Life Cycle Assessment (LCA) Results of MIG and TIG Welding Technologies Using the IMPACT 2002+ Methodology

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Abstract—**The aim of this LCA studies is to investigate the potential environmental impacts of arc welding technologies such as Metal Inert Gas (MIG), Tungsten Inert Gas (TIG) processes that follows the framework, principles, requirements, and guidelines given by the International Organisation for Standards (ISO). For a 1 m of welding activities, LCA studies have been carried out in accordance with cradle to gate system boundary employing the SimaPro LCA application tool and the ecoinvent version 3.6 database and applying the comprehensive life cycle impact assessment (LCIA) methodology IMPACT 2002+, version 2.14 that translates the input and output inventory data into the environmental impacts. From the evaluation of LCIA results, it has been demonstrated that the TIG welding process showed higher environmental impacts than the MIG welding process, in midpoint impact categories such as global warming potential, aquatic acidification, ozone layer depletion, and aquatic eutrophication. This mainly occurred due to the slower welding speed of the TIG welding process which results in higher shielding gas and electrical energy consumption. Endpoint damage categories such as human health, climate change, ecosystem quality, and resources have also been investigated for both welding processes. Finally, it is demonstrated from LCIA results that the overall environmental footprint of TIG welding process is about 1.3 times higher than that of MIG welding process.**

Index Terms—**life cycle assessment, IMPACT 2002+, welding processes, environmental impacts**

I. Introduction

The arc welding is the most important joining technology in the manufacturing sectors. The arc welding process joins materials by achieving localised coalescence under the action of heat from the arc. The localised coalescence helps the faying surfaces to fuse into each other and make a single unit [1]. Welding is mainly utilized to fabricate different constructional structures by joining metallic elements. The productions industries required different joining techniques. Welding is required in the fabrication processes that had vast applications in air, water, and space. Welding is employed in the different industrial sectors such as automotive, aerospace, shipbuilding, construction, nuclear, power generation, electronics, household appliances, petrochemicals, machinery fabrication, and others [2].

In the form of different governmental rules and regulations, the production sector is under high pressure to improve the environmental performances of different manufacturing operations. Besides the strict environmental legislation, the production sector has also realized that improving environmental performance can bring long term economic benefits and better survival in the market [3].

Welding is one of the most important processes in the manufacturing industries. In terms of material and energy consumption, every welding process is different from each other and thus has different environmental impact. It is estimated that 0.5-1% of the consumables in arc welding are converted into particulate matter, gases, and emissions [4]. A large amount of energy is consumed on the global levels since the pollutants released through welding processes are in tons. The environmental requirements are demanding development of the joining processes and applications by improving the environmental impact. Improving the environmental performance means reducing input energy consumption, reducing hazardous input and output material flows, improving work conditions, reducing risks related to the occupational safety, optimizing related costs, and others [5].

Life Cycle Assessment (LCA) is a state-of-the-art methodology for assessing the environmental implications of a product of the manufacturing process. It is the most advanced and proven technology for evaluating the environmental impacts at the process level and preventing burden shifting between life cycle phases [6]. The IMPACT 2002+ methodology for life cycle impact assessment provides a viable implementation of a combined midpoint/damage approach, which links all

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sorts of life cycle inventory results (elementary flows and additional interventions) to four damage categories. New concepts and approaches, particularly for the comparative assessment of human toxicity and ecotoxicity, have been developed for IMPACT 2002+. Intake fractions, best estimates of dose-response slope factors, and severities are used to determine human damage factors for carcinogens and non-carcinogens [7].

In this paper, we aim to analyse LCIA results of Metal Inert Gas (MIG) and Tungsten Inert Gas (TIG) welding processes for comparing the corresponding environmental impacts in midpoint impact categories such as global warming potential, ozone layer depletion, aquatic acidification, and others. Endpoint damage categories such as human health, climate change, ecosystem quality, and resources have also been investigated for both arc welding processes.

II. Methods

A. Welding Processes and the System Boundaries

Arc welding is the most widely used process to create permanent joints between metal parts and is used across the full range of manufacturing industries, e.g., aerospace, automotive, construction, oil, and gas. The arc welding processes, MIG and TIG are the welding processes which are uses to weld aluminium alloys. The introduction of inert gas in the arc welding processes such as TIG and MIG made a turning point for welding aluminium alloys and then major advancement happens for fabrication of the aluminium alloys.

MIG is one of the most widely utilized welding techniques and is used to weld aluminium, carbon steel, stainless steel, and others. Metal Inert Gas (MIG) process uses a continuous solid wire electrode which is heated by the arc and fed into the weld pool from a welding torch. The welding torch fulfills two important functions - it transfers the welding current to the wire and provides the inert gas for shielding the arc and weld pool. MIG can be done semi-automatically or automatically. In this study, we have performed LCA studies for semiautomatic MIG to weld aluminium. TIG welding is an arc welding technology that produces welds with a non-fill tungsten electrode. The filler metal comes from an external source, usually in the form of a bare-metal filler rod. A shielding inert gas, such as argon, protects the weld pool region from the ambient and possible contamination. Although other welds, known as autogenous welds, do not require a filler metal, it is typically applied. Welding thin pieces of stainless steel and light metals like aluminium, magnesium, stainless steel, and copper alloys are best done with the TIG technique. The procedure gives the operator more control over the welding process than other methods, resulting in welds that are stronger and more reliable. TIG welding has the disadvantage of being more complex and slower than many other welding processes [8].

The system boundaries of LCA studies for the MIG and TIG welding processes have been graphically presented in Fig. 1a and 1b, respectively.

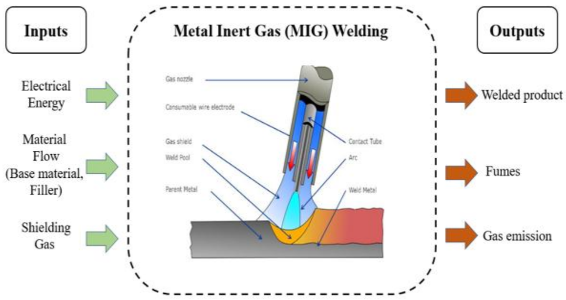

Figure 1a. System boundary of the LCA study related to the welding of aluminium using MIG process [courtesy: TWI]

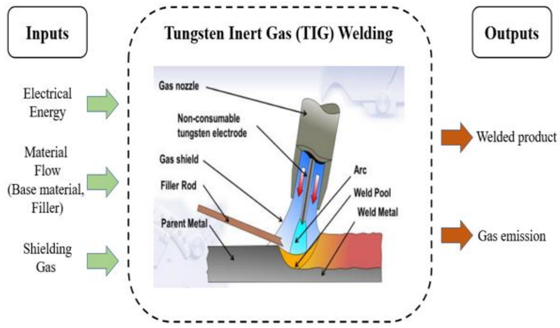

Figure 1b. System boundary of the LCA study related to the welding of aluminium using TIG process [courtesy: TWI]

B. Life Cycle Assessment (LCA)

LCA is a strategy for assessing environmental impacts associated with all phases of a product's life cycle (i.e., from raw materials extraction through material processing, manufacture, distribution, and use). The LCA approach follows ISO 14040 and 14044 standards [9] and has a set structure. Fig. 2 illustrates the four stages of LCA analysis under the guidelines of ISO standards. These four stages include goal and scope definition of the products life cycle, inventory analysis which provides a description of material and energy within the product system, impact assessment based on the details from the inventory analysis, and finally the interpretation of the life cycle which involves critical review, determination of data sensitivity, and result presentation [10].

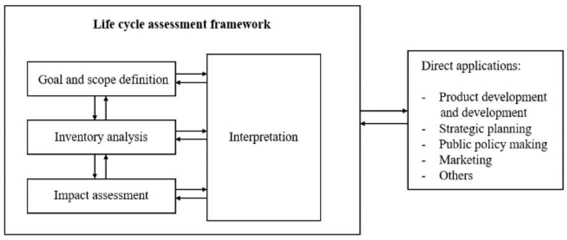

Figure 2. Stages of life cycle assessment (LCA) according to EN ISO 14040

The benefits of using the LCA method are as follows:

- Comparing two systems that deliver the same service/ product as defined by the functional unit.
- Providing environmental footprints data, such as carbon footprint.
- Promoting with a link to the environmental statement or eco-labelling formulation.

III. Inventory Data

The goal of this LCA study is to investigate the environmental impacts of MIG and TIG welding technologies. The scope of the LCA study includes the consumption of electrical energy, filler materials, and shielding gases as input and the emission of fumes as output. The functional unit of this LCA study is 1m of the weld seam. The inventory data of welding parameters are taken from Hobart's "Guide for Aluminium Welding" [11]. The inventory data and the technical parameters of MIG and TIG welding processes are listed in Table I. Welding time, welding voltage, welding current, and number of passes have been used for the determination of filler material, shielding gas, and electricity consumptions. The general power source efficiency is estimated to be 75%, while the deposition efficiency is considered to be 95% for both the TIG and MIG welding processes. The chemical compositions of the consumed materials were obtained from product datasheets. Fume emissions have been calculated using the reference's emission rates for the respective processes. Life cycle impact assessment studies were conducted in accordance with the cradle-to-gate system boundary, using the SimaPro LCA application tool and the ecoinvent version 3.6 database, as well as the comprehensive life cycle impact assessment methodology IMPACT 2002+, v2.14, which translates input and output inventory data into environmental impacts.

TABLE I. Inventory Data for MIG and TIG Welding Processes

Basic data	Metal Inert Gas (MIG) welding	Tungsten Inert Gas (TIG) welding
Base material to be welded	EN AW 5083	EN AW 5052
Thickness of the plate (mm)	9.5	9.6
Root opening (mm)	2.4	3.2
Welding joint type	Butt weld	Butt weld
Welding geometry	Square butt weld	Square butt weld
Welding position	PA	PA
Cross-sectional area of the weld (mm^2)	22.8	30.72
Filler materials	ER5356	R5356
Shielding gas flow rate (l/min)	24	17
Average welding speed (mm/min)	635	220
Number of passes	2	2
Welding voltage (V)	27	17
Welding current (A)	257	350
Deposition efficiency (%)	95	95
Mass of the filler material (kg)	0.06336	0.0854
Power source efficiency (%)	75	75
Electrical energy consumption (kWh)	0.486	1.202
Average transportation distance (km)	200	200
Transportation flow (tkm)	0.013	0.017
Amount of fume (kg)	0.03168	-
Shielding gas consumption (kg)	0.135	0.275

IV. Results and Discussions

Based on the inventory data, the life cycle impact assessment is carried out employing the IMPACT 2002+ method. The comparisons of welding technologies based on characterisation factors, damage assessment, and the single score have been made for 1m of welding activities. As shown in Fig. 3, the dominance of TIG welding has been identified in most of the midpoint categories except aquatic ecotoxicity and terrestrial ecotoxicity. The main reason for this is the relatively low welding speed of TIG welding which accounts for higher consumption of electricity and shielding gas. Fig. 4 illustrates the four damage assessment impact categories (human health, ecosystem quality, climate change, and resources) for 1m of welding activities of TIG and MIG welding processes. TIG welding accounts for the higher value in human health, climate change, and resources damage categories due to the higher consumption of shielding material and electrical energy of the TIG process. Because it generates fumes that are detrimental to the environment, the MIG welding process has a higher impact on the ecosystem quality damage category. The quantification of environmental footprints with respective units for 1 m of welding activities of TIG and MIG welding processes over four endpoint damage categories is listed in Table II.

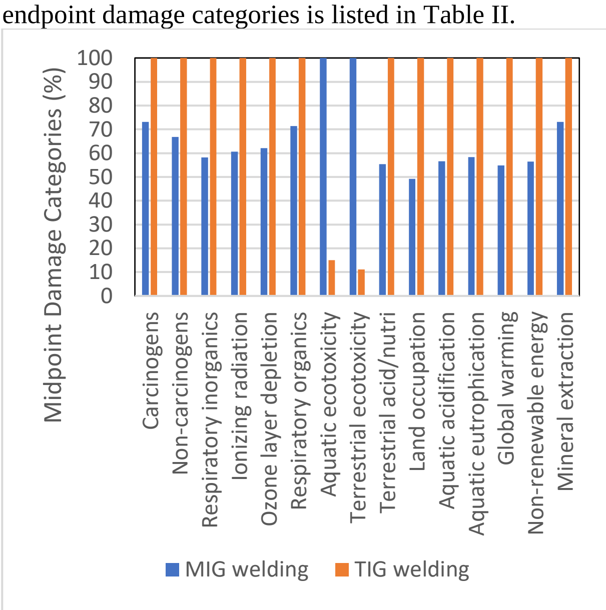

Figure 3. Environmental impacts of MIG and TIG welding processes in the characterisation midpoint damage categories

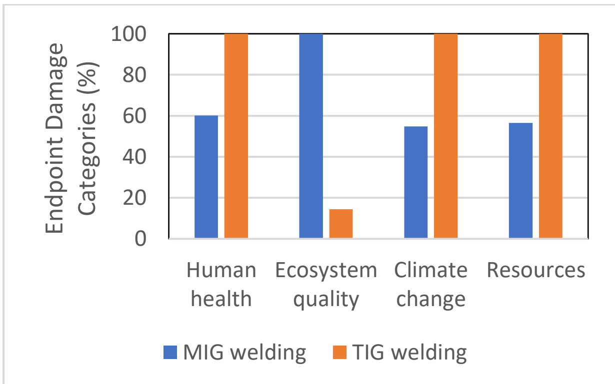

Figure 4. Environmental impacts of MIG and TIG welding processes in the four endpoint damage categories

TABLE II. QUANTIFICATION OF ENVIRONMENTAL FOOTPRINTS FOR 1M WELDING ACTIVITIES OF MIG AND TIG WELDING PROCESSES OVER FOUR ENDPOINT DAMAGE CATEGORIES

Damage category	Unit	Metal Inert Gas (MIG) Welding	Tungsten Inert Gas (TIG) Welding
Human health	DALY	1.57E-06	2.61E-06
Ecosystem quality	PDF*m 2*yr	2.38E+00	3.44E-01
Climate change	kg CO2 eq	1.34E+00	2.44E+00
Resources	MJ primary	2.16E+01	3.83E+01

The quantified values of four endpoint damage categories have been converted to single score values in units of eco-points (Pt). The respective overall environmental footprints (in units of µPt) of the filler materials, shielding gas, and electricity consumption in the MIG and TIG welding processes are given in Fig. 5. It is evident that filler materials account for the most in both processes. It is also indicated that TIG welding consumes more shielding gas and electrical energy than that of the MIG welding process.

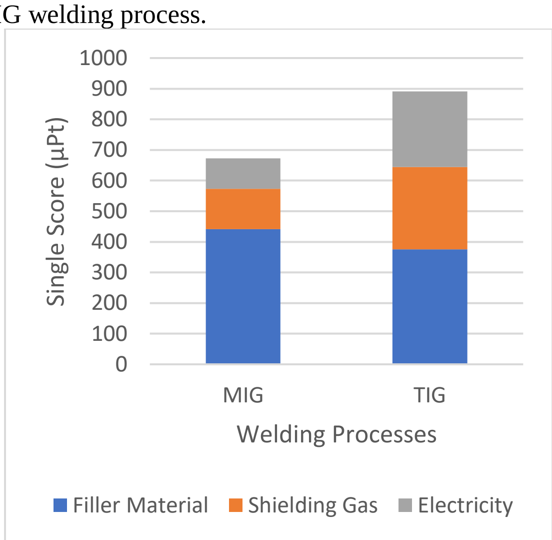

Figure 5. Contribution of the filler material, shielding gas and electricity consumption in the welding processes

A graphical presentation of the overall environmental footprints (in units of µPt) for 1 m welding activities of MIG and TIG welding processes over four endpoint damage categories is shown in Fig. 6.

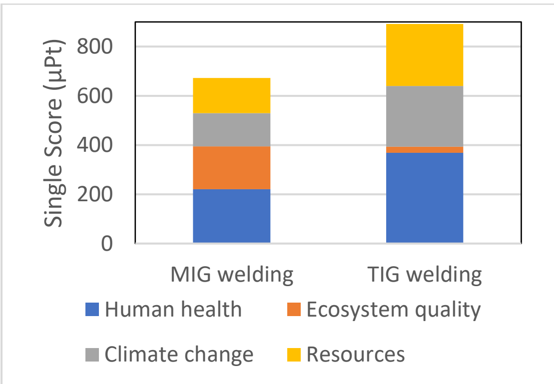

Figure 6. Environmental impacts of MIG and TIG welding processes in the four endpoint categories, based on single point score

It is seen from Fig. 6 that human health, climate change, and resources damage categories of TIG welding process showed higher than that of MIG welding process due to more material energy consumption and the ecosystem quality damage category of MIG process is much higher than that of TIG process due to fume emissions in the MIG process. Hence, the overall environmental footprint of the TIG welding process is about 30% higher than that of the MIG welding process. In the reference [12] LCA has been studied for the TIG and MIG welding processes to weld aluminium using CED and ReCiPe impact assessment methodologies and they have found TIG is correspondingly 40% and 15% higher damaging than that of MIG.

V. CONCLUSION

The present study illustrates the environmental performances of MIG and TIG arc welding processes to weld aluminium alloys for 1 m of welding activities. Because of the low welding speed, the TIG welding process consumes a higher amount of shielding gas and electricity that contributes to most of the midpoint and endpoint damage impact categories. On the other hand, because of the generation of welding fume in the MIG welding process, it accounts for a higher impact value in the ecosystem quality factor as it releases welding fume during the process. Finally, it is concluded that the overall environmental footprint of the TIG welding process is about 1.3 times higher than that of the MIG welding process. By employing automation in TIG welding the welding speed of the process can be increased, and this will subsequently lessen the electricity and shielding gas consumption which will result in lowering the environmental damaging factors. The contribution of this study can provide information to industries for developing and selecting sustainable processes.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Surja Sarkar, Mahfuza Ahmed, and M. A. Hye Chowdhury modelled the assessment framework, analysed the data, and prepared the draft of the paper. Geoff Melton reviewed and edited the paper. Mahfuza Ahmed and M. A. Hye Chowdhury reviewed and edited the paper to the final version. Finally, all the authors approved the final version.

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