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A Review of Welding and Fabrication Processes and Resulting Impacts on Environmental Sustainability: Risk and Control Measures

Victor Etok Udoh[1,*], Imoh Ime Ekanem[2], Aniekan Essienubong Ikpe[2]

[1] Department of Welding and Fabrication Engineering, Akwa Ibom State, Polytechnic, Nigeria; victor.ude@akwaibompoly.edu.ng.

[2] Department of Mechanical Engineering, Akwa Ibom State, Polytechnic, Nigeria; richyekanem@gmail.com; aniekan.ikpe@akwaibompoly.edu.ng.

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Abstract

The application of welding and fabrication processes are common metal-metal joining techniques widely adopted in industries such as construction, manufacturing, and automotive, but they also pose some level of hazard to the environment depending on the specific method. Despite the growing awareness of environmental issues, the impact of welding and fabrication processes on pollution remains a major concern. There is a need for effective control strategies to curtail emissions while protecting the environment from the resulting impacts of these processes. This study is based on a review of existing literature on the environmental impact of welding and fabrication processes. The literature review included studies on the emission of pollutants from welding operations, the effects of these pollutants on the environment and human health, and the current practices for controlling emissions. In addition, the methodology also involved an overview of the effects of welding particulate and gaseous substances on human health and environmental sustainability, risk assessment procedures, safety precautions and preventive methods to provide a comprehensive overview of the problem. The findings were based on the synthesis of the information obtained from the aforementioned methodology. The results indicated that welding and fabrication processes are significant sources of air and water pollution. These processes release a number of pollutants, including nitrogen oxides, sulfur dioxide, carbon monoxide, particulate matter, Volatile Organic Compounds (VOCs) and Hazardous Air Pollutants (HAPs), which can have harmful effects on the environment and human health. In addition, the use of certain materials in welding operations, such as lead, chromium, and cadmium, can result in the release of toxic substances that pose a risk to workers and nearby communities. From the findings, it is essential to implement sustainable practices to reduce emissions and protect the environment from the adverse effects of these processes. This can be achieved through the use of advanced technologies, such as emission control devices and cleaner fuels, as well as proper waste management practices to minimize the release of pollutants into the environment. Regulatory measures are also necessary to ensure compliance with environmental standards and promote responsible practices in the industry.

Keywords: Environmental sustainability, Atmospheric contamination, Volatile compounds, Welding and fabrication.

1 | Introduction

Welding and fabrication processes are essential in various industries, such as construction, automotive, and manufacturing. However, these processes can have significant impacts on the environment through the

Corresponding Author: victor.ude@akwaibompoly.edu.ng

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emission of pollutants. It is crucial to understand the environmental implications of welding and fabrication and implement strategies for emission control and environmental protection. Welding is a process that involves joining two or more materials, usually metals, by melting them together [1]. Fabrication, on the other hand, involves the manipulation of materials to create a final product. Both processes involve the use of heat, electricity, and chemicals, which can result in the release of harmful pollutants into the environment. The welding and fabrication processes can release a variety of pollutants into the environment, including particulate matter, Volatile Organic Compounds (VOCs), and Hazardous Air Pollutants (HAPs) [2], [3]. These pollutants can have adverse effects on air quality, human health, and the environment.

Particulate matter can cause respiratory problems and contribute to smog formation, while VOCs and HAPs can be carcinogenic and toxic to humans and wildlife. There is a growing awareness of the environmental impacts of welding and fabrication processes, and many industries are taking steps to reduce their emissions and protect the environment. Strategies for emission control include the use of cleaner technologies, such as laser welding and plasma cutting, and the implementation of pollution control devices, such as scrubbers and filters [4]. Additionally, companies can reduce their emissions by improving ventilation systems, using low-emission materials, and implementing recycling programs. Overall, it is essential for industries that use welding and fabrication processes to prioritize environmental protection and implement strategies for emission control. By reducing their emissions and implementing sustainable practices, companies can minimize their impact on the environment and contribute to a cleaner, healthier planet. The impacts of welding and fabrication processes on environmental pollution are significant, but there are strategies available for emission control and environmental protection [5]. Industries must prioritize sustainability and implement measures to reduce their emissions and protect the environment. By taking proactive steps to address these issues, companies can minimize their environmental impact and contribute to a more sustainable future.

2 | Impacts of Welding and Fabrication Processes on the Environment

Welding and fabrication processes are essential in various industries, including construction, manufacturing and automotive [6]. However, these processes have significant impacts on the environment, including air pollution, water pollution, hazardous waste generation, ozone depletion, and greenhouse gas emissions. The negative effects of welding and fabrication processes on the environment are as follows:

I. Air pollution: during these processes, various harmful gases and particulate matter are released into the atmosphere, contributing to air pollution. These pollutants can have adverse effects on human health, causing respiratory problems, cardiovascular diseases, and even cancer. Additionally, they can also harm the environment by contributing to smog formation and acid rain [7].

II. Water pollution: the use of chemicals, such as cleaning agents and metal coatings, can contaminate water sources through runoff or improper disposal. This pollution can harm aquatic ecosystems, affecting marine life and water quality. It can also pose risks to human health if contaminated water is consumed or used for irrigation [8].

III. Hazardous waste generation: these processes produce a considerable amount of waste, including metal shavings, slag, and used chemicals. Improper disposal of this waste can lead to soil contamination and groundwater pollution. Moreover, some of these wastes are classified as hazardous, posing risks to human health and the environment if not managed properly [9].

IV. Ozone depletion: the use of certain chemicals, such as Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs), can deplete the ozone layer, leading to increased UV radiation reaching the Earth's surface. This can have detrimental effects on human health, including skin cancer and cataracts, as well as on ecosystems, such as damage to crops and marine life [10].

V. Greenhouse gas emissions: these are a significant contributor to climate change, and welding and fabrication processes are not exempt from this impact. The burning of fossil fuels for energy in these processes releases

carbon dioxide and other greenhouse gases into the atmosphere, contributing to global warming. This can lead to more frequent and severe weather events, rising sea levels, and disruptions to ecosystems and biodiversity [11].

The impacts of welding and fabrication processes on the environment are significant and cannot be ignored. Industries need to adopt sustainable practices to mitigate these impacts and reduce their environmental footprint. This can be achieved through the use of cleaner technologies, proper waste management, and the implementation of pollution prevention measures. By taking proactive steps to address these issues, we can protect the environment, human health, and future generations from the negative consequences of welding and fabrication processes.

3|Welding Effects of Particulate and Gaseous Substances on Human Health and Environment

Welding is a common industrial process that involves joining materials together by melting them and then allowing them to cool and solidify. While welding is essential for the construction of buildings, bridges, and various structures, it also poses risks to both human health and the environment due to the release of particulate substances such as lead oxide, iron oxide, nickel oxide, beryllium oxide, chrome VI compounds, thorium oxide, and manganese. Particulate substances released during welding operations can have detrimental effects on human health (*Fig. 1*).

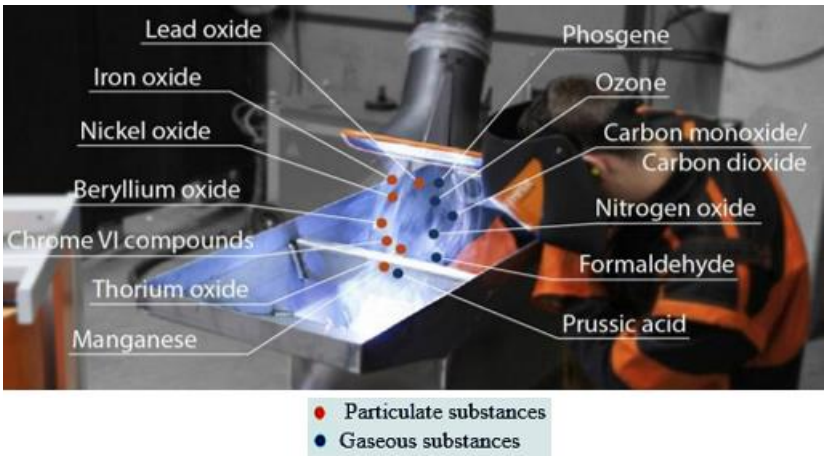

Fig. 1. Particulate and gaseous substances from welding and fabrication practices [12].

In addition to the health risks posed to humans, particulate substances released during welding operations can also have negative effects on the environment. These substances can contaminate soil, water and air, leading to ecosystem disruption and potential harm to wildlife. However, the process of welding involves the use of various gaseous substances that can have harmful effects on both humans and the environment.

Table 1. Particulate and gaseous substances and their effects on human health and environment.

Particulate Substance	Effects on the Human/Environment	Gaseous Substance	Effects on the Human/Environment
Lead oxide	Exposure to lead oxide can lead to lead poisoning, which can cause symptoms such as abdominal pain, fatigue, and neurological issues. Also, lead oxide can accumulate in soil and water, posing risks to plants and animals.	Phosgene	Phosgene is a highly toxic gas that is commonly used in welding operations. Exposure to Phosgene can cause irritation to the eyes, nose, and throat, as well as respiratory problems and even death in severe cases.

Table 1. Continued.

Particulate Substance	Effects on the Human/Environment	Gaseous Substance	Effects on the Human/Environment
Iron oxide	Exposure has been linked to respiratory issues such as bronchitis and pneumonia. Nickel oxide exposure can result in skin allergies and lung cancer. Iron oxide can also contribute to water pollution, affecting aquatic life.	Ozone	Ozone, another gaseous substance produced during welding, can cause respiratory issues and exacerbate existing respiratory conditions such as asthma.
Nickel oxide	Nickel oxide can cause respiratory problems, leading to cardiovascular diseases. Nickel oxide can contaminate soil and water, impacting plant growth and aquatic ecosystems.	Carbon monoxide/Carbon dioxide	Carbon monoxide, a byproduct of incomplete combustion during welding, can lead to carbon monoxide poisoning, which can be fatal if not treated promptly. Carbon dioxide, a common shielding gas used in welding, can displace oxygen in the air, leading to asphyxiation in confined spaces.
Beryllium oxide	Beryllium oxide exposure is known to cause chronic beryllium disease, a debilitating lung condition. Beryllium oxide can leach into groundwater, posing risks to aquatic organisms.	Nitrogen oxide	Nitrogen oxide, produced during high-temperature welding processes, can contribute to air pollution and respiratory issues in humans.
Chrome VI compound	Chrome VI compounds have been classified as carcinogenic to humans by the International Agency for Research on Cancer (IARC). Chrome VI compounds can persist in the environment and bio-accumulate in organisms, leading to long-term ecological harm.	Formaldehyde	Formaldehyde, a common component of welding fumes, is a known carcinogen and can cause respiratory irritation and other health problems with long-term exposure.
Thorium oxide	Thorium oxide exposure can lead to lung and pancreatic cancer. Thorium oxide can contaminate soil and water, affecting plant and animal populations.	Prussic acid	Prussic acid, also known as hydrogen cyanide, is a highly toxic gas that can cause respiratory failure and death in high concentrations.
Manganese	Manganese exposure has been associated with neurological disorders such as Parkinson's disease. Manganese exposure can lead to toxicity in aquatic organisms, disrupting food chains.		

The release of both particulate and gaseous substances during welding operations poses significant risks to both human health and the environment. Welders and employers need to take necessary precautions to minimize exposure to these substances, such as using proper ventilation systems, wearing protective equipment, and implementing safe work practices. Additionally, regulatory agencies should enforce strict guidelines to limit the release of harmful particulate substances into the environment. By addressing these issues, we can protect both human health and the environment from the adverse effects of welding operations.

4 | Contribution of Welding to Environmental Pollution

Welding is a widely used industrial process that plays a crucial role in the manufacturing and construction sectors [13]. However, the process of welding also contributes to environmental pollution in various ways. The environmental impact of welding and measures that need to be taken to mitigate its negative effects are:

I. The release of harmful gases and fumes: during the welding process, high temperatures are used to melt and join metal pieces, which can result in the release of toxic gases such as nitrogen oxides, carbon monoxide, and ozone. These gases can have detrimental effects on air quality and human health, leading to respiratory problems and other health issues [14].

II. Welding also produces metal fumes and particulate matter that can contaminate the air and soil. These particles can settle on surfaces and enter the food chain, posing a risk to both human health and the environment. The use of welding electrodes and consumables can also contribute to pollution, as they often contain heavy metals and other toxic substances that can leach into the soil and water.

III. The use of certain welding techniques, such as arc welding, can produce ozone-depleting substances, such as CFCs and HCFCs. These substances can contribute to the depletion of the ozone layer, leading to increased ultraviolet radiation reaching the Earth's surface and potential harm to human health and ecosystems.

IV. Burning of fossil fuels, such as gas or diesel, to power the equipment. This combustion releases harmful pollutants into the atmosphere, including carbon dioxide, nitrogen oxides, and particulate matter. These pollutants can contribute to air pollution and climate change, leading to adverse effects on human health and the environment [15].

V. Energy consumption associated with the process: welding requires a significant amount of energy to generate the high temperatures needed to melt metal, which can contribute to greenhouse gas emissions and climate change. In addition, the use of fossil fuels to power welding equipment can further exacerbate the environmental impact of the process.

To mitigate the environmental impact of welding, several measures can be taken. One approach is to use cleaner welding technologies, such as laser welding or electron beam welding, which produce fewer emissions and consume less energy compared to traditional welding methods. Additionally, implementing proper ventilation systems and using Personal Protective Equipment (PPE) can help reduce exposure to harmful gases and fumes [16]. Welding is a necessary industrial process that contributes to environmental pollution through the release of harmful gases, fumes, and energy consumption. To address these issues, it is essential to adopt cleaner welding technologies and implement proper safety measures to protect both the environment and human health. By taking proactive steps to reduce the environmental impact of welding, we can help create a more sustainable future for generations to come.

5 | Fumes Generated During Welding

Some common fumes generated during welding include two potentially harmful substances:

I. Extremely fine metallic particulates emitted during the welding process: these tiny particles are barely discernible to the naked eye, yet they can accumulate rapidly, posing a significant inhalation risk. This metallic dust comprises many hazardous metals, including lead, cadmium, iron, zinc, aluminum, nickel, tin, and silver, generated by the welded material and the welding consumables [17].

II. Potentially hazardous gasses resulting from the heating of metal when mixed with welding rods or wires. Examples include carbon monoxide, hydrogen fluoride, ozone, and nitrogen. Additionally, carbon dioxide and helium are two protective gases essential to the welding process [18].

The inhalation of these vapors poses a significant risk of severe pulmonary illnesses and neurological damage. Common consequences resulting from prolonged exposure to welding fumes include, based on the International Agency for Research on Cancer (IARC), different malignancies, emphysema, renal failure, lead poisoning, anemia, Parkinsonian symptoms, metal fume fever, inflammation of the nasal passages, sinuses, throat, and lungs, as well as asthma [19]. The harm caused by welding fumes can manifest gradually without any visible symptoms, as shown in *Fig. 2*.

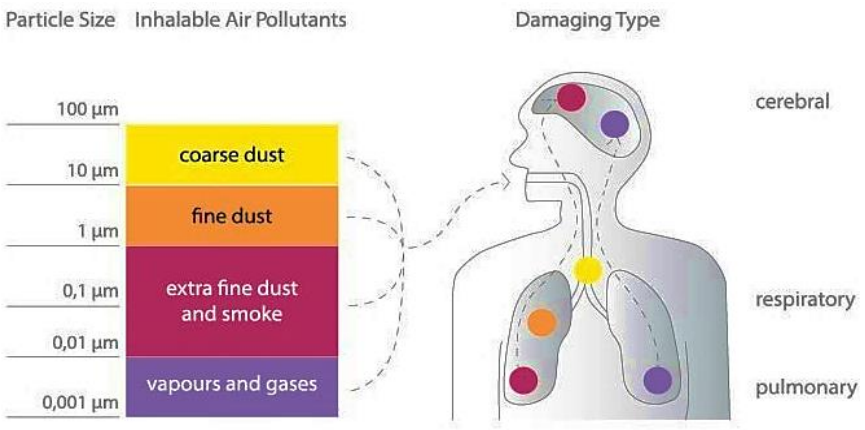

Fig. 2. Pulmonary illnesses and neurological damages caused by welding fumes [20].

6 | Prevention of Welding Particulates and Gaseous Substances on Environment

Welding processes are essential in various industries, but they can also pose environmental and health risks due to the release of particulates and gaseous substances. In order to prevent environmental pollution and atmospheric contamination, it is crucial to implement measures that effectively control and mitigate these emissions. The measures that can be taken to prevent welding particulates and gaseous substances from causing harm to the environment are as follows:

I. The use of proper ventilation systems in the welding area: ventilation systems help to capture and remove welding fumes and gases before they can escape into the environment. Local exhaust ventilation systems, such as fume hoods and extraction arms, are particularly effective in capturing welding emissions at the source. It is important to ensure that these ventilation systems are properly designed, installed, and maintained to maximize their efficiency [21].

II. The use of appropriate welding techniques and equipment: for example, using low-emission welding processes, such as Gas Metal Arc Welding (GMAW) or Flux-Cored Arc Welding (FCAW), can help to reduce the amount of fumes and gases generated during welding. Additionally, using high-efficiency welding equipment, such as modern welding machines with built-in fume extraction systems, can further minimize emissions [22].

III. Implementation of good housekeeping practices in the welding area: this includes keeping the work area clean and free of clutter, as well as properly storing and disposing of welding consumables, such as electrodes and fluxes. By maintaining a clean work environment, the risk of emissions escaping into the environment can be significantly reduced [23].

IV. Provision of proper training and education to welding operators on the hazards of welding emissions and the importance of following proper safety procedures: this includes wearing appropriate PPE, such as respirators and protective clothing, to minimize exposure to welding fumes and gases [14]. By ensuring that welding operators are well-informed and properly trained, the risk of environmental pollution and atmospheric contamination can be effectively mitigated.

Preventing welding particulates and gaseous substances from causing harm to the environment requires a comprehensive approach that includes the use of proper ventilation systems, welding techniques, equipment, housekeeping practices, and training. By implementing these measures effectively, the environmental impact of welding processes can be minimized, ensuring a safer and healthier work environment for all.

7 | Prevention of Welding Particulates and Gaseous Substances on Human Health

Welding is a common industrial process that involves the joining of materials through the application of heat. While welding is essential for the fabrication of various structures and products, it also poses significant health risks to workers due to the generation of welding particulates and gaseous substances. These hazardous substances can have detrimental effects on human health, including respiratory problems, skin irritation, and even long-term health issues such as cancer. Therefore, it is crucial to implement effective measures to prevent the exposure of workers to welding fumes and gases. These include the following:

I. Ventilation systems: one of the most effective ways to control welding fumes and gases is through the use of ventilation systems. Local exhaust ventilation systems can capture and remove welding fumes at the source, preventing them from dispersing into the work environment and being inhaled by workers [24]. Additionally, general ventilation systems can help dilute and remove any remaining fumes and gases in the workplace.

II. Personal Protective Equipment (PPE): in situations where ventilation systems are not sufficient to control welding fumes and gases, workers should be provided with appropriate PPE, such as respirators and protective clothing. Respirators can help filter out harmful particles and gases, while protective clothing can prevent skin contact with hazardous substances [25].

III. Substitution of materials: another effective method for reducing exposure to welding fumes and gases is to substitute hazardous materials with less toxic alternatives. For example, using low-emission welding processes or selecting materials with lower fume generation can help minimize the health risks associated with welding [26].

IV. Training and education: proper training and education of workers on the hazards of welding fumes and gases, as well as the importance of following safety procedures, are essential for preventing exposure [27]. Workers should be informed about the potential health effects of welding and trained on how to use ventilation systems and PPE correctly.

V. Regular monitoring and maintenance: regular monitoring of air quality in welding environments and maintenance of ventilation systems are crucial for ensuring that exposure to welding fumes and gases is kept at safe levels [28]. Monitoring can help identify any potential issues with ventilation systems or welding processes that may lead to increased exposure.

Preventing welding particulates and gaseous substances on human health requires a comprehensive approach that includes the implementation of ventilation systems, the use of PPE, the substitution of materials, training and education of workers, and regular monitoring and maintenance. By following these methods, employers can protect the health and safety of their workers and create a safer working environment in welding operations.

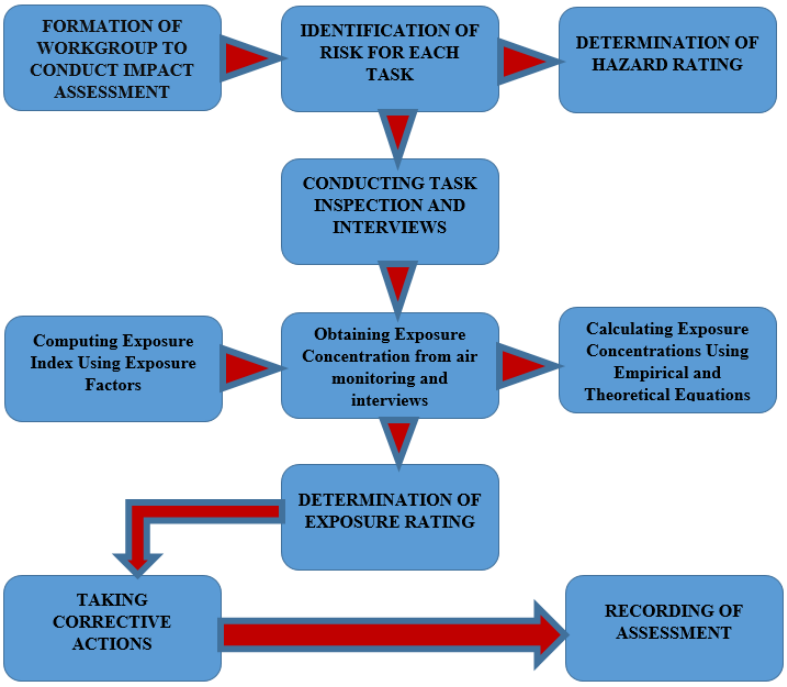

Fig. 3. Risk assessment framework for welding and fabrication practices.

8 | Risk Assessment Procedures during Welding and Fabrication Processes

Risk assessment is a crucial aspect of ensuring safety in the welding and fabrication process. This process involves identifying potential hazards, evaluating the risks associated with these hazards, and implementing control measures to mitigate these risks (*Fig. 3*). Breakdown of the risk assessment procedures that should be considered during welding and fabrication processes are as follows:

I. Identify potential hazards: this can include hazards such as exposure to fumes and gases, electrical hazards, fire hazards, and physical hazards such as burns and cuts. It is important to thoroughly assess the work environment and the tasks involved in the welding and fabrication process to identify all potential hazards [29].

II. Evaluate the risks associated with these hazards: this involves determining the likelihood of an incident occurring and the potential consequences of such an incident. Risk assessment tools such as risk matrices can be used to quantify the level of risk associated with each hazard [30].

III. Control measures should be implemented to mitigate these risks: this can include implementing engineering controls such as ventilation systems to reduce exposure to fumes, providing PPE such as welding helmets and gloves, and implementing safe work practices such as proper training and supervision [31].

IV. It is important to regularly review and update the risk assessment process to ensure that it remains effective in identifying and mitigating risks. This can involve conducting regular inspections of the work environment, reviewing incident reports, and seeking feedback from workers on potential hazards [32].

A detailed risk assessment process is essential for ensuring safety in the welding and fabrication process. By identifying potential hazards, evaluating risks, and implementing control measures, the risk of incidents and injuries can be significantly reduced. Employers and workers need to work together to ensure that the risk assessment process is thorough and effective in maintaining a safe work environment.

9 | Safety Precautions for Welding and Fabrication Process

Welding and fabrication processes are essential in various industries, including construction, manufacturing, and automotive. However, these processes involve inherent risks that can lead to serious injuries or even fatalities if proper safety precautions are not followed. In order to ensure the safety of workers and prevent accidents, it is crucial to implement a comprehensive set of safety measures such as the following:

I. Conduct a thorough risk assessment of the work environment: this includes identifying potential hazards such as flammable materials, electrical hazards, and confined spaces. By understanding the risks involved, appropriate safety measures can be put in place to mitigate these hazards and protect workers from harm [33].

II. Use PPE: this includes items such as welding helmets, gloves, goggles, and flame-resistant clothing. PPE is essential in protecting workers from burns, eye injuries, and exposure to harmful fumes and gases. Employers need to provide adequate training on the proper use of PPE and ensure that all workers are equipped with the necessary gear before starting any welding or fabrication work [34].

III. Proper ventilation is crucial in maintaining a safe work environment during welding and fabrication: adequate ventilation helps to remove harmful fumes and gases produced during the welding process, reducing the risk of respiratory problems and other health issues. Employers should ensure that ventilation systems are in place and functioning properly to protect workers from exposure to hazardous substances [35].

IV. Follow proper welding and fabrication techniques to minimize the risk of accidents: this includes ensuring that equipment is properly maintained and inspected regularly, using the correct welding procedures for the specific job, and following all safety guidelines provided by equipment manufacturers. By adhering to best practices in welding and fabrication, the likelihood of accidents and injuries can be significantly reduced.

Safety precautions are essential in welding and fabrication processes to protect workers from harm and prevent accidents. By conducting a thorough risk assessment, providing appropriate PPE, ensuring proper ventilation, and following best practices in welding and fabrication, employers can create a safe work environment for their employees. Employers must prioritize safety and invest in training and resources to ensure that all workers are able to perform their jobs safely and effectively.

10 | Conclusion

The findings from this study on the impacts of welding and fabrication processes on environmental pollution clearly indicate that these industrial activities contribute significantly to air and water pollution, as well as soil contamination. Therefore, the evidence presented in this study highlights the need for effective strategies for emission control and environmental protection. One such strategy identified for emission control is the implementation of proper ventilation systems in welding and fabrication facilities. These systems can help to capture and remove harmful fumes and particulate matter before they are released into the environment. Additionally, the use of advanced technologies such as laser welding and robotic fabrication can help to reduce the overall environmental impact of these processes.

Furthermore, the adoption of sustainable practices, such as using recycled materials and implementing waste management programs, can also play a crucial role in reducing pollution from welding and fabrication activities. By promoting a culture of environmental responsibility within the industry, minimizing the negative effects on the ecosystem can be achieved. Based on the findings of this study, the following recommendations are suggested to mitigate these effects and promote sustainable practices.

I. Implementation of emission control technologies, such as fume extraction systems and air filtration devices, to capture and remove pollutants at the source. These technologies can significantly reduce the release of harmful emissions into the atmosphere, thereby minimizing the environmental impact of welding and fabrication activities.

II. The use of cleaner welding techniques and materials can help reduce emissions and improve air quality. For example, switching to low-emission welding processes, such as GMAW or Shielded Metal Arc Welding (SMAW), can lower the amount of pollutants released during welding operations. Similarly, using environmentally friendly materials, such as low-VOC paints and coatings, can help minimize the generation of harmful emissions during fabrication processes.

III. Implementing proper ventilation systems and conducting regular maintenance of equipment can also contribute to reducing emissions and protecting the environment. Adequate ventilation can help dilute and disperse pollutants, while routine maintenance can ensure that equipment operates efficiently and minimizes emissions.

By adopting and implementing the aforementioned recommendations, industries can minimize the environmental footprint resulting from the process which contributes to a healthier and more sustainable future.

Author Contributions

Victor Etok Udoh conceptualized the study, led the research design, and oversaw the manuscript preparation. Imoh Ime Ekanem conducted an extensive literature review on welding and fabrication processes and their environmental impacts. Aniekan Essienubong Ikpe contributed to the analysis of risk and control measures, as well as editing and refining the manuscript. All authors reviewed, revised, and approved the final manuscript.

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Data Availability

No new data were generated or analyzed during this study. All information used is based on previously published studies, and references are available within the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest related to this work.

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