

Review of welding processes: Influence of operational parameters on microstructural and mechanical properties

Revisão dos processos de soldagem: Influência dos parâmetros operacionais nas propriedades microestruturais e mecânicas

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Abstract

Welding is one of the main processes for permanently joining metallic materials, being widely applied in industrial sectors such as civil construction, automotive, naval, and aerospace industries. With technological advancements, various welding processes have been developed, each presenting specific characteristics in terms of cost, productivity, joint quality, and applicability. In this context, understanding the particularities of each technique becomes fundamental for an appropriate selection according to project requirements. This work aims to

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conduct a literature review of the main types of welding, with emphasis on shielded metal arc welding (SMAW), MIG/MAG, TIG, submerged arc welding (SAW), as well as more advanced techniques such as laser and plasma welding. The methodology adopted consisted of analyzing scientific articles, books, and technical standards in the engineering field, seeking to identify the main advantages, limitations, and industrial applications of each process. The results obtained from the literature indicate that there is no universally superior welding process, with the choice depending on factors such as the type of material, operating conditions, cost involved, and required quality. Processes like MIG/MAG stand out for their high productivity, while TIG offers greater control and finish quality. On the other hand, technologies like laser welding offer high precision, but at higher costs. In conclusion, technical knowledge of different welding processes is essential to guarantee efficiency, quality, and economic viability in industrial applications.

Keywords: Welding Processes, Analysis of Operational, Thermal and Metallurgical Aspects, Review.

Resumo

A soldagem é um dos principais processos de união permanente de materiais metálicos, sendo amplamente aplicada em setores industriais como construção civil, indústria automobilística, naval e aeroespacial. Com o avanço tecnológico, diversos processos de soldagem foram desenvolvidos, cada um apresentando características específicas em termos de custo, produtividade, qualidade da junta e aplicabilidade. Nesse contexto, torna-se fundamental compreender as particularidades de cada técnica para uma seleção adequada conforme as exigências do projeto. O presente trabalho tem como objetivo realizar uma revisão bibliográfica dos principais tipos de soldagem, com ênfase nos processos por eletrodo revestido (SMAW), MIG/MAG, TIG, arco submerso (SAW), além de técnicas mais avançadas, como soldagem a laser e plasma. A metodologia adotada consistiu na análise de artigos científicos, livros e normas técnicas da área de engenharia, buscando identificar as principais vantagens, limitações e aplicações industriais de cada processo. Os resultados obtidos a partir da literatura indicam que não há um processo de soldagem universalmente superior, sendo a escolha dependente de fatores como o tipo de material, condições operacionais, custo envolvido e qualidade requerida. Processos como MIG/MAG destacam-se pela alta produtividade, enquanto o TIG apresenta maior controle e qualidade de acabamento. Por outro lado, tecnologias como a soldagem a laser oferecem elevada precisão, porém com custos mais elevados. Conclui-se que o conhecimento técnico dos diferentes processos de soldagem é essencial para garantir eficiência, qualidade e

viabilidade econômica nas aplicações industriais.

Palavras-Chave: Processos de Soldagem, Análise dos Aspectos Operacionais, Térmicos e Metalúrgicos, Revisão.

1 Introduction

Welding is one of the most important processes in the manufacturing and maintenance of metallic structures and is widely used in sectors such as civil construction, automotive, shipbuilding, and aerospace industries. This process enables the permanent joining of materials, ensuring mechanical strength and structural integrity of the manufactured components (Ilario, 2016; Marques, Modenesi, & Bracarense, 2017; Kou, 2017; Leite, 2024).

With the advancement of manufacturing technologies, several welding methods have been developed, including processes based on electric arc, gas, resistance, and more advanced techniques such as laser welding. These processes exhibit significant differences in terms of cost, efficiency, weld quality, and applicability, requiring careful selection according to the specific requirements of each application (Bernardes, 2018; Cary & Helzer, 2019; Kalpakjian & Schmid, 2020).

Furthermore, recent studies have highlighted the fundamental role of welding in modern industry, where it is applied in applications ranging from small-scale structures to large industrial systems. The evolution of welding technologies has contributed to increased productivity and improved weld quality (Pinheiro & Ramalho, 2023; Pimentel et al., 2024; Romano et al., 2025).

In this context, there is growing interest in improving welding processes, particularly regarding defect reduction, control of the heat-affected zone, and enhancement of production efficiency (Ferreira et al., 2018; Gomes & Rocha, 2021; Almeida et al., 2023). Studies indicate that different welding techniques, such as MIG/MAG and TIG, exhibit distinct performance depending on the operating conditions and materials employed (Silva & Santos, 2019; Oliveira et al., 2022; Costa et al., 2024). Therefore, this study aims to provide a literature review of the main welding processes, contributing to a comparative analysis and supporting the selection of the most suitable welding method for different industrial applications.

2 Literature Review

2.1 Fundamentals of Welding

Welding is defined as a permanent joining process for materials, primarily metals, through the application of heat, pressure, or both, with or without the use of filler material. This process is

widely employed in modern industry due to its efficiency and its ability to produce joints with high mechanical strength and structural integrity (Ilario, 2016; Kou, 2017; DebRoy et al., 2018).

During the welding process, the Heat-Affected Zone (HAZ) is formed, undergoing microstructural changes as a result of the imposed thermal cycle. These changes directly influence properties such as mechanical strength, hardness, and toughness, making the control of operational parameters essential (Davis, 2018; Kou, 2021; Oliveira et al., 2022).

Furthermore, factors such as the heat source, welding speed, base metal composition, and the use of filler metal directly affect the performance of the welded joint. Proper control of these parameters is crucial for minimizing defects and ensuring process quality in a wide range of industrial applications (DebRoy et al., 2018; Pimentel et al., 2024; Romano et al., 2025).

2.2 Classification of Welding Processes

Welding processes can be classified according to various criteria, the most common being based on the joining mechanism of the materials. In general, welding processes are categorized as either fusion welding or pressure welding (Figure 1), depending on whether melting of the base metal occurs during the joining process.

This classification is widely adopted in the technical literature because it facilitates the understanding of the different welding methods and their industrial applications (AWS, 2020; Weman, 2018; Lippold, 2015). In fusion welding, the base metal is heated above its melting temperature, forming a weld pool that solidifies upon cooling to produce the welded joint.

Figure 1 – Types of Welding



Source: Authors' own elaboration (2026).

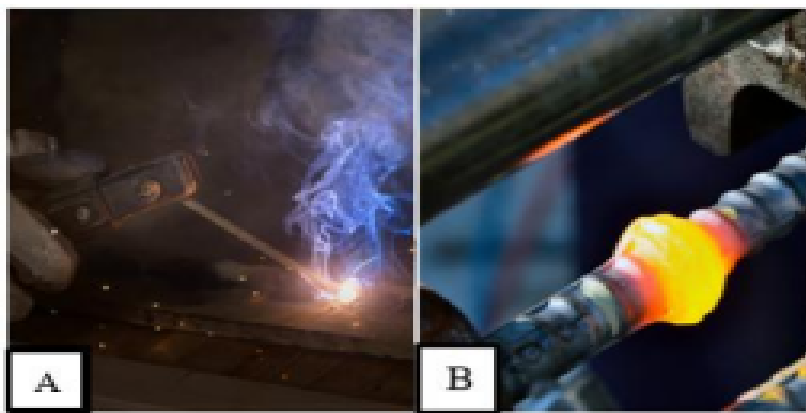
This group includes processes such as arc welding, laser welding, and plasma welding, which are widely employed in modern industry due to their versatility, efficiency, and ability to

join a wide range of metallic alloys (Figure 2A) (Kou, 2017; DebRoy et al., 2018; Steen & Mazumder, 2019). These processes are commonly applied in sectors such as automotive, aerospace, shipbuilding, and heavy manufacturing, where high productivity and reliable joint performance are essential. The continuous development of fusion welding technologies has further expanded their industrial applicability, enabling improved process control, automation, and weld quality.

In contrast, pressure welding is performed without significant melting of the base metal and is characterized by the application of mechanical force, with or without the addition of heat. In these processes, bonding occurs through intimate contact between the materials under pressure, promoting metallurgical joining while minimizing the thermal effects commonly associated with fusion welding.

Examples of pressure welding include resistance welding and friction welding, both of which are widely recognized for their low thermal distortion, high repeatability, and suitability for large-scale industrial production (Figure 2B) (Messler, 2004; Totten, 2006; Mishra & Ma, 2005). Additionally, these processes generally produce narrower heat-affected zones (HAZs) and lower residual stresses, making them particularly attractive for applications requiring dimensional accuracy and enhanced mechanical performance.

Figure 2 – A) Fusion welding (shielded metal arc welding); B) Pressure welding joining two reinforcing bars.



Source: Inpesolda, 2021

In addition to this classification, welding processes can also be categorized according to their level of automation, being classified as manual, semi-automatic, or fully automated. The degree of automation directly influences process productivity, weld quality, operational consistency, and manufacturing costs. Manual welding processes depend heavily on the skill and experience of the welder, whereas automated systems provide greater repeatability, precision, and

efficiency, particularly in high-volume industrial production. Consequently, the selection of an appropriate level of automation is an important factor in optimizing manufacturing performance and ensuring consistent weld quality (Groover, 2020; Cary & Helzer, 2019; Kalpakjian & Schmid, 2020).

2.3 Factors Influencing Welding Quality

The quality of a welded joint is directly influenced by a set of factors that interact throughout the welding process. Among the most important factors affecting the final performance of a weld are the heat source, welding speed, base metal characteristics, proper selection of consumables, operating conditions, and effective control of process parameters (Kou, 2017; DebRoy et al., 2018; Kalpakjian & Schmid, 2020). These variables influence not only the geometry of the weld bead but also the microstructural evolution, mechanical properties, and overall integrity of the welded joint.

Careful control of these factors is essential to minimize the occurrence of welding defects, such as porosity, lack of fusion, cracking, and excessive distortion, while ensuring the desired mechanical and metallurgical properties. Furthermore, the interaction between thermal, operational, and metallurgical variables plays a crucial role in determining the quality, reliability, and service performance of welded structures.

Figure 3 illustrates the main factors that influence weld quality, highlighting the relationship between thermal, operational, and metallurgical variables and their combined effect on the welding process.

Figure 3 – Main factors influencing the achievement of high-quality welds, highlighting the interaction between thermal, operational, and metallurgical variables.



Source: Adapted from DebRoy et al. (2018).

In addition to thermal parameters, the proper selection of consumables, such as electrodes, filler wires, and shielding gases, plays a fundamental role in arc stability and in protecting the weld pool from atmospheric contamination. The improper use of these elements may result in the formation of discontinuities such as porosity, slag inclusions, and cracks, compromising the integrity and performance of the welded joint (Marques, Modenesi, & Bracarense, 2017; Weman, 2018; Oliveira et al., 2022). Therefore, the compatibility between the consumables and the base metal must be carefully considered to ensure adequate metallurgical and mechanical properties in the final weld.

Another important factor relates to operating conditions, including joint preparation, welding position, and parameter control during process execution. Automated welding processes, such as MIG/MAG and submerged arc welding (SAW), provide greater repeatability, consistency, and process control, whereas manual processes, such as Shielded Metal Arc Welding (SMAW), are more susceptible to operational variations that may affect the final weld quality (Groover, 2020; Almeida et al., 2023; Romano et al., 2025). Consequently, operator skill and adherence to established welding procedures remain essential for achieving satisfactory results.

Additionally, the characteristics of the base metal, including its chemical composition, thickness, thermal conductivity, and metallurgical condition, significantly influence its behavior during welding. These factors affect heat distribution, cooling rates, microstructural transformations, and the formation of the Heat-Affected Zone (HAZ), thereby impacting the mechanical properties and service performance of the welded structure. For this reason, a thorough understanding of material properties and process variables is essential for ensuring weld

quality and structural reliability.

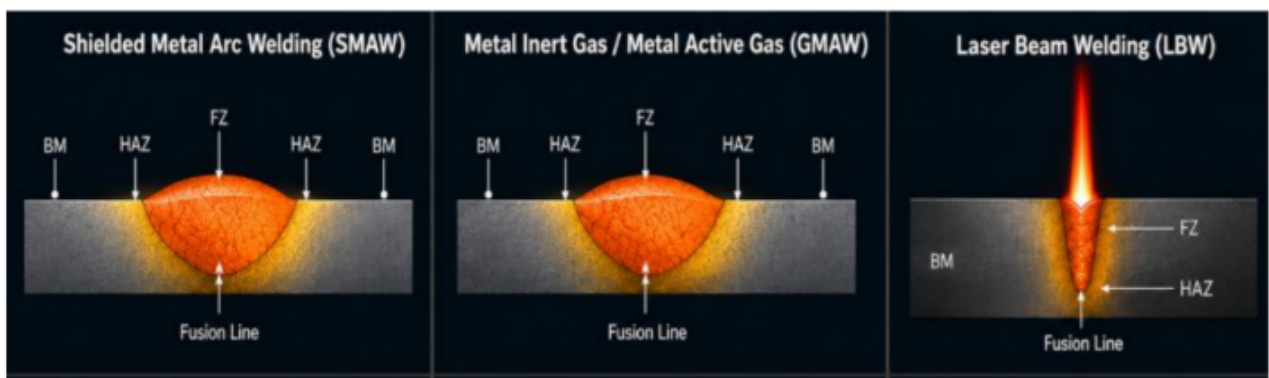
2.4 Welding Zones and Their Differences Among Welding Processes

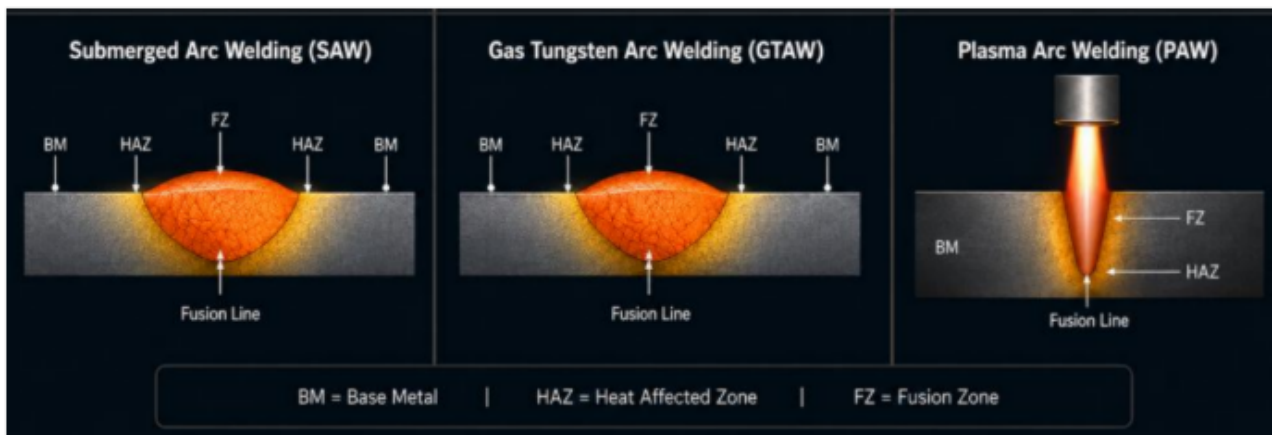
Weld zones correspond to the distinct regions formed within a material after the welding process, each exhibiting specific thermal, microstructural, and mechanical characteristics determined by the thermal cycle imposed during welding (Leite, 2024).

As illustrated in Figure 4, all welding processes produce the same fundamental regions: the Base Metal (BM), the Heat-Affected Zone (HAZ), and the Fusion Zone (FZ). However, the characteristics of these regions vary significantly depending on the heat input and thermal cycle associated with the welding process.

The extent and properties of each zone are directly influenced by welding parameters such as current, voltage, travel speed, and cooling rate. These factors govern the thermal history of the material and consequently affect microstructural transformations, residual stress development, and the mechanical performance of the welded joint. Therefore, understanding the formation and characteristics of the weld zones is essential for evaluating weld quality and predicting the in service behavior of welded structures.

Figure 4 – Welding processes exhibit the same fundamental regions: base metal (BM), heat affected zone (HAZ), and fusion zone (FZ).





Source: Adapted from Varbai et al. (2025).

The Heat-Affected Zone (HAZ) is the region of the material that does not undergo melting but experiences microstructural and property changes as a result of the heating and subsequent cooling cycles associated with the welding process. According to Weman (2003), the extent of the HAZ is directly dependent on the amount of heat introduced during welding, making heat input one of the primary factors controlling the characteristics of this region.

According to Wang et al. (2025), increasing heat input promotes grain growth and enlarges the width of the HAZ, which may adversely affect mechanical properties such as toughness and strength. Similarly, Varbai et al. (2025) reported that variations in welding energy significantly influence microstructural evolution and susceptibility to failure, particularly in advanced metallic alloys. These findings emphasize the importance of controlling heat input to achieve the desired balance between productivity and weld performance.

Consequently, welding processes characterized by high heat input, such as Submerged Arc Welding (SAW) and Shielded Metal Arc Welding (SMAW), tend to produce wider and more heterogeneous HAZs. In contrast, processes with lower heat input and greater thermal control, such as Gas Tungsten Arc Welding (GTAW/TIG), generally result in narrower HAZs and finer microstructures. The reduced thermal exposure associated with these processes contributes to improved preservation of the base metal properties and enhanced weld quality.

Within this context, Gas Metal Arc Welding (GMAW/MIG-MAG) exhibits an intermediate behavior, combining high productivity with relatively effective control of microstructural development, depending on the selected welding parameters. As a result, GMAW has become one of the most widely used welding processes in industrial applications, offering a balance between deposition rate, weld quality, and manufacturing efficiency.

On the other hand, high-energy-density processes such as Laser Beam Welding (LBW) and Plasma Arc Welding (PAW) exhibit distinct thermal characteristics. According to Zhao et al. (2025), laser welding is characterized by a highly concentrated energy beam that produces a narrow and deep fusion zone associated with extremely high cooling rates. These conditions promote refined microstructures and reduced phase segregation. Furthermore, Narayan et al. (2025) reported that the high energy density of the laser significantly reduces the size of the HAZ when compared with conventional welding processes.

Similarly, Plasma Arc Welding (PAW) provides high energy density and superior arc stability, resulting in excellent penetration and precise thermal control. However, due to the characteristics of the plasma arc, heat distribution is slightly broader than that observed in laser welding, leading to a somewhat larger HAZ, although still considerably smaller than those produced by conventional arc welding processes.

Therefore, it can be concluded that the differences among the weld regions are not related to their fundamental nature, but rather to their dimensions, morphology, and microstructural response.

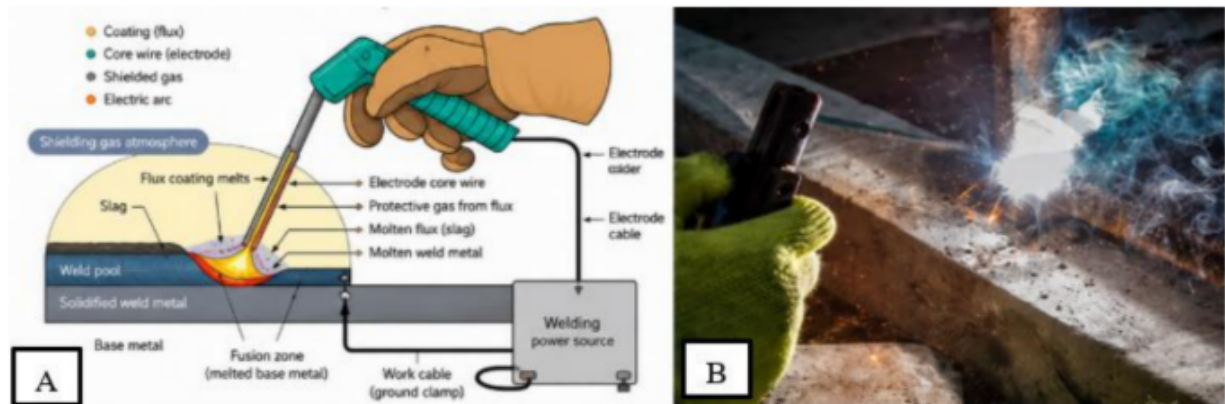
2.5 Shielded Metal Arc Welding (SMAW)

Shielded Metal Arc Welding (SMAW) is one of the most traditional and widely used welding processes in the metalworking industry. In this process, the heat required for melting the materials is generated by an electric arc established between a coated consumable electrode and the workpiece, resulting in the formation of the welded joint, as illustrated in Figures 5A and 5B (Ilario, 2016; Weman, 2018; Cary & Helzer, 2019).

SMAW is widely recognized for its versatility, portability, and relatively low equipment cost, making it suitable for a broad range of applications, including construction, maintenance, repair operations, and field welding. Furthermore, the process can be applied in various welding positions and is capable of joining different types of ferrous and non-ferrous alloys.

During welding, the electrode coating decomposes under the action of the arc, generating shielding gases and forming a slag layer that protects the molten weld pool from atmospheric contamination. This protection is essential for preventing oxidation and ensuring the metallurgical quality of the welded joint. After solidification, the slag must be removed to allow inspection and, when necessary, the deposition of subsequent weld passes.

Figure 5 – A) Schematic representation of the SMAW welding process; B) Weld produced by the Shielded Metal Arc Welding (SMAW) process.



Source: Adapted from Weman (2018). Source: Adapted from Inpesolda (2021).

The electrode coating in Shielded Metal Arc Welding (SMAW) plays a crucial role by protecting the weld pool from atmospheric contamination, stabilizing the arc, and generating a slag layer that shields the molten metal during solidification. These functions make SMAW highly suitable for field conditions and harsh environments, where portability, operational flexibility, and reliability are essential (Marques, Modenesi, & Bracarense, 2017; Kou, 2017; Pimentel et al., 2024).

In addition to these advantages, SMAW is characterized by its simplicity of operation, low equipment cost, and wide versatility. It can be applied in various industrial contexts, including construction, maintenance, repair, and fabrication, and does not require complex infrastructure. Its adaptability across different working conditions contributes to its extensive use in practical welding applications.

Another important feature of SMAW is its ability to be performed in all standard welding positions, which enhances its flexibility. The flat position (1G/1F) is the simplest, allowing better control of the molten pool, while the horizontal position (2G/2F) demands more skill due to the influence of gravity on the weld metal flow. The vertical position (3G/3F) requires careful control of heat input and technique to ensure proper penetration and weld quality.

Finally, the overhead position (4G/4F) is the most demanding configuration, as welding is performed above the operator, making molten metal control more difficult and increasing spatter formation. Because gravity acts directly against the weld pool in this position, it requires a higher level of skill and experience to achieve acceptable results, highlighting the progressive increase in difficulty across welding positions.

Figure 6 – Shielded Metal Arc Welding (SMAW) Welding Positions.



Source: Authors' own elaboration (2026).

However, despite its numerous advantages, the SMAW process also presents certain limitations, including lower productivity when compared to semi-automatic and automated welding processes, the need for frequent electrode replacement, and a high dependence on operator skill and experience (Oliveira et al., 2022; Costa et al., 2024; Romano et al., 2025). In addition, slag removal between welding passes increases processing time and may affect overall production efficiency, particularly in large-scale manufacturing applications.

Due to these characteristics, Shielded Metal Arc Welding remains widely employed in maintenance, repair, and field construction activities, especially in locations where more automated welding processes are impractical or economically unfeasible. Its portability and relatively simple equipment requirements make it particularly suitable for remote environments and situations involving difficult access.

Despite the continuous development of more advanced welding technologies, SMAW continues to play an important role in modern industry because of its robustness, versatility, and ease of application. Furthermore, the process is capable of producing high-quality welds under a wide range of operating conditions, ensuring its continued relevance in sectors such as construction, infrastructure, shipbuilding, and industrial maintenance (Silva & Santos, 2019;

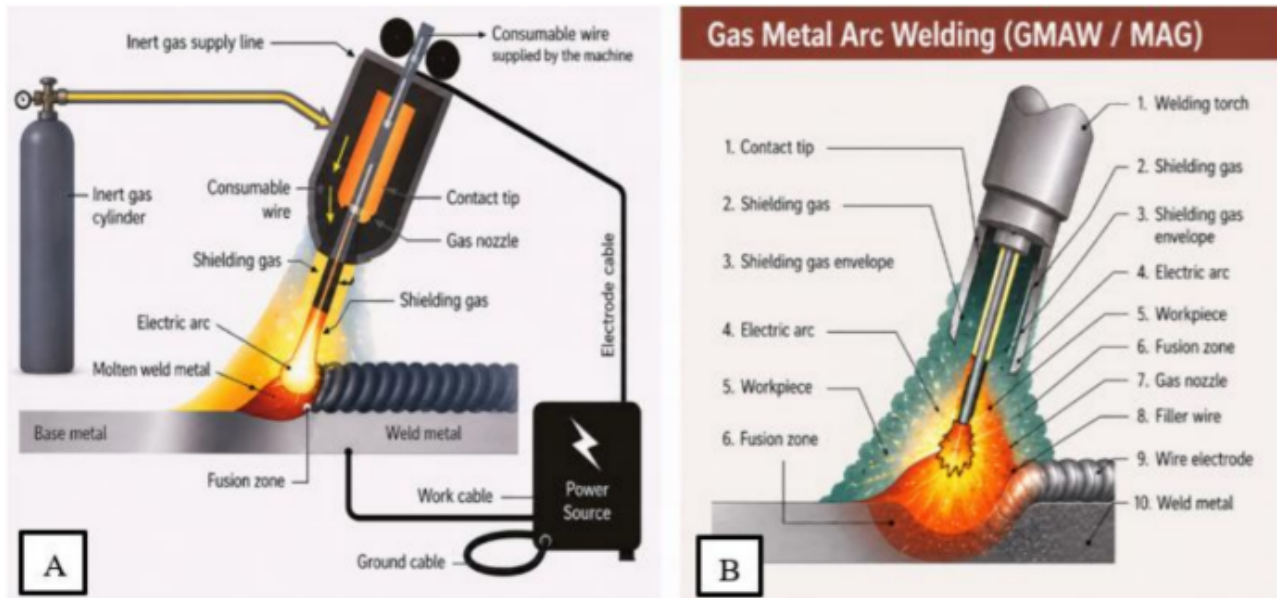
2.6 MIG/MAG and TIG Welding

Gas Metal Arc Welding (GMAW), commonly known as Metal Inert Gas (MIG) and Metal Active Gas (MAG) welding, is an arc welding process that employs a continuously fed consumable wire electrode protected by a shielding gas, which may be either inert (MIG) or active (MAG), as illustrated in Figures 7A and 7B. Due to its high deposition rate, productivity, and ease of automation, this process has become one of the most widely used welding methods in large-scale industrial applications (Weman, 2018; Cary & Helzer, 2019; Kalpakjian & Schmid, 2020).

A key distinction between MIG and MAG welding lies in the type of shielding gas employed. MIG welding utilizes inert gases, such as argon or helium, which do not react significantly with the molten metal. In contrast, MAG welding uses active gases, such as carbon dioxide or gas mixtures containing carbon dioxide and argon, which actively participate in the welding process. The selection of the shielding gas directly influences arc stability, penetration characteristics, metal transfer mode, and weld bead geometry, making the process highly versatile for a wide variety of materials and thicknesses (Kou, 2017; DebRoy et al., 2018; Pimentel et al., 2024).

The continuous wire feeding system eliminates the need for frequent electrode replacement, contributing to higher productivity and greater operational efficiency when compared to processes such as Shielded Metal Arc Welding (SMAW). Furthermore, the process can be readily integrated with automated and robotic welding systems, allowing improved process consistency, repeatability, and weld quality in modern manufacturing environments.

Figure 7 – A) Schematic representation of the MIG (Metal Inert Gas) welding process, highlighting continuous wire feeding and inert gas shielding; B) Schematic representation of the MAG (Metal Active Gas) welding process, showing the use of active shielding gas and metal transfer.



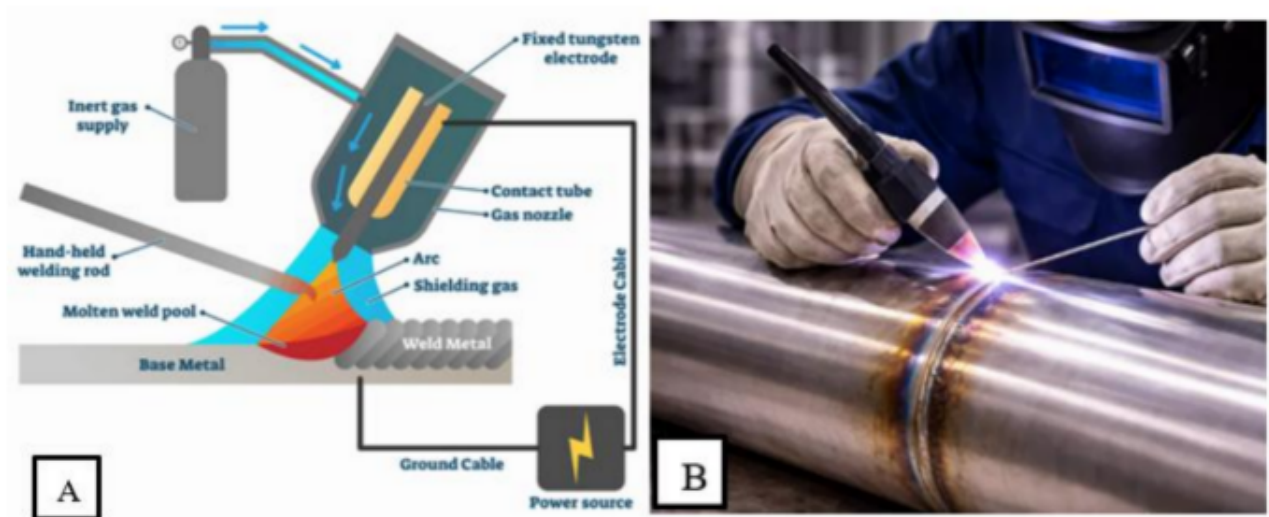
Source: Adapted from Weman (2018).

Among the main advantages of the MIG/MAG process are its high deposition rate, increased welding speed, and ability to produce high-quality welded joints, particularly in controlled environments. These characteristics contribute to improved productivity and make the process especially attractive for large-scale manufacturing applications. However, MIG/MAG welding also presents certain limitations, including sensitivity to air drafts, which may compromise shielding gas effectiveness, and a higher initial equipment cost compared with some conventional welding processes. These factors may restrict its use under specific operating conditions (Oliveira et al., 2022; Costa et al., 2024; Romano et al., 2025).

In contrast, Tungsten Inert Gas (TIG) welding, also known as Gas Tungsten Arc Welding (GTAW), utilizes a non-consumable tungsten electrode and an inert shielding gas to protect the weld pool. This process provides excellent control of the welding operation and produces welds with superior surface finish and high metallurgical quality. As illustrated in Figures 8A and 8B, TIG welding is widely employed in applications that require high precision, excellent weld appearance, and superior joint integrity (Marques, Modenesi, & Bracarense, 2017; Davis, 2018; Kou, 2021).

Because the tungsten electrode is not consumed during welding, filler metal can be added independently when required, allowing greater control over heat input and weld bead formation. This characteristic makes GTAW particularly suitable for welding thin sections and materials that are sensitive to thermal effects, such as stainless steels, aluminum alloys, titanium alloys, and other high-performance materials commonly used in aerospace, chemical, and energy industries.

Figure 8 – A) Schematic representation of the TIG (Tungsten Inert Gas) welding process; B) Application of the TIG welding process on an industrial pipeline.

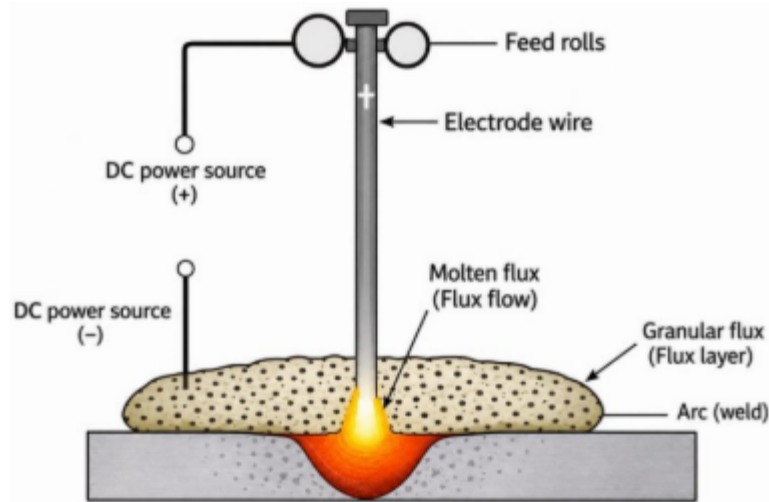


Source: Adapted from Davis (2018). Source: Alusolda (2022).

TIG welding offers several advantages, including precise arc control, reduced spatter generation, and high metallurgical weld quality. However, it generally exhibits lower productivity when compared to MIG/MAG welding and requires a higher level of operator skill, making it more suitable for welding thin materials and for critical applications where weld quality is of primary importance (Silva & Santos, 2019; Almeida et al., 2023; Gomes & Rocha, 2021).

2.7 Submerged Arc Welding (SAW), Laser Welding, and Plasma Welding Submerged Arc Welding (SAW) is an automatic or semi-automatic welding process in which an electric arc is established between a consumable electrode and the workpiece, remaining submerged beneath a layer of granular flux. This flux protects the weld pool from atmospheric contamination, stabilizes the arc, and contributes to weld quality, as illustrated in Figure 9 (Weman, 2018; Cary & Helzer, 2019; Kalpakjian & Schmid, 2020).

Figure 9 – Schematic representation of the Submerged Arc Welding (SAW) process.



Source: Adapted from Weman (2018).

The SAW process offers several advantages, including a high deposition rate, elevated productivity, and excellent weld quality. As a result, it is widely used in the fabrication of large scale structures, such as pressure vessels, pipelines, and heavy industrial components, as illustrated in Figure 10 (Kou, 2017; DebRoy et al., 2018).

Figure 10 – Submerged Arc Welding (SAW) being used to join pipelines and industrial components.

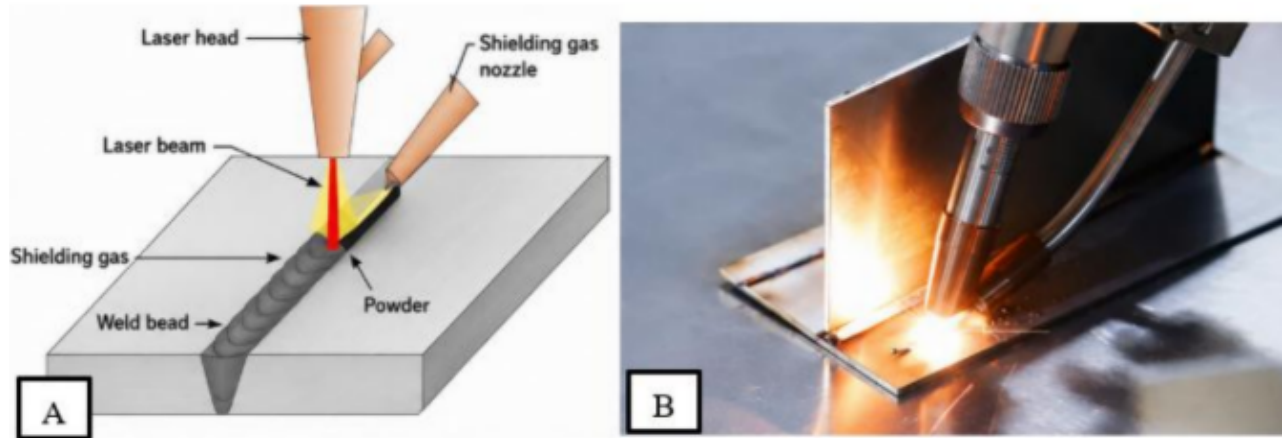


Source: Alusolda, 2021

However, its application is limited to flat or horizontal positions, and it requires greater operational control (Steen & Mazumder, 2019). Laser welding is considered an advanced technology that uses a highly concentrated high-energy beam to promote localized fusion of the materials, as shown in Figures 11A and 11B. This process allows high precision, low thermal

distortion, and a small Heat-Affected Zone (HAZ), being widely used in high-technology industries such as aerospace and electronics (Steen & Mazumder, 2019; Davis, 2018; Pimentel et al., 2024).

Figure 11 – A) Schematic representation of the laser welding process; B) Laser welding being performed on an aluminum plate.



Source: Adapted from STEEN; MAZUMDER (2019).

Similarly, Plasma Arc Welding (PAW) uses a constricted electric arc that generates a high temperature plasma jet, providing greater control and process stability compared to conventional techniques. This method offers high weld quality and can be applied to materials of different thicknesses, making it suitable for applications that require precision and high performance (Silva & Santos, 2019; Oliveira et al., 2022; Costa et al., 2024).

Despite its technical advantages, both laser and plasma welding processes involve high implementation and operational costs, which may limit their large-scale application. Nevertheless, recent studies indicate that these technologies have been gaining increasing industrial relevance due to the continuous demand for higher efficiency, automation, and improved weld quality in manufacturing processes (Gomes & Rocha, 2021; Almeida et al., 2023; Romano et al., 2025).

2.8 Microstructure and Mechanical Strength in Welding

The microstructure of welded joints is strongly influenced by the thermal cycle imposed during the welding process, especially in the Heat-Affected Zone (HAZ) and in the weld metal. Temperature variation and cooling rate promote phase transformations and grain growth, which directly affect the mechanical properties of the material. Processes with higher heat input tend to produce coarser microstructures, whereas processes with lower heat input favor finer and more

refined structures (Kou, 2017; DebRoy et al., 2018; Kalpakjian & Schmid, 2020).

In processes such as MIG/MAG and Submerged Arc Welding (SAW), the high heat input results in a larger HAZ and longer exposure time at elevated temperatures, promoting grain growth and potentially reducing mechanical strength and toughness. In contrast, TIG welding provides better control of the thermal cycle, resulting in more homogeneous microstructures and less degradation of mechanical properties (Cary & Helzer, 2019; Weman, 2018; Oliveira et al., 2022).

Advanced processes such as Laser Beam Welding (LBW) and Plasma Arc Welding (PAW) are characterized by high energy density and low overall heat input, leading to high cooling rates. This behavior promotes microstructural refinement and, consequently, increases the hardness and mechanical strength of welded joints, as well as a reduction in the size of the Heat-Affected Zone (Steen & Mazumder, 2019; Kou, 2021; Costa et al., 2024).

Furthermore, the mechanical strength of welded joints is directly related to the presence of discontinuities and the integrity of the resulting microstructure. Defects such as porosity, cracks, and inclusions may act as stress concentrators, significantly reducing the mechanical performance of the joint.

Therefore, proper control of welding parameters is essential to ensure adequate mechanical properties and structural reliability (Marques, Modenesi, & Bracarense, 2017; Silva & Santos, 2019; Gomes & Rocha, 2021).

3 Methodology

The present study is characterized as a qualitative research based on a bibliographic review, aiming to analyze and synthesize information on the main welding processes reported in the scientific literature. This approach enables the consolidation of existing knowledge, contributing to a theoretical and comparative understanding of different welding methods.

Data collection was carried out through a survey of academic and scientific databases, including national and international journals, technical books, and welding standards. Publications from 2016 to 2026 were prioritized in order to ensure the currency of the information, without disregarding classical references considered essential to the theoretical foundation.

As inclusion criteria, studies directly addressing welding processes, their characteristics, applications, advantages, and limitations were selected. Studies that were not directly related to the topic or that did not meet adequate scientific rigor were excluded.

Data analysis was performed using a descriptive and comparative approach, allowing the identification of similarities and differences among the welding processes studied, such as

SMAW, MIG/MAG, TIG, and SAW, as well as advanced techniques such as laser beam welding and plasma arc welding. In this way, the study aims to provide a broad and critical overview of the application of these processes in industry.

4 Results and Discussion

The literature review allowed the identification that different welding processes exhibit distinct behaviors as a function of thermal and operational parameters, directly influencing microstructure, mechanical properties, and weld joint quality. In general, it was observed that the selection of a welding process is related to the balance between productivity, thermal control, and final weld performance (Kou, 2017; DebRoy et al., 2018; Kalpakjian & Schmid, 2020).

From a thermal perspective, heat input has proven to be one of the main factors influencing the formation of the fusion zone and the Heat-Affected Zone (HAZ). Processes such as MIG/MAG and Submerged Arc Welding (SAW) exhibit high heat input, promoting greater penetration but resulting in wider HAZs and more pronounced microstructural changes.

In contrast, processes such as TIG welding and Laser Beam Welding (LBW) present lower overall heat input, allowing better microstructural control and reduced thermal distortion (Cary & Helzer, 2019; Steen & Mazumder, 2019; Pimentel et al., 2024). Based on this analysis, it becomes relevant to technically compare the main welding processes according to their operational and thermal parameters, as presented in Table 1.

Table 1 – Technical Comparison of Welding Processes

Process	Heat Input	Deposition Rate	Penetration	Efficiency
SMAW	Medium	Low	Medium	Low
MIG/MAG	High	High	Medium to High	High
TIG	Low	Very Low	Low	Medium
SAW	Very High	Very High	High	Very High
Laser	Very Low	Medium	Very High	High
Plasma	Low to Medium	Medium	High	High

2019; Pimentel et al., 2024

Deposition rate was also identified as a key parameter in the analysis of welding processes. MIG/MAG and Submerged Arc Welding (SAW) exhibit high deposition rates and

greater production efficiency, making them widely used in large-scale industrial applications. In contrast, SMAW presents a lower deposition rate due to frequent electrode replacement, while TIG welding shows low productivity but provides greater process control (Weman, 2018; Oliveira et al., 2022; Romano et al., 2025).

From a practical perspective, it can be observed that the choice between higher productivity and greater process control depends directly on the application requirements. In industrial environments, productivity is generally prioritized, whereas in critical applications, weld quality becomes the dominant factor. In addition to technical aspects, welding process cost also plays a fundamental role in industrial decision-making, directly influencing the feasibility of each method.

Table 2 shows that processes such as SMAW present low implementation and operational costs, while more advanced technologies, such as laser and plasma welding, involve significantly higher costs in terms of both equipment and maintenance. Therefore, it can be concluded that the selection of a welding process involves a trade-off between cost and performance, requiring careful evaluation of the specific requirements of each application.

Table 2 – Cost Comparison of Welding Processes

Process	Equipment Cost	Operating Cost	Maintenance Cost	Total Cost
SMAW	Low	Low	Low	Low
MIG/MAG	Medium	Medium	Medium	Medium
TIG	Medium	High	Medium	Medium to High
SAW	High	Medium	High	High
Laser	Very High	High	Very High	Very High
Plasma	High	High	High	High

Source: Kou, 2017

Regarding penetration, it was observed that high-energy density processes, such as laser beam welding (LBW) and plasma arc welding (PAW), are capable of producing welds with high penetration depth and narrow weld bead width, thereby reducing thermal influence on adjacent regions (Davis, 2018; Kou, 2021; Costa et al., 2024).

Process efficiency is directly related to the amount of energy effectively used for material fusion. Automated processes, such as MIG/MAG and SAW, exhibit higher energy efficiency and better repeatability, whereas manual processes, such as SMAW, show greater operational

variability (Groover, 2020; Almeida et al., 2023; Romano et al., 2025).

From a metallurgical standpoint, the thermal cycle directly influences phase formation and grain growth in the HAZ. Processes with higher heat input tend to promote coarser microstructures, while those with lower heat input favor finer microstructures, affecting properties such as hardness and mechanical strength (Kou, 2017; Oliveira et al., 2022; Pimentel et al., 2024).

In addition, the occurrence of discontinuities such as porosity, cracks, and slag inclusions is associated with inadequate control of welding parameters and inappropriate process selection (Marques, Modenesi, & Bracarense, 2017; Silva & Santos, 2019; Gomes & Rocha, 2021). In general, it can be concluded that welding process selection must consider an integrated analysis of thermal, operational, metallurgical, and economic parameters. An inappropriate choice may compromise not only joint quality but also process feasibility and application safety.

5 Conclusion

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