

Energy Consumption Analysis of Welding Techniques: A Comparative Review

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Abstract: The quest for energy efficiency has become a central concern in contemporary industrial practices; and welding technologies, integral to many industries, are no exception. This technical paper comprehensively examines the energy consumption profiles of various welding techniques utilized across diverse sectors. This research explores the intricate interplay between energy efficiency, welding methods, and their applications through an extensive literature review, meticulous comparative analyses, and real-world case studies. Factors influencing energy consumption, including material properties, process parameters, joint design, and equipment efficiency, are scrutinized. In addition, energy-efficient strategies and innovations that hold promise for the future are discussed. By shedding light on the energy consumption trends of various welding techniques, this paper seeks to empower industries, engineers, and policymakers with valuable insights and recommendations for fostering sustainable, cost-effective, and environmentally responsible welding practices. It underscores the pivotal role that energy-efficient welding can play in shaping the future of manufacturing and infrastructure development.

Keywords: Welding Energy Efficiency; Energy consumption in welding; Welding Techniques; Sustainability

1. Introduction

Welding is a crucial part of many industries, connecting raw materials to create the things we use daily. Managing energy use in welding techniques is significant because it touches upon key aspects of modern industry, sustainability, and taking care of the environment. But here's the catch: welding consumes a lot of energy. This balance between being important for industry and using lots of energy highlights the urgent need to examine and improve the energy efficiency of welding methods.

Welding is used in areas like manufacturing and building, which are significant energy users worldwide. As the world shifts towards more environmentally friendly and sustainable practices, welding must align with these goals. Because inefficient energy use in welding leads to higher costs, more environmental impact, and greater use of non-renewable energy sources. Plus, by making welding more energy-efficient, we can help reduce pollution and save precious natural resources.

The importance of making welding techniques more energy-efficient is evident. It's not just about saving money and energy; it's about being kind to the planet and using resources wisely. As industries, engineers, and decision-makers look for ways to

produce things efficiently while being environmentally friendly, energy-efficient welding techniques become a key part of the solution. By figuring out how to use less energy in welding, we can make things in a way that respects the environment and helps us all have a better, more sustainable future.

Welding, which dates back hundreds of years, has played a pivotal role in shaping modern industries. Its significance is paramount across various sectors, including manufacturing, construction, automotive, aerospace, energy, etc.

In manufacturing, welding is essential for producing various products, from machinery and appliances to consumer goods. In construction, it is indispensable for creating infrastructure, bridges, buildings, and other essential structures. The automotive industry relies on welding to assemble vehicles with strong and secure joints. The aerospace sector benefits from the precision and strength of welding in crafting aircraft components.

In the energy sector, where it is used for constructing pipelines, nuclear reactors, and oil platforms. Moreover, it finds application in art, enabling artists to create intricate sculptures and innovative designs. As a foundation of industrial processes, welding's significance is universal and indispensable, making it a key player in the development and advancement of modern civilization.

The need to review energy consumption in different welding techniques is of paramount importance in today's context. With growing concerns about resource conservation, environmental sustainability, and the efficiency of industrial processes, optimizing energy use in welding becomes a strategic imperative. The comparison between FCAW and SMAW processes was carried out by Silva et al. within the same welding energy levels for each one (high and low) and for the welding parameters recommended by the consumables manufacturer for each process (electrode diameter, current, voltage, polarity and gas) [1]. Sproesser et al. [2] evaluated GTAW with TGTAW with respect to energy efficiency. Electricity consumption is reduced by more than 20 % using the high power TGTAW process.

Energy consumption is closely related to the energy flows of the GMAW process, which are described in detail in the literature [3-10]. Among all efficiency indicators presented, effective efficiency has the biggest influence on the energy consumption of GMAW. This is because it determines the relative amount of energy that can be used for melting the wire and the base material. In [5] and [8], the influence of several process parameters and the material transfer mode is studied. Bosworth [5] found that for the same deposition rate, pulsed instead of non-pulsed welding demanded a lower process power, which favors pulsed welding in terms of energy efficiency. Haelsig et al. [8] observed a higher effective efficiency for TGTAW in contrast to Standard GMAW and thus indicated an increased energy efficiency of TGTAW.

This review article discusses about the energy consumption in various welding processes, parameters influencing the welding efficiency, and innovative strategies to align the welding sector with contemporary demands for responsible energy utilization and sustainable practices.

2. Methods and Materials

2.1 Energy Efficiency of Welding Processes

Until recently, among the criteria for selection of welding process, foremost has been the need for better quality of welds to maximize the performance of welds in service or higher productivity to bring down the cost and cycle time for making the welds. The energy efficiency of the process as one of the criteria for process selection is now receiving greater attention. There have been many attempts to evaluate the energy efficiency of welding processes. Most of these consider only the energy necessary to produce the weld. They do not reflect the total energy requirements of a welding process accurately. So to compare the energy efficiency of each process, it is necessary to consider energy consumption in total. Abnave [11] performed the comparative study on the basis of energy consumption as shown in Table 2. The

primary energy comprises the energy required for heating the material to produce a satisfactory weld and the secondary is the energy required for services and auxiliary equipment.

Table 2. Comparison of welding processes on the basis of total energy consumption for preparing 12 mm AA6061 weldment.

Welding Process	Primary Energy (KJ)	Secondary Energy (KJ)	Total Energy (KJ)
MMA	1420	1278	2698
GMAW	1280	277	1557
SAW	1450	864	2314
LW	120	4268	4388
EBW	120	5283	5403
FSW	1100	347	1447

Figure 1 shows the total energy used in various welding processes. It depicts that the total energy consumption for friction stir welding is the lowest among the other welding processes.

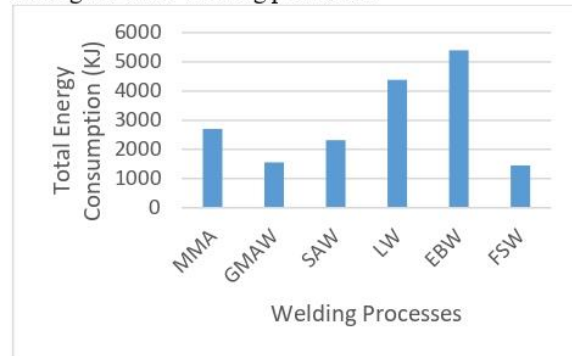


Fig. 1: Comparative analysis of welding processes based on total energy consumption

2.2 Energy Consumption Metrics

Measuring energy consumption in welding processes is essential for evaluating efficiency and optimizing resource utilization. Several metrics and units are commonly used to quantify energy consumption in welding, and they help in comparing and improving the energy efficiency of different processes. The primary metrics and units include:

Energy input represents the total amount of energy used during the welding process. It is typically measured in Joules (J) or Watt-hours (Wh). Energy input accounts for the electrical energy supplied to the welding equipment, including arc heating and any auxiliary systems like cooling. Heat input is a critical metric for assessing the thermal energy transferred to the workpiece per unit length (in welding) or unit area (in surfacing or cladding). It is often expressed in Joules per millimeter (J/mm) for welding processes like arc welding. Reducing heat input can lead to improved energy efficiency and reduced heat-affected zones. Efficiency measures the ratio of useful welding

energy to the total energy input. It is expressed as a percentage and helps assess how effectively the energy input is converted into useful welding heat. Higher efficiency indicates less energy waste.

Specific energy quantifies the energy required to melt or weld a unit mass of material. It is often measured in Joules per gram (J/g) or Joules per kilogram (J/kg). Lower specific energy values indicate more efficient energy usage. Welding Speed (millimeters per second or meters per minute): Welding speed measures how quickly the welding process progresses. Higher welding speeds may lead to improved energy efficiency, as the energy is applied over a shorter time period. Kilowatt (kW): Kilowatts are often used to measure the power input to welding equipment. This metric is essential for calculating energy consumption when considering the duration of welding. Energy input in kilowatt-hours (kWh) can be determined by multiplying the power in kilowatts by the welding time in hours.

2.3 Factors Affecting Energy Consumption

Several factors exert a profound influence on the energy consumption in welding processes. These include the specific welding method employed, the material properties, joint design, and process parameters. The efficiency of the welding equipment and the choice of consumable materials, such as electrodes or filler wires, also significantly impact energy usage. Furthermore, the welding speed, arc stability, and shielding gas management influence the overall energy efficiency of the process. The welding environment, including ambient conditions and the welding position, can introduce variations in heat transfer and energy consumption. By carefully considering and optimizing these factors, welders and engineers can not only reduce energy consumption but also enhance the sustainability and cost-effectiveness of their welding operations.

3. Results and Discussion

3.1 Comparative Analysis

A comprehensive comparison of welding processes in terms of energy efficiency is a tedious task due to the multitude of variables involved. So, a qualitative comparison is given for the welding processes with the factors affecting the welding efficiency (Table 1). This table provides a general overview of energy efficiency for different welding processes, but the actual efficiency in practice can vary based on specific applications and process optimization. When selecting a welding process for a particular application, it's essential to consider various factors and conduct a detailed analysis to determine the most energy-efficient option.

Table 1. Comparison of welding processes based on

energy efficiency

Welding Process	Energy Efficiency	Factors Influencing Efficiency
Gas Metal Arc Welding (GMAW - MIG)	Moderate to High	Equipment, consumable type, shielding gas, process parameters
Gas Tungsten Arc Welding (GTAW - TIG)	High	Precision, control, process parameters
Shielded Metal Arc Welding (SMAW - Stick)	Moderate	Electrode selection, process parameters
Submerged Arc Welding (SAW)	Moderate to High	Application, electrode type, process parameters
Friction Stir Welding (FSW)	High	Solid-state process, minimal heat input
Laser Beam Welding (LBW)	High	Precise control, minimal heat-affected zone
Electron Beam Welding (EBW)	High	Focused electron beam, vacuum environment
Hybrid Welding	Variable	Dependent on hybrid process combination and optimization
Resistance Welding	High	Localized heat application, minimal heat loss
Oxy-Fuel Welding	Moderate	Fuel and oxygen efficiency, heat input

3.2 Energy Efficiency Improvement Strategies

In the realm of welding processes, a series of energy efficiency improvement strategies and methods [12] have emerged to conserve energy resources and enhance the overall sustainability of operations. One key approach involves optimizing process parameters, such as voltage, current, and travel speed. For example, in Gas Metal Arc Welding (GMAW), precisely controlling these parameters not only ensures high-quality welds but also minimizes energy consumption. Another strategy lies in the selection of energy-efficient welding methods and equipment. For instance, advanced inverter-based welding machines are designed to reduce energy waste compared to older models. High-efficiency welding power sources provide better electrical efficiency and an improved power factor (the ratio of real working power to apparent power being provided by the utility). In high-efficiency welding, power to the transformer is shut off during system idling, and cooling fans only run

when needed, avoiding continuous electrical consumption. These new power sources provide 10 to 40% energy savings over older units.

In addition, innovative techniques like hybrid welding combine the strengths of different welding processes to maximize efficiency. In hybrid welding, a process like Gas Tungsten Arc Welding (GTAW) is complemented with a laser or electron beam. This combination not only improves energy efficiency but also delivers superior results in applications like aerospace component manufacturing. Efficient shielding gas management, as seen in applications like Gas Shielded Metal Arc Welding (GMAW), is another essential strategy. Precisely controlling the type and flow rate of shielding gases not only protects the weld from atmospheric contamination but also contributes to energy savings. Furthermore, judiciously employing preheating and post-weld heat treatment techniques is vital for certain applications. These methods help optimize energy usage, particularly in projects where high weld quality is essential, such as in the construction of pressure vessels and pipelines.

4. Conclusion

The following conclusions can be drawn based on this literature review:

- Based on the total energy consumed, friction stir welding is recommended as a cost-effective, environment-friendly welding process for Al alloy weldments.
- By embracing these energy efficiency improvement strategies, welders and industries can reduce energy consumption, cut operational costs, and minimize their environmental footprint while still achieving high-quality welds for a sustainable and cost-effective future.

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