, and safety of welded joints. These attributes include the composition of the base material as well as the electrode, the melting temperature, the welding speed, the type of electric current used, and the type of welding protection, either by gas or flux. Additionally, factors such as the position of the weld, the geometry of the parts, and the mechanical properties of the weld also play a crucial role. These elements must be carefully selected to ensure the integrity and durability of the welded parts.

When selecting a welding method, there are several key attributes that need to be considered to ensure that the process is best suited for the specific job. Some of these attributes include (Figure 1):

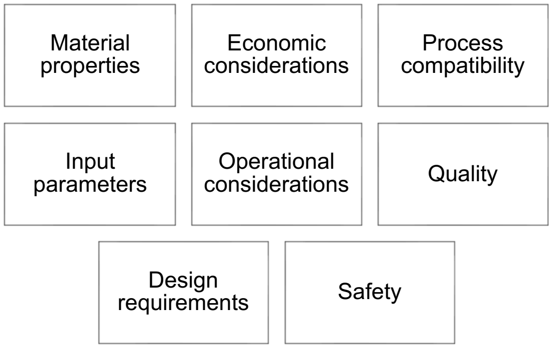

Figure 1. Critical factors in choosing the right welding method.
Source: Author's own elaboration.

These attributes allow for a more thorough and informed evaluation, ensuring that the welding method that best meets the needs of the project is chosen (Soltan & Omar, 2022). Other authors have defined several factors (the type of product, type of material, thickness of the material, method of use, level of quality, type of joint, and welding position) that determine the most suitable welding process (Darwish *et al.*, 1997). Olabode *et al.* (2013) described other attributes such as, the type of welded joint, material thickness, weld quality requirements, suitability of fillers, economic considerations, and constraints specific to each welding process. While, Jafarian & Vahdat (2012) considered the joint design, production volume, cost, and mechanical properties required, which collectively influence the selection of the right welding process.

To do this, some details described below show each previously mentioned factor in more depth.

Material property. The selection of welding techniques should be tailored to the specific properties of the materials to be joined, including melting points and thermal conductivity (Omlor *et al.*, 2023). Dissimilar materials require specialized processes to ensure a strong bond, highlighting the importance of understanding compatibility of materials (Chaturvedi & Arungalai, 2021). The type of materials that are welded, such as copper in electric drives, require specific welding techniques to minimize defects like porosity and spatter (Omlor *et al.*, 2023). Different materials require specific welding processes; for example, aluminum alloys present unique challenges (*e.g.*, controlling heat input and porosity) (Olabode *et al.*, 2013). In addition, the type of material, thickness, joint design, required weld quality, production speed, and cost considerations influence the selection of the right welding method (Chen *et al.*, 2019).

Process compatibility. This refers to the capacity of different manufacturing methods or techniques to work effectively and without conflict within the same system or set of operations. In the context of welding, process compatibility involves the proper integration and adaptation of different welding processes (GMAW, GTAW, arc, etc.) or welding with other manufacturing processes (cutting, heat treatment, or machining), ensuring that they do not negatively interfere with each other and that the desired results are achieved.

The quality of welded joints depends on the optimal weld geometry and process parameters, which requires a thorough evaluation of the available welding methods (Chaturvedi & Arungalai, 2021). A structured decision-making framework can help select the most suitable welding process based on physical and economic criteria, ensuring that the selection is in line with the requirements of the project (Omar & Soltan, 2020). Key factors include process parameters, material compatibility, and desired weld quality. These factors influence the selection of the right welding method (Thakur *et al.*, 2019), although others (availability of consumables, the type of welding process, position flexibility, weldability on the base metal, initial preparation, procedures, post-weld cleaning, capital cost, and operating factor) may be considered (Wardana *et al.*, 2019).

Operational considerations. Factors including equipment availability, staff experience, and project scale also influence the choice of welding method (Al-Mendwi & Doos, 2023). Methodologies like quality function deployment (QFD), combined with multi-criteria decision making (MCDM), can streamline the selection process (Al-Mendwi & Doos, 2023). While these factors are crucial, it is also essential to consider the evolving nature of welding technologies and the potential for the emergence of new methods, which can disrupt traditional decision-making frameworks.

Quality features. The quality of the welding is influenced by parameters such as penetration and bead reinforcement. Optimizing these parameters is essential to achieve high-quality results (Correia & Ferraresi, 2006). MCDM methods like AHP and TOPSIS can effectively assess these quality factors, leading to better informed decisions (Capraz *et al.*, 2015). Key factors in this aspect include quality requirements, cost analysis, welding parameters, consumable prices, and specific conditions of the case study (Rezende *et al.*, 2000).

Economic considerations. The economic implications, including non-quality costs, should be considered in the selection process. A holistic approach can help to solve conflicting goals, for instance, minimizing costs and maximizing quality (Correia & Ferraresi, 2006).

- Cost and availability of equipment: Economic feasibility and availability of the necessary equipment can influence the choice of a welding method (Omar & Soltan, 2020).
- Production volume: High-volume production can favor automated welding processes for the benefit of efficiency.

The key factors are cost, failure rate, base metal, dimensions, shape, location, required standard, and welded joint readiness. These parameters are interdependent and crucial for process selection (Lovegrove *et al.*, 1989).

Input parameters. Critical parameters including arc voltage, welding current, and travel speed significantly influence weld quality, affecting penetration, bead height, and heat-affected zone characteristics (Wordofa & Ramulu, 2023). In GTAW, optimization of current, travel speed, and gas flow is essential to achieve the desired weld geometry and material properties.

In addition, key factors for a consistent finish in the weld application include the materials to be joined and the specific requirements of the welding process, namely, the application of heat, pressure, welding current, voltage, speed, nozzle distance, wire feed rate, gas flow rate, and torch angle, which influence weld quality and strength (Mahore & Sharma, 2017), the strength of the bond, the control of heat input, the minimization of distortion, the microstructural integrity, and the specific materials to be joined (Salvador, 2023b).

Material design requirements and compatibility. Additionally, design requirements and material compatibility significantly influence the choice of a welding technique, as improper selection can lead to detrimental results (Chaturvedi & Arungalai, 2021). The selection of welding methods should be in line with the type and thickness of the material to avoid defects (Darwish *et al.*, 1997).

Security considerations. Important criteria for the selection of the welding process include safety considerations, as identified through expert evaluation in the study (Capraz *et al.*, 2015).

While these factors are critical, some argue that intuitive decision-making based on past experiences can still play a role in process selection. However, relying solely on intuition can overlook essential criteria, which can lead to inefficiencies. The focus is often on the technical aspects of welding method selection, it is also essential to consider the economic implications and innovation potential of welding technologies, which can improve production processes and reduce costs in the long term.

Methodology

In order to provide accurate results, this research adopted a methodological approach that combines literature review and comparative analysis, a structured approach that allows the analysis and comparison of different welding methods applicable to the design and development of component joints. The methodology is based on an exhaustive literature review of scientific and technical literature on the main welding processes, their characteristics, advantages, limitations, and selection criteria. This approach allows the identification of patterns, trends and gaps in knowledge that inform the selection of the most appropriate methods according to the specifications of the sector, ensuring a comprehensive understanding of the technical and economic factors that affect the choice of welding technologies for specific applications. Figure 2 shows an overview of the flowchart of the methodology.

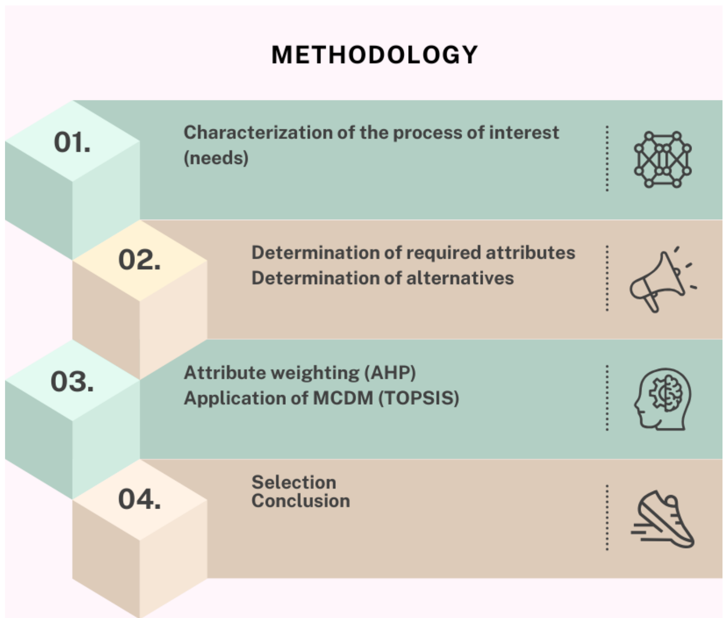

Figure 2. Overview of the methodology considered.
Source: Author's own elaboration.

I. Characterization of the process of interest (needs)

It is critical to identify the main needs that guide the selection of the right welding method. These needs include union quality, union strength, material compatibility, process speed, safety and regulation requirements, operating costs, maintenance, and adaptability and automation.

This characterization allows to guide the comparative analysis of welding processes, prioritizing those methods that best fit these needs for the development of an efficient and safe component joining station.

II. Determining required attributes

The following essential attributes are identified: material properties, economic considerations, process compatibility, input parameters, operational considerations, quality, design requirements, safety to select the appropriate welding method, which are mentioned in Figure 1 of the previous section.

III. Identification of alternatives

Several welding process options have been identified, which might be suitable based on previously determined attributes. Key alternatives include:

1. Arc welding (GMAW, GTAW): GMAW welding is effective for applications that require speed and is suitable for automation, while GTAW offers precision in high-quality welds, especially in thin materials (Bhogendro *et al.*, 2020).

2. Resistance welding (point and projection): It is very common in automated production lines; this process is ideal for joining thin metal parts, for example, in the automotive industry.

3. Friction stirring welding (FSW): This process is ideal for joining dissimilar materials, such as aluminum and other light metals, with high quality results. Its low heat generation reduces distortion and makes it a suitable choice for temperature-sensitive applications (Bhogendro *et al.*, 2020).

4. Laser welding: It offers precision and speed, with minimal heat-affected zone. This process is suitable for high-precision applications. It can be integrated into automated systems, although its high initial cost and safety requirements limit it to specialized applications (Bhogendro *et al.*, 2020).

5. Ultrasonic welding: It is ideal for non-metallic materials and applications that require fast joining without significant heat input. This method is efficient and allows for fast-duty cycles, although it is limited to specific materials and thin thickness.

6. Induction welding: This method generates heat using high-frequency currents, achieving a strong and fast bond without direct contact. It is effective for industrial applications that require temperature control and is easily integrated into automated stations (Bhogendro *et al.*, 2020).

The final selection will depend on an optimal balance between these factors or the attributes identified above to meet the specific needs of the component bonding station.

IV. Attribute weighting (AHP)

The methodology selected to choose the welding process consists of the application of the AHP method, followed by the TOPSIS method. To apply this methodology, a panel of five experts with combined experience from academia and industry was considered, as well as a moderator. Specifically, manufacturing and industrial engineers with important experience in the specific process of interest conformed the panel.

To perform the AHP (hierarchical analytical process) weighting method, the following steps can be followed.

Results

In this section, the implementation of the proposed methodology is presented through a comparative analysis of welding processes evaluated for a component joining station using the TOPSIS method (technique for order of preference by similarity to ideal solution). This multi-criteria approach made it possible to identify the most appropriate alternatives, weighing various factors that affect the efficiency and quality of a manufacturing process. Through this analysis, the aim was to select the welding process that best suits the specific needs of a particular project, optimizing not only technical performance, but also factors related to cost, safety, and sustainability. The results of the analysis and the alternatives' classification according to the established criteria are detailed below.

The case study is briefly described as part of the first step of the methodology in Figure 2, which intends to characterize the needs of the process of interest. The process consists of in replacing a fuse subassembly welding station which requires natural gas to join covers of fuses. This process involves direct operator exposure to fire, combustion smoke, and a lack of precise control over the welding process, as it is performed visually. Human intervention is high, which increases safety risks and affects quality, as there is no adequate control over operating parameters. The equipment used is obsolete and lacks protective measures, creating the need to automate the process to reduce exposure and improve both safety and quality. Thus, a semi-automated welding station needs to be developed to improve the manufacturing process of fuse subassemblies, ensuring greater precision, efficiency, and quality in soldering. In this sense, attributes must be defined and weighted according to the needs of the specific process to then be used in a selection process of different welding alternatives. This process is discussed in the next sections.

Defining the relevant attributes for the selection of the welding process

The multi-criteria decision strategy for selecting the optimal welding method in an industrial process involves evaluating various technical, economic, and safety criteria. The weighing of these criteria allows for prioritizing the options and choosing the method that best suits the specific requirements of the process, ensuring both quality and efficiency in production. Figure 3 reflects the number of publications that indicated the main attributes that are important when selecting a welding process. It can be noted that material properties is the most frequent attribute that must be considered, followed by economic considerations and the process compatibility. These attributes were considered to perform a selection of different welding processes in the next section.

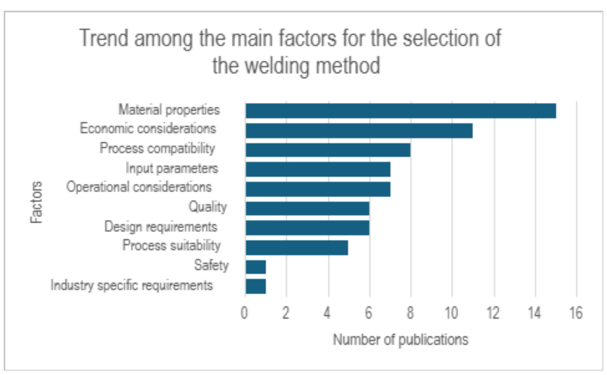

Figure 3. Trend among the main factors for the selection of the welding method.
Source: Author's own elaboration.

AHP and TOPSIS application

In this section, the implementation of decision-making methods is presented. First, the AHP method was implemented considering the attributes mentioned in the previous section, with the intention of obtaining weights. These weights were then used to determine the relative importance of each attribute, and compile experts evaluations leading to the application of the TOPSIS method to identify the best welding method.

The main characteristic of AHP is that it is based on pairwise comparison, which is based on Saaty's 1-9 scale given in Table 1. It compares the criteria in pairs using a numerical scale from 1 to 9, where 1 means equal importance and 9 means extreme importance.

Table 1. Numerical ratings for pairwise comparisons.

Intensity of Importance	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance

Source: Capraz *et al.* (2015).

In AHP, comparisons between criteria within the same group were discussed, until a common agreement was reached. Next, a pairwise comparison matrix was created (Table 2) to be used for the calculations of the weights.

Table 2. Comparison criteria for the AHP method.

	Material properties	Economic considerations	Process compatibility	Input parameters	Operational considerations	Quality	Design requirements	Safety
Material properties	1.00	3.00	7.00	3.00	3.00	5.00	7.00	0.33
Economic considerations	0.33	1.00	3.00	3.00	3.00	3.00	7.00	0.33
Process compatibility	0.14	0.33	1.00	0.33	0.33	3.00	3.00	0.20
Input parameters	0.33	0.33	3.00	1.00	0.33	3.00	3.00	0.20
Operational considerations	0.33	0.33	3.00	3.00	1.00	3.00	3.00	0.33
Quality	0.20	0.33	0.33	0.33	0.33	1.00	3.00	0.14
Design requirements	0.14	0.14	0.33	0.33	0.33	0.33	1.00	0.14
Safety	3.00	3.00	5.00	5.00	3.00	7.00	7.00	1.00

Source: Author's own elaboration.

After determining the weights of all the criteria, each expert designated the evaluation scores of the different welding processes based on each criterion. A scale of 1-10 was considered to assess each welding method with respect to the eight criteria considered, where 1 stands for the worst performance of the welding method in a specific criterion and 10 stands for the best performance of the method.

The averages of these scores were used during the calculation of the TOPSIS method. As a result of the AHP study, Table 3 shows the weights for each criterion, the classification of the criteria, and the corresponding consistency index. Table 3 shows that the safety factor is the criterion with the highest weight and, therefore, the most important (weight = 0.319142534), while the design requirements factor is determined as the least important criterion (weight = 0.025450966).

Table 3. The obtained weights of the criteria for the case study.

Criteria	Weight	Ranking	Consistency Ratio
Material properties	0.2280	2	
Economic considerations	0.1514	3	
Process compatibility	0.0551	6	
Input parameters	0.0756	5	0.0889 (Acceptable)
Operational considerations	0.1048	4	
Quality	0.0402	7	
Design requirements	0.0254	8	
Safety	0.3191	1	

Source: Author's own elaboration.

Finally, once the steps of the TOPSIS method indicated in Table 4 were performed, the classification list of the alternative welding processes was determined. In this way, the best type of welding process was obtained. The weights of the criteria in Table 3 are applied in TOPSIS to categorize the types of welding processes and choose the best. Each expert answered to assess the options according to each criterion, using a scale of 1-10: 1 point represents the worst performance and 10 points represent the score of the best performer. After each expert answered, the results were summarized in Table 4.

Table 4. Compilation of expert answers for the alternatives considered.

METHOD	Material properties	Economic considerations	Process compatibility	Input parameters	Operational considerations	Quality	Design requirements	Safety
Arc welding (GMAW, GTAW)	9	7	8	10	9	10	8	9
Resistance welding (Spot and Projection)	8	9	8	9	7	9	8	8
Friction stir welding (FSW)	9	7	9	9	8	10	8	8
Laser welding	9	7	8	9	8	10	8	9
Ultrasonic welding	10	8	9	9	8	10	8	9
Induction welding	9	8	8	9	8	9	8	10

Source: Author's own elaboration.

In addition, the average of these scores was considered and applied for the TOPSIS calculations. Table 5 shows that TOPSIS standardization ensures that all criteria are treated equally, facilitating an accurate and balanced evaluation of alternatives.

Table 5. TOPSIS standardization of the decision matrix.

METHOD	Material properties	Economic considerations	Process compatibility	Input parameters	Operational considerations	Quality	Design requirements	Safety
Arc welding (GMAW, GTAW)	0.4074	0.3710	0.3913	0.4450	0.4581	0.4218	0.4082	0.4147
Resistance welding (Spot and Projection)	0.3621	0.4770	0.3913	0.4005	0.3563	0.3796	0.4082	0.3686
Friction stir welding (FSW)	0.4074	0.3710	0.4402	0.4005	0.4072	0.4218	0.4082	0.3686
Laser welding	0.4074	0.3710	0.3913	0.4005	0.4072	0.4218	0.4082	0.4147
Ultrasonic welding	0.4527	0.4240	0.4402	0.4005	0.4072	0.4218	0.4082	0.4147
Induction welding	0.4074	0.4240	0.3913	0.4005	0.4072	0.3796	0.4082	0.4608

Source: Author's own elaboration.

Table 6 details the distance of each alternative concerning the positive ideal (Si^{*}), negative ideal (Si^{-}) solutions, and the proximity coefficient (CC_i) of each alternative. The calculation of both ideal solution distances and the closeness coefficient, comparison, and ranking of different welding processes are also presented.

Table 6. Obtained ranking based on TOPSIS.

Welding Processes	Si^{*}	Si^{-}	CC_i	Normalized CC_i	Rank
Arc welding (GMAW, GTAW)	0.0242	0.0212	0.0455	0.4669	3
Resistance welding (Spot...	0.0378	0.0161	0.0538	0.2983	5
Friction stir welding (FSW)	0.0356	0.0121	0.0477	0.2528	6
Laser welding	0.0251	0.0188	0.0439	0.4290	4
Ultrasonic welding	0.0179	0.0273	0.0452	0.6040	2
Induction welding	0.0149	0.0326	0.0475	0.6870	1

Source: Author's own elaboration.

As Table 6 indicates, according to normalized CC_i values, the best welding process is found to be induction welding for the case study.

Discussion

The comparative analysis of welding processes carried out in this article mentions the advantages and limitations of each technique depending on the specific needs of the component joining stations. Although the literature review has agreed that the main factors to be taken into account in the process are the ownership of the materials and economic considerations, they also highlight the importance of working on projects that provide total safety for the operator and, of course, the quality of their products. This goes in accordance with the specific needs of the case study, as can be noted in the obtained weights from the AHP, where safety and material properties were the attributes with a higher value and directly related to the quality of products and the safety of operators. Furthermore, this is also aligned with the needs of the case study, as it is a transition from a manual station with high risk to a semi-automated station. Likewise, of the most mentioned processes among the authors, some stand out, for instance, electric arc welding, GTAW, GMAW, and induction, since they offer different results in terms of costs, production time, and quality of the final product. It is evident that the selection of the appropriate technique depends on factors such as the type of material, the precision required, and the operating conditions. This analysis suggests that a careful evaluation of the technical and economic criteria is essential for decision-making in the implementation of efficient and cost-effective welding stations. In this case, an induction welding process was found to be the most appropriate according to the considered attributes and their respective weights. This option provides a high performance in safety, quality, and material properties, which are aligned with the requirements of the welding process.

Conclusions

In the discussion of the results obtained through the TOPSIS analysis, it is observed that the induction welding process occupies the first position, which indicates its outstanding efficiency and effectiveness compared to other welding methods. This result is consistent with previous studies highlighting the superiority of induction welding in terms of weld quality, lower deformations, and better thermal control. Multi-criteria analysis, such as the TOPSIS method, offers the advantage of evaluating and comparing different welding processes by considering multiple relevant factors, such as quality, cost, speed, energy efficiency, and adaptability to different materials. This allows for more informed and balanced decisions, since it is not based on a single criterion alone, but on a set of them, which facilitates the selection of the most suitable welding method for a specific application.

In the case of induction welding, this analysis can highlight its energy efficiency and thermal control in specific applications, but it can also make some limitations evident, such as its lower versatility compared to more conventional methods like GMAW or GTAW. Thus, multi-criteria analysis not only optimizes the choice of a method, but it also helps to adapt it to the specific needs and priorities of the plant or industry, maximizing efficiency and reducing operating costs in the long term. The study may contribute to the increased use of multi-criteria decision-making approaches in various manufacturing processes.

Acknowledgments

We would like to express our sincere acknowledgment thanks to the SECIHTI and UACJ for providing the necessary resources to carry out this research. Without their collaboration, this work would not have been possible.

Conflicts of interest

The authors declare no conflicts of interest.

References

Al-Mendwi, K. A. K., & Doos, Q. M. (2023). Selection of welding process to large scale project on site by QFD and multi criteria methods. *AIP Conference Proceedings*, 2651. https://doi.org/10.1063/5.0131380

Belmoro, B. J. B., & Gumasing, M. J. (2023). Antecedents of safety and health in the workplace: sustainable approaches to welding operations. *Sustainability*, *15*(19), 14641. https://doi.org/10.3390/su151914641

Bhogendro, R. K., Maji, P., Samadhiya, A., Karmakar, R., Ghosh, S. K., & Saha, S. C. (2020). An experimental investigation on joining of copper and stainless steel by induction welding technique. *International Journal of Precision Engineering and Manufacturing*, *21*(4), 613–621. https://doi.org/10.1007/s12541-019-00284-w

Capraz, O., Meran, C., Wörner, W., & Gungor, A. (2015). Using AHP and TOPSIS to evaluate welding processes for manufacturing plain carbon stainless steel storage tank. http://www.amse.acmsse.h2.pl/vol76_2/7628.pdf

Chaturvedi, M., & Arungalai, S. (2021). *Advanced welding techniques. Holistic view with design perspectives*. Springer. https://doi.org/10.1007/978-981-33-6621-3

Chen, S., Zhang, Y., & Feng, Z. (eds.) (2019). Transactions on intelligent welding manufacturing. Springer. https://doi.org/10.1007/978-981-13-8192-8

Correia, D. S., & Ferraresi, V. A. (2006). Applying a non-quality cost methodology to the selection of welding processes. *Welding International*, *20*(12), 953–958. https://doi.org/10.1533/wint.2006.3690

Darwish, S. M., Tamimit, A. A., & Al-Habdant, S. (1997). A knowledge base for metal welding process selection. *International Journal of Machine Tools and Manufacture*, *37*(7), 1007-1023. https://doi.org/10.1016/S0890-6955(96)00073-9

Jafarian, M., & Vahdat, S. E. (2012). A fuzzy multi-attribute approach to select the welding process at high pressure vessel manufacturing. *Journal of Manufacturing Processes*, *14*(3), 250–256. https://doi.org/10.1016/j.jmapro.2011.10.006

Leo, G. (July 3, 2024). *Soldadura MIG vs soldadura TIG: ¿Cuáles son las diferencias?*. https://www.madearia.com/es/blog/mig-welding-vs-tig-welding/

Lovegrove, G. L., Curtis, G. J., & Farrar, R. A. (1989). Welding advisory system for process selection "WASPS". *Proceedings of the 2nd International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems*. https://doi.org/10.1145/66617.66669

Mahore, N., & Sharma, T. (2017). Study of MIG welding process with different type technique: a review. *IJSTE-International Journal of Science Technology & Engineering*, *4*(6), 1-5. http://www.ijste.org/articles/IJSTEV4I6002.pdf

Olabode, M., Kah, P., & Martikainen, J. (2013). Aluminium alloys welding processes: challenges, joint types and process selection. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *227*(8), 1129–1137. https://doi.org/10.1177/0954405413484015

Omar, M., & Soltan, H. (2020). A framework for welding process selection. *SN Applied Sciences*, *2*(364). https://doi.org/10.1007/s42452-020-2144-2

Omlor, M., Seitz, N., Butzmann, T., Petrich, T., Gräf, R., Hesse, A. C., & Dilger, K. (2023). Quality characteristics and analysis of input parameters on laser beam welding of hairpin windings in electric drives. *Welding in the World*, *67*(6), 1491–1508. https://doi.org/10.1007/s40194-023-01500-y

Prasad, R. V. V. S. V., Ambadas, P. R., Panda, S., Ansari, M. S. A., & Deepthi, K. (2023). Machine learning algorithms to visualize the weld quality and evaluation of health issues during the welding. *2023 International Conference on New Frontiers in Communication, Automation, Management and Security (ICCAMS)*. https://doi.org/10.1109/ICCAMS60113.2023.10525844

Rezende, C., Ferraresi, V. A., & Scotti, A. (2000). Quality and cost approach for welding process selection. *Journal of the Brazilian Society of Mechanical Sciences*, *22*(3), 389–398. https://doi.org/10.1590/S0100-73862000000300002

Salvador, D. C. (2023a). Advancements in welding techniques: a comprehensive review. *International Journal of Advanced Research in Science, Communication and Technology*, *3*(1), 1013–1018. https://doi.org/10.48175/ijarsct-11908

Salvador, D. C. (2023b). Comparative study of welding techniques for joining dissimilar metals. *International Journal of Advanced Research in Science, Communication and Technology*, *3*(1) 988–992. https://doi.org/10.48175/ijarsct-11903

Soltan, H., & Omar, M. (2022). A roadmap for selection of metal welding process: a review and proposals. *Welding in the World*, *66*(12), 2639–2675. https://doi.org/10.1007/s40194-022-01379-1

Thakur, A., Gebrelibanos, H., & Gabrey, T. (2019). Arc welding process selection through a quality and costs. *International Journal of Current Engineering and Technology*, *9*(03), 383-394. https://doi.org/10.14741/ijcet/v.9.3.6

Wardana, R. W., Warinsiriruk, E., & Joy-A-Ka, S. (2019). Selection of welding process for repairing shredder hammer by integrated data envelopment analysis (DEA) and P-robust technique. *MATEC Web of Conferences*, *269*, 04002. https://doi.org/10.1051/matecconf/201926904002

Weldero. (July 19, 2024). *Impacto de la soldadura en la calidad estructural: cómo influyen los distintos métodos de soldadura en la resistencia y la durabilidad*. https://weldero.com/es/guias/impacto-de-la-soldadura-en-la-calidad-estructural-como-influyen-los-distintos-metodos-de-soldadura-en-la-resistencia-y-la-durabilidad/

Wordofa, T. N., & Ramulu, P. J. (2023). Gas metal arc welding input parameters impacts on weld quality characteristics of steel materials a comprehensive exploration. *Manufacturing Technology*, *23*(3), 366–379. https://doi.org/10.21062/mft.2023.046

Zarovchatskaya, E. V., Misnik, A. E., & Averchenkov, O. E. (2024). Method for complex increase of welding production control efficiency based on swarm intelligence algorithms and evolutionary modeling. *Vestnik of Samara State Technical University. Technical Sciences Series*, *32*(1), 56–73. https://doi.org/10.14498/tech.2024.1.4