Sustainability assessment of welding processes: a review

Elisaveta Doncheva[a], Jelena Djokikj[a], Nikola Avramov[a], Martin Petreski[a], Aleksandra Krstevska[a]

University of ss.Cyril and Methodius, Faculty of Mechanical engineering – Skopje, Skopje, North Macedonia[a],

elisaveta.doncheva@mf.edu.mk[a], jelena.djokich@mf.edu.mk[a], nikola.avramov@mf.edu.mk[a], martin.petreski@mf.edu.mk[a], aleksandra.krstevska@mf.edu.mk[a]

Abstract
Over the past several years, sustainability has become an important performance metric in industry and a significant driver for the development of innovative concepts and technologies, taking into account economic, social and environmental aspects. Welding is one of the major techniques used in manufacturing industries that requires a large amount of energy and resources and also it is considered dangerous to health and the environment. Energy-saving and constraints in carbon emissions have become a priority in the manufacturing sector therefore, the minimum energy-oriented sustainable welding processes are highly recommended. This paper aims to provide a structured overview of the wide field of research in sustainable production with a focus on the sustainability assessment of welding processes. It describes and outlines the available methodologies used and explores the most recent advances in the field. Based on a broad literature review, research gaps are identified and the scope of future work is discussed. Furthermore, this paper contributes to the advancement of current practices in measuring and assessing the sustainability of welding processes.

Keywords:
Sustainable manufacturing, environment impact, welding, LCA, SLCA

1. Introduction

In previous years, the focus and key driver for welding process improvement among researchers and manufacturing companies has been increasing efficiency, achieving continuous high quality, reducing time and costs, and improving the working environment. Many governments and corporations now regard sustainable development as the ultimate goal. This is primarily due to several factors, including a decrease in the availability of non-renewable resources, increased regulation on industrial process pollution, increased safety rules, and a growing desire for efficiency. [1]. The three most important aspects of sustainability are economic, social, and environmental development. This is known as the triple bottom line theory [2].

Welding is an important manufacturing process that, unfortunately, consumes a significant amount of resources and costs, particularly in the construction industry. This explains why the welding industry's principal interest is in economic issues, however, without appropriate assessment methods, this will not guarantee success in manufacturing companies. Furthermore, the welding industry is unconcerned about its environmental impact, and social issues are frequently overlooked and ignored. However, society is very much concerned about environmental hazards, which is a significant determinant for further developing welding techniques and applications [3]. Because the negative effects on both the environment and humans are irreversible, efforts to reduce hazards in the workplace and make sound decisions when selecting a welding process are essential. The concept of sustainability and sustainable development promises a clear perspective on the impact of products or processes on the environment, costs, society, and the physical performance of the product. Implementing sustainability principles and methods in the manufacturing sector will allow companies to look beyond the economic benefits and consider the environment and meet the consumer's expectations of product quality.

It is difficult to assess the sustainability of welding processes in the context of various economic, environmental, and social factors. There are numerous indicators and data for various welding processes that must be classified and carefully selected. This can be a complex and perplexing process for manufacturers, but a simplified and well-structured analysis can lead to numerous benefits. Increased profits, resource conservation, social advancement, and environmental protection are all part of a proper sustainability assessment before making decisions on welding operations [1]. This paper is primarily concerned with the methodologies used to assess the sustainability of welding processes, analyzes the differences between them, and investigates future advancement possibilities.

2. Sustainability in manufacturing and assessment methodologies

Sustainable manufacturing, also known as green engineering, was the first initiative to implement a sustainability assessment methodology in the manufacturing sector, leading to many proposed frameworks for quantifying and assessing sustainable performance [1][4]. Due to the lack of standardized methodology and generalized assessment criteria, a wide variety of indicator sets, indices, and frameworks have been published and confused manufacturers [1]. According to the National Institute of Standards and Technology (NIST), sustainability is based on economic, social, and environmental but there are two additional aspects to be considered: technological advancement and performance management. The NIST, also proposed a total of 212 indicators for each sustainability aspect as a starting point for manufacturers when creating assessments of their processes or products [5]. Figure 1 is a schematic representation that highlights the categories discussed in [1][5]. These five indicator categories are a type of measure or aggregation of measures [5]. The first step in assessing sustainability is to define a clear objective and comprehend the process or product under consideration. This is also important for the following step, in which indicators are chosen and evaluated, and primary data are gathered [6]. The general steps for sustainability assessments are depicted in Fig.2, as are the criteria for selecting indicators for collecting primary data.

Fig. 1 Sustainability aspects categorization

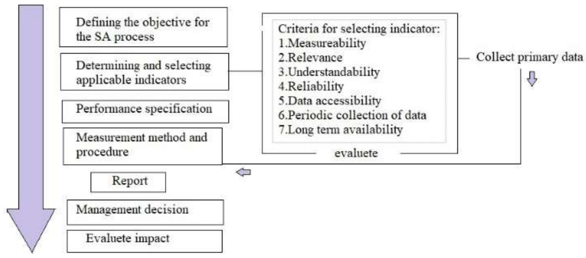

Fig. 2 Sustainability assessment steps and evaluation of indicators

The next step is to choose an appropriate measuring method. Life Cycle Assessment (LCA) is a key methodology for measuring environmental impact in sustainable engineering [7]. Based on the ISO standard, LCA consists of four phases: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation [2]. This methodology compiles all relevant and significant input and output flows and assesses the potential environmental impacts. It considers raw material supply, manufacturing, application, and disposal or recycling [6]. It is best suited for comparing products or processes that perform the same function in order to determine sustainability performance, and it is especially well suited for manufacturing processes that strive for better sustainability results [7]. Based on energy and material consumption, each stage is assessed for its environmental impact. Resource and energy optimization is critical for a company's long-term green growth while remaining competitive [6]. Companies have a great deal of responsibility for the negative impact on the environment, both directly and indirectly [6]. Furthermore, as energy prices for electricity, gas, and oil have risen in recent years, cost-effective energy production is important. Another significant problem is the social impact, which can be measured using an ISO-standardized tool called Social Life Cycle Assessment (SLCA) [2], which assesses social well-being and measures the societal impact of manufacturing processes.

3. Sustainability assessment of welding processes

Welding is a joining process with a major role in the manufacturing industry, but unfortunately, the interest in implementing sustainability is still very low. It is a process of joining metal components that requires a significant amount of energy and resources, and it is regarded as a hazardous process that emits fumes and other hazards that endanger welders' health. Nonetheless, there have been few studies that quantify the negative effects of the processes on the environment and society [9], and research is still predominantly concentrated on developing welding processes and investigating their applications on different materials. This study focuses on methodologies for assessing sustainability in welding processes, particularly on methodologies used to assess environmental impact.

The first step, as stated in previous discussions in this paper, is to define the objective of the analysis. The goal is to develop a sustainability assessment methodology for welding processes that will use the triple bottom line methodology or three major categories: environmental, social, and economic impact [4]. It is important to select the indicators involved in the process properly to address these aspects of sustainability. The most important indicators to consider when evaluating the welding process, according to the paper's author [2], are global warming potential, acidification, photochemical ozone creation potential, and eutrophication. The primary source of pollution in the surrounding environment is the fumes produced as a by-product of the processes. It is a dangerous substance that can cause serious health issues in welders.

The input and expected output of the processes vary, but in most cases, the input consists of material, electricity, shielding gas, and electrodes and the output consists of weld, fumes, and gases.

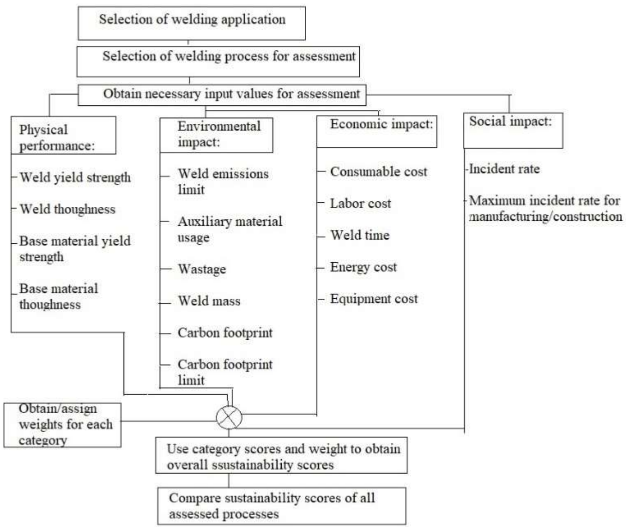

Fig. 3 Sustainability assessment of welding process flow chart [1]

This data is suitable for the most common welding processes, like gas metal arc welding (GMAW) and manual metal arc welding (MMAW). To understand the process of selecting indicators for the welding process, a simplified flow chart is published in [1], as shown in Fig.3. It covers the majority of the critical aspects to consider when implementing sustainability assessment methodology on the welding process.

MAW is broadly used and uses coated electrodes, but it has low productivity and limitations in welding speed and time loss due to electrode changes and slag removal [2][4]. One of the key strategies for improving the environmental performance of the MMAW process is to reduce energy consumption in the process, which will result in several environmental and economic benefits to the overall performance [4]. GMAW can be fully automated and provide a high level of productivity and flexibility, with high deposition rates and welding [8]. Additionally, the implementation and transition to robotic welding provide benefits in terms of improving social, environmental, and economic effects [11]. LAHW (laser arc-hybrid welding) is a promising new technology for sustainable manufacturing. It is a leader in resource savings, lower distortion, and less rework due to faster welding speeds and productivity, fewer passes, and a lower volume of molten material [4]. Comparison research between MMAW, GMAW, and LAHW is done by authors in papers [2][4], and results show that MMAW contributes higher environmental impact levels than GMAW or LAHW.

Table 1 Environmental impact of FSW, GMAW, GTAW [1]

Environmental impact							
Indicators	Welding emissions (g/m^3)	CO2 footprint (kg)	CO2 footprint limit (g)	Auxiliary material used(g)	Auxiliary material max (g)	Mat. wastage(g)	Weld mass (g)
GTAW	0	0.344	0.0868	0.01	0.012	0	4
	Category total =0 (actual score was negative)						
GMAW	0.00817	0.0488	0.0446	0.0051	0.009	0	4.5
	Category total =0.577						
FSW	0	0.02805	0.181	0	0	0	5.4
	Category total =0.9612						

The primary reason is that MMAW consumes significantly more material and electricity per 1 m weld seam, and titanium dioxide consumption for electrode coating in MMAW is critical in contributing to the primary burden of acidification and eutrophication [4]. Other welding processes, such as friction stir welding (FSW), do not use electrodes or filler materials, so the input and output data are different; additionally, the process does not use high temperatures, resulting in lower emissions; and there is a minor metallurgical change in the base materials to be joined [11].

Gas tungsten arc welding (GTAW) is a fusion welding process that employs a non-consumable tungsten electrode, an inert gas to shield the melted metal and protect it from contamination, and manually fed filler metal in the form of a rod [1]. A comparison of GMAW, GTAW, and FSW with sustainability methodologies was made in the paper [1]. The results on environmental impact are summarized in Table 1. According to the results, FSW delivers very good results with no significant environmental impact. This process operates at low temperatures, with no shielding gas and no emissions. It should also be noted that GTAW failed the results in this investigation when compared to GMAW; the process does not generate waste, but the massive power consumption of the process increased the carbon footprint significantly [1].

4. Conclusions

The purpose of this paper is to provide a brief overview of the options for sustainability assessment methods in welding, with a particular emphasis on environmental impacts. It intends to describe the role of sustainability, as well as outline some of the approaches used and steps required when implementing methods for welding processes. The majority of the paper's discussions are based on the literature and publications of authors who used standardized LCA methods and experiments to evaluate the influence on various welding processes. Some of them used equations from reliable literature to calculate the environmental impact [1]. Furthermore, they proposed subsequent steps and measures for identifying the relevant indicators in order to collect enough data for reliable results. The paper's [8] findings imply that the number of indications and data strongly influences the results. It is critical to define and establish the appropriate set of indicators, as well as evaluate and measure them. Furthermore, some considerations and analyses remain to be completed; for example, the majority of the research reviewed did not address the optimization of welding parameters and their impact on final results.

Sustainability decisions and making the right choices when using welding technologies with a low environmental impact that are also economically and socially acceptable are difficult and complex. There is a relationship between economic, environmental, and social aspects that strongly influence each of these aspects and further investigation needs to be done.

References

[1] Jamal J, Sustainability assessment of welding processes, 2017 A Thesis Presented to the Faculty of the American University of Sharjah College of Engineering In Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering.

[2] Chang Y, Sproesser G, Neugebauer S,Wolf K, Scheumann R, Pittner A, Rethmeier M, Finkbeiner M, Environmental and Social Life Cycle Assessment of Welding Technologies, 2015 Procedia CIRP, Volume 26, pp. 293-298.

[3] Pekkari B, Environmental Concerns Are Driving The Development of The Welding Processes and Applications (Physics, Processes, Instruments & Measurements, international symposium of JWRI 30th anniversary), 2003 *transactions of JWRI, 32*, 11-18.

[4] Sproesser G, Chang Y, Pittner A, Finkbeiner M, and Rethmeier M, Sustainable Technologies for Thick Metal Plate Welding, 2017 Sustainable manufacturing: challenges, solutions, and implementation perspectives, pp.71- 84.

[5] Joung, C. B, Carrell J, Sarkar P. K, and Shaw C. F, Categorization of indicators for sustainable manufacturing,2013 *Ecological Indicators*, 24, pp. 148-157.

[6] Nörmann N, Cost and Environmental Impacts in Manufacturing: A Case Study Approach, 2015 University of Rhode Island

[7] Bonvoisin J, Stark R, Seliger G, Field of Research in Sustainable Manufacturing. 2017 Sustainable Manufacturing. Sustainable Production, Life Cycle Engineering, and Management. Springer, Cham., pp. 3-20.

[8] Sproesser G, Schenker S, Pittner A, Borndörfer R, Rethmeier M, Chang Y, Finkbeiner M, Sustainable Welding Process Selection Based on Weight Space Partitions, 2016 Procedia CIRP, Volume 40, pp.127-132.

[9] Alkahla I and Pervaiz S, Sustainability assessment of shielded metal arc welding (SMAW) process, 2017 IOP Conference Series: Materials Science and Engineering, Volume 244, Issue 1, pp. 012001.

[10] Epping K; Zhang H, A Sustainable Decision-Making Framework for Transitioning to Robotic Welding for Small and Medium Manufacturers, 2018 *Sustainability*, *10*, 3651.

[11] Kah P, Martikainen J, Current trends in welding processes and materials: improve in effectiveness, 2011 Reviews on Advanced Materials Science, 30(2), pp189-200.