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Review for A Comprehensive Examination of the Detrimental Effects Caused by Welding Fumes on Human Well-Being and the Ongoing Risks to Public Health

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ABSTRACT

This article examines the intricate health hazards of welding, emphasizing cancer risks, respiratory and neurological impacts, and the need for ventilation measures. Utilizing advanced techniques, welding fumes' composition and morphology, revealing elevated risks for stainless steel welders were analyzed. A novel robotic system for continuous exposure assessments, advocates for a thorough re-evaluation of welding practices. It navigates the complexity of risk factors, addressing short-term and long-term health risks, including emissions' broader environmental impacts. The research underscores the importance of controlled animal models, investigating the link between welding and various cancers. Acknowledging collaborative efforts, the study aims to enhance our understanding of safer working conditions in the welding community. The article narrates the negative side of welding fumes on the health of human beings and its detrimental effects on the human life cycle. The authors have gone through the various articles and presented a comprehensive review that brings out the problems associated with welding.

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INTRODUCTION

For the millions who wield welding torches, sparks, and skill aren't the only companions. Lurking unseen in the fumes are potential health risks, casting a shadow over this vital craft. Scanning electron microscopes and Transmission electron microscopes were utilized to analyze the composition and morphology of welding fumes from GMAW (Gas Metal Arc Welding) across various size ranges(Sowards *et al*., 2010). Welding fume-related occupational health risks, emphasizing respiratory and neurological impacts, advocating for adequate ventilation measures, and addressing specific hazards associated with manganese exposure were observed (Jafari & Shafiei, 2010). Rat lung responses to diverse welding fumes, highlighting the complexity of MMAW (Manual Metal Arc Welding) fumes with elevated Mn and Cr were identified with increased Mn deposition in specific dopamine-rich brain regions(Antonini *et al*., 2010). Welding fume health effects, highlighting the necessity for controlled animal models, and introducing a novel robotic system for continuous and reproducible inhalation exposure assessments were discussed (Antonini *et al*., 2006). This passage navigates the

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labyrinthine complexity of risk factors, from specific welding processes to the interplay of metals and materials. Emissions like carbon monoxide, ozone, and nitrogen oxides also contribute to health and environmental impacts. Harmful contents released by the welding fumes causing health risks (Fig.1), particularly in confined spaces with rising exposure from new procedures were identified (Pires *et al*., 2006). To shed light on these hidden dangers, the passage introduces a major study investigating the link between welding and lung cancer and mesothelioma in a large Canadian cohort. Physio-chemical traits of airborne particulates, highlighting the carcinogenicity of welding fumes in industrial contexts were observed (Moroni & Viti, 2009). Further occupational risks of welding, particularly in stainless steel welding, involve known carcinogens (hexavalent chromium and nickel) (Keane *et al*., 2009). Welding hazards, particularly in stainless steel welding with carcinogenic elements explore risks related to manganese exposure, emphasizing the need to understand its role in diseases like manganism, and aims to identify welding processes with minimal manganese species (Amani, F. *et al*., 2017). Electron microscopy techniques paint a vivid picture of these measured by the Comet assay in lymphocytes, with metal concentrations (Al, Cd, Co, Cr, Mn, Ni, Pb, Zn) in the blood and urine of welders exposed to welding fumes are observed (Azzarà *et al*., 2010). Funding by D&L Welding Fume Analysis LLC underscores the industry's role in understanding and mitigating this occupational hazard (Das Aritra, *et al*., 2015, Alexander, V *et al*., 2016). Ultimately, the study's findings aim to deepen our understanding of welding fume characteristics, paving the way for safer working conditions and a healthier future for the welding community. (Bowler *et al*., 2007) Health effects of manganese (Mn) exposure, particularly in welders, highlighting manganism's Parkinson's-like symptoms. Commonly observed health risks, welding fume metal oxide compounds, gases, and exposure limits were showcased (Kim *et al*., 2005, Chadha & Singh, 2013, Rahul *et al*., 2019, Sjögren *et al*., 2022). Workers' exposures were categorized into four grades, with the highest exposure observed among welders in the maintenance workshop. The highest grades of manganese (Mn) and iron (Fe) exposure were both 4, while chromium (Cr) exposure reached a maximum grade of 3. Subgroup analysis revealed that compared to non-welders, welders had a 2.17-fold higher risk of lung-related diseases (95% CI: 1.31–3.57, $p < 0.05$). Specifically among male welders, the risk was 2.24 times higher (95% CI: 1.34–3.73, $p < 0.05$) compared to non-welders. Furthermore, welders who smoked had a significantly elevated incidence of lung-related diseases with a risk of 2.44 (95% CI: 1.32–4.51, $p < 0.01$) compared to

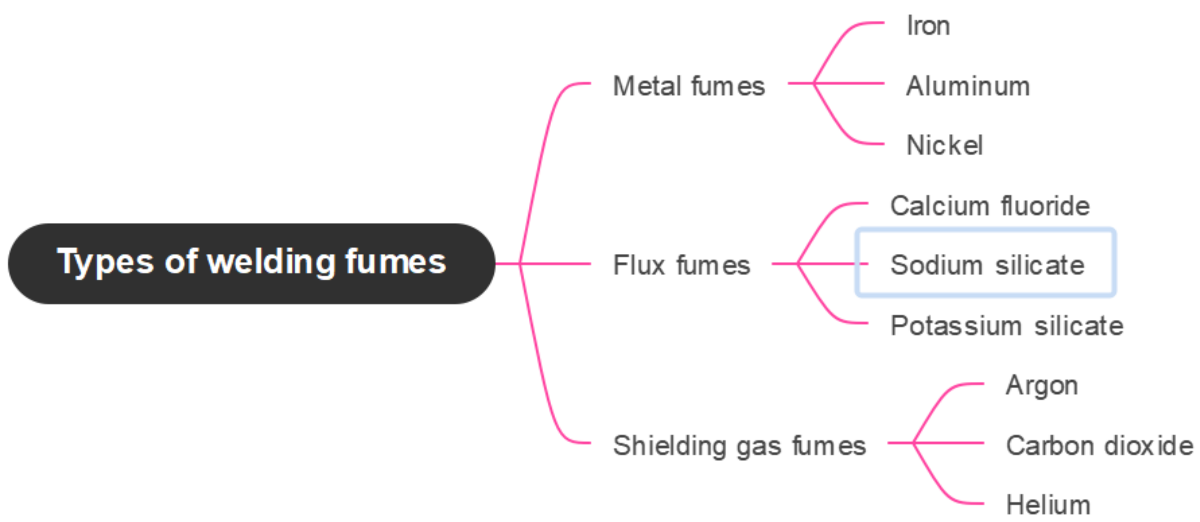

Fig. 1. Types of welding fumes

non-smoking welders. The total years of work acted as a protective factor, with each additional year associated with a decreased risk of lung-related diseases (OR 0.72, 95% CI: 0.66–0.78, $p < 0.01$). High-high and high-low exposure categories were identified as independent risk factors, with risks of 5.39 (95% CI: 2.52–11.52, $p < 0.001$) and 2.17 (95% CI: 1.07–4.41, $p < 0.05$) times higher for lung-related diseases, respectively. This introduction highlights the complex and concerning health risks associated with welding while emphasizing the ongoing research efforts to unravel the mysteries and mitigate the dangers for the millions who rely on this vital craft. It paints a compelling picture, urging us to look beyond the spark and acknowledge the shadow lurking within the fumes. Based on the above literature, the article encompasses the effect of welding fumes on the health of human beings and the safety measures to be taken.

MATERIALS AND METHODS

Ilorin South Local Government Area conducted a study focusing on self-employed electric-arc welders, journeymen, and apprentices. A cross-sectional study in January 2012 involved 285 respondents from 100 randomly selected workshops. Questionnaires assessed knowledge of welding smoke effects, and data were analyzed using EPI-INFO software. Results were presented through charts and tables. Scoring determined knowledge levels and usage of personal protective equipment was categorized as Always, Often, or Occasional during welding sessions(Adewoye *et al*., 2013). A six-axis robotic arm, power supply, water-cooled arc welding torch, and wire feeder were used for GMAW fume generation. Fumes were drawn through ports, diluted with air, and sampled in the exposure chamber. Concentration was determined with 1.0 l/min samples on 37 mm filters every 30 min. Filters were recovered and the fume was redeposited for metal analysis. Recovery exceeded 90%, and fume concentrations were determined gravimetrically. The recovered fume underwent antistatic treatment, grinding, and weighing for replicate analyses. The process ensured better precision with coefficients of variation typically 5–10%. The treated material was sealed for analysis, demonstrating recovery exceeding 95%(Keane *et al*., 2010). C57BL/6 and apoE−/− mice were exposed to GMAW-Stainless Steel welding fume at 40 mg/m3, with exposure conditions monitored. Pulmonary metal deposition was assessed in C57BL/6 mice. Atherosclerotic-prone apoE−/− mice were exposed to air or GMAW-Stainless Steel, and tissues were harvested for analysis, including serum chemistry, gene expression, and plaque evaluation. Plaque development in the aorta was quantified using imaging software and validated by Oil-Red O staining. Statistical analysis employed Student's t-test, with significance set at $p < 0.05$(Erdely *et al*., 2011). Mice exposed to GMA-SS welding fume (40 mg/m3) were monitored. Pulmonary metal deposition was assessed in C57BL/6 mice. Atherosclerotic-prone apoE−/− mice exposed to air or GMA-SS underwent analysis, including serum chemistry, gene expression, and plaque evaluation in the aorta. Plaque development was quantified using imaging software and validated by Oil-Red O staining The Student's t-test was used to evaluate statistical significance ($p < 0.05$)(Aritra Das *et al*., 2015). 84 welding apprentices in Southern Brazil, exploring risk communication on welding fumes' respiratory and cardiovascular effects were studied (Fig.2). The apprentices attended a four-month training program, and risk communication was implemented using a before-and-after design. A pre-test assessed participants' characteristics and perceptions, and risk communication was conducted through dialogues, literature review, and theoretical classes. A post-test was administered after two months. Descriptive analysis, t-tests, and Poisson Regression were employed for data analysis. Risk communication and preventive measures for welding apprentices' occupational health were attempted to be enhanced (Cezar-Vaz *et al*., 2015).

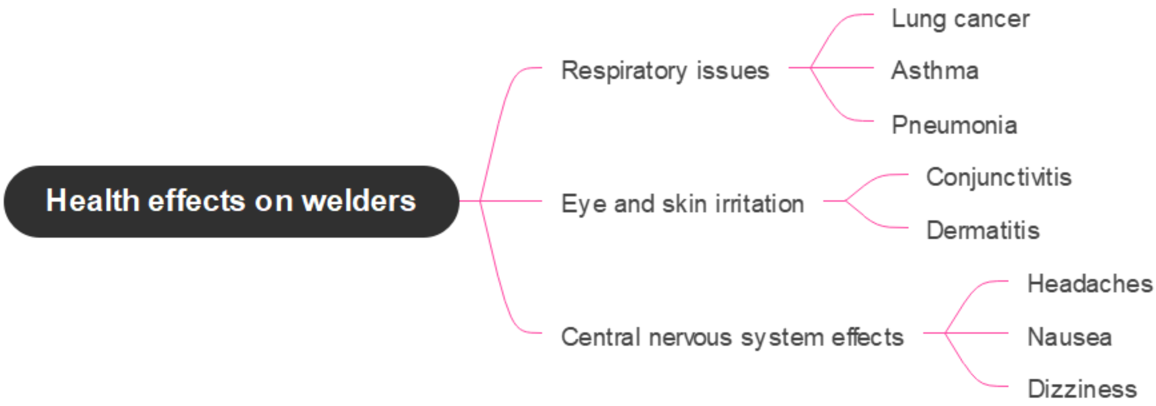

Fig. 2. Health effects on welders

LUNG CANCER

While the potential link between welding and lung cancer has been extensively studied, conclusive evidence remains elusive. Early studies suggested a possible, but unclear, association, often confounded by factors like smoking and asbestos exposure(Antonini *et al*., 2003). The debate was further divided over specific welding types: some research implicated stainless steel (SS) welding due to chromium and nickel presence, while others found elevated risks in mild steel (MS) welders as well. Animal studies haven't yielded definitive results either, with mixed outcomes regarding tumor formation and genotoxicity. (Riccelli *et al*., 2020)In vitro studies, however, showed both SS and MS fumes to be toxic to cells, with SS fumes exhibiting mutagenic and transforming effects linked to chromium and nickel. Further complicating the picture, recent studies paint a less conclusive picture. Some report no increased lung cancer risk in welders, while others show continued elevations. Additionally, DNA analysis in welders suggests potential damage and genotoxicity risk, but a direct connection to cancer remains unproven. (Loomis *et al*., 2022)Overall, the relationship between welding and lung cancer appears complex and multifactorial. While the evidence suggests a potential risk, more research is needed to identify specific causative agents, quantify risk across different welding types and exposure levels, and understand the interaction with other factors like smoking. Welding, while a valuable trade, can take a toll on the respiratory system. Welders face a spectrum of lung diseases (Fig.3), ranging from mild and temporary to chronic and life-threatening. Benign conditions like metal fume fever and siderosis may cause temporary irritation or iron oxide deposits in the lungs, while acute infections like pneumonia pose a more immediate threat. Chronically, fibrosis, asthma, and chronic obstructive pulmonary disease can develop, progressively impairing lung function. The gravest risk is lung cancer, a potentially fatal consequence of long-term exposure to welding fumes. (Rahul *et al*., 2019)This spectrum highlights the importance of proper ventilation, protective gear, and regular health monitoring for welders to safeguard their precious breath. The relationship between welding fume inhalation and lung function in welders remains complex and inconclusive. Studies conducted across diverse settings with varying exposure levels and ventilation conditions yielded ambiguous results. (MacLeod *et al*., 2017)While some point towards transient effects that reverse during non-working periods, others show minimal impact of welding alone on lung function. The severity of exposure, individual susceptibility, and additional factors like tobacco smoking further complicate the picture.(Kendzia *et al*., 2019) Notably, shipyard welders with heavy fume exposure in confined spaces exhibit greater

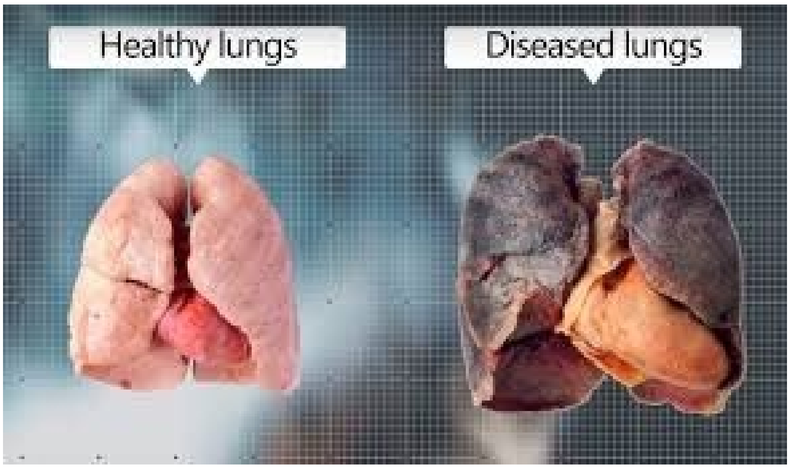

Fig. 3. Comparison of healthy and infected lungs of a welder

lung function decline compared to those in well-ventilated environments. While welding may be associated with work-related respiratory symptoms and minor across-shift lung function reductions, evidence for significant chronic effects is lacking. Unfortunately, the absence of studies using laboratory animals hinders definitive conclusions on the long-term pulmonary impact of welding fumes. Welders faced a heightened risk of developing specific lung cancer subtypes. (Honaryar *et al*., 2019)They were 50% more likely to suffer from small cell lung cancer compared to non-welders, with even occasional welders showing a significantly elevated risk. Squamous cell lung cancer risk also stood out, with occasional welders experiencing a 30% increase and regular welders a weaker, non-significant 20% increase.(Michalek *et al*., 2019) The link with adenocarcinoma was less pronounced, and no connection was found with large-cell lung cancers. Interestingly, when compared solely to other blue-collar workers, the increased risk associated with all subtypes except occasional welders' squamous cell carcinoma diminished, suggesting potential confounding factors within the wider population. (Riccelli *et al*., 2020)This finding underscores the importance of considering job-specific hazards within broader occupational contexts when assessing cancer risks.

Welders run a serious risk of developing lung cancer from prolonged exposure to welding fumes, which are a complex mixture of gasses that cause cancer and particles smaller than microns. Bypassing nasal filtering, these vapors deeply penetrate the sensitive alveolar region, where metal oxides, silicates, and chromium compounds cause oxidative stress, DNA damage, and chronic inflammation (Chadha & Singh, 2016). This starts a chain of events that leads to genetic alterations, unchecked cell division, and eventually the onset of lung cancer. The International Agency for Research on Cancer has classified nickel, chromium VI, and manganese found in welding fumes as Group 1 carcinogens, which further supports the connection between welding fumes and lung cancer pathogenesis (Li *et al*., 2022). Furthermore, the risk is increased by the synergistic effects of concurrent smoking exposure, underscoring the urgent need for all-encompassing preventive measures in welding workplaces. (Cherrie & Levy, 2020)Welding, a widespread industrial process, exposes millions of workers globally to hazards like metal fumes, ultraviolet radiation, and noise, with concerns about potential cancer risks, especially in stainless steel welding due to potential hexavalent chromium exposure, prompting recommendations for stricter control measures.

The following are the two case studies to represent the high and low risk of lung cancer.

High Risk of Lung Cancer

" Welding and Lung Cancer in a Pooled Analysis of Case-Control Studies"

This meta-analysis pooled data from multiple case-control studies and found a significantly increased risk of lung cancer among welders compared to non-welders. The study highlighted that exposure to welding fumes, which contain carcinogenic metals like chromium and nickel, contributed to an elevated risk of lung cancer. The findings suggested that long-term exposure in welding occupations could substantially increase the likelihood of developing lung cancer (Kendzia B *et al*, 2013).

Low Risk of Lung Cancer

"Occupational Exposure to Welding Fumes and Risk of Lung Cancer: Results from Two Case-Control" Studies in Montreal, Canada

This study investigated the association between occupational exposure to welding fumes and lung cancer risk in two case-control studies conducted in Montreal, Canada. Contrary to some expectations, the findings indicated that the overall risk of lung cancer associated with welding was relatively low when accounting for other factors such as smoking and concurrent exposures. The study emphasized the importance of comprehensive exposure assessment and control measures in reducing potential health risks associated with welding (Vallières E *et al*, 2012).

INFECTIONS

Research suggests a link between welding fume inhalation and an increased risk of potentially fatal pneumonia in welders.(Abdullahi & Sani, 2020) The Norwegian Labor Inspection Authority has even warned physicians to consider occupational exposure when diagnosing pneumonia in patients. Studies show that welders experience more frequent and severe respiratory infections, even across their entire working life (Knott *et al*., 2023). Cases like a welder with recurrent pneumonia due to fume exposure further highlight the potential severity. Analyses of mortality data also reveal a significant increase in pneumonia deaths among welders, suggesting a causal link (MacLeod *et al*., 2017). While the mechanism remains unclear, evidence points towards welding fumes potentially suppressing the immune system's antibacterial defenses, making welders more susceptible to lung infections. (Antonini *et al*., 2011)Welders face a significantly higher risk of developing pneumococcal pneumonia throughout their careers, with evidence dating back to the 1950s. Studies have consistently shown elevated pneumonia mortality rates among working-age welders, but not in older retirees. (Yang, Lin, Lin, *et al*., 2018)Research suggests exposure to ferrous fumes and recent work experience contribute the most to this risk, particularly for lobar pneumonia. While pneumococcal vaccination was initially recommended for welders in the UK, later guidelines focused on effective fume control as the primary prevention strategy. (Leso *et al*., 2019)Despite improved working conditions, pneumococcal pneumonia mortality remains high in young welders, highlighting the potential benefits of vaccination as a complementary measure. (Amani *et al*., 2017)While welding fumes offer little direct infectious risk, they can pose significant respiratory concerns. These fumes, a complex mixture of metal oxides and gases, can irritate the airways, leading to conditions like metal fume fever and welder's lung. (Khalaf, 2020)Inhaling certain particles like manganese or silica can also cause chronic lung damage over time. Additionally, exposure to ozone, a byproduct of arc welding, can exacerbate existing respiratory issues like asthma. To mitigate these risks, proper ventilation, respiratory protection like respirators, and adherence to welding safety protocols are crucial. Remember, prioritizing safety during welding practices goes a long way in protecting your respiratory health.

ASTHMA

Occupational asthma (OA) remains a concern for welders, despite conflicting evidence. (Bakri *et al*., 2020)While a large population study saw no link between welding and asthma, other research indicates a potential association, particularly with stainless steel (SS) welding and exposure to metals like Chromium (Cr) and Nickel (Ni). (Awosan *et al*., 2017)The development of OA can be immediate or occur years later, with symptoms ranging from coughing and wheezing to decreased lung function. Although some welders can continue working after diagnosis, many are forced to change careers due to persistent symptoms. (Falcone *et al*., 2018)Further research is needed to fully understand the mechanisms behind OA in welders and establish the true extent of the risk. Subjects with asthma and controls were selected based on standardized procedures and survey responses, involving a detailed recruitment process outlined in the flow chart. The time-dependent relationship between occupational exposure and asthma status, considering factors like onset age and clinical expression, was elucidated. Follow-up assessments included lung function tests and allergy evaluations. (Dumas *et al*., 2013)Asthma-onset age and clinical expression were defined over successive 5-year periods. To address missing data on asthma history, corrections were made, with comparisons conducted between subjects with and without missing data. (Torén *et al*., 1999) Comprehensive understanding of the relationship between occupational exposure, asthma, and associated factors in a well-defined cohort. (Lai *et al*., 2016) In Gothenburg, Sweden, 407 adult students with recent-onset asthma were identified from the Environment and Asthma in Gothenburg (MASTIG) study, alongside 1,904 controls randomly selected from the same area. Kendzia Asthmatics were identified based on medical care seeking for asthma-like symptoms between 1983 and 1986. Controls were from the population register of 1986. (Erdely *et al*., 2011)Asthma diagnosis criteria included a typical history and additional criteria such as PEF variations, bronchodilator response, and methacholine challenge results. The questionnaire in 1996 covered occupational exposures, certain occupations, respiratory symptoms, and smoking habits. Testing of hypotheses related to specific exposures (acrylates, isocyanates, welding fumes) and general exposures (dust, fumes, irritants) was carried out. The classification of occupational exposures was self-reported. The questionnaire response rates were 79% for cases and 77% for controls.

RESPIRATORY PROBLEMS

Welding fume, a potent cocktail of particulate matter and gases, wreaks havoc on the respiratory system. (Pourtaghi *et al*., 2009)Welding poses respiratory hazards due to metal fume exposure, with composition varying based on the welded metal; studies indicate associations with chronic bronchitis and respiratory symptoms, emphasizing the need for awareness and control measures. Its tiny, insidious particles, less than 5 microns in size, infiltrate the welder's lungs, settling deep within the delicate alveolar region. (Antonini *et al*., 2006)The detrimental effects were first unveiled by Groth & Lyngenbo's landmark study, which linked chronic bronchitis and even upper respiratory disorders like persistent colds and sinusitis to prolonged fume exposure. Subsequent studies by (Adewoye *et al*., 2013) painted a grimmer picture, showcasing fume-induced asthma and even a horrifying case of massive hemoptysis linked to alveolar hemorrhage. Han *et al*.'s research added another layer of concern, demonstrating increased heart rate variability in welders, a potential indicator of cardiovascular stress. (F. *et al*., 2007)These findings underscore the urgent need for increased health awareness among welders and stricter implementation of preventive measures like respirator use. (Keane *et al*., 2010) Research continues to delve deeper into the mechanisms behind these respiratory woes, but one thing is clear: welding fumes should be given utmost importance, and safeguarding the lungs of every welder is paramount. (Lai *et al*., 2016)Welding fume is a serious health hazard that can cause a variety of respiratory problems, including chronic bronchitis, asthma, and even lung cancer. (Erdely *et al*., 2011)The tiny particles in welding fumes are easily inhaled and can settle deep in the lungs, where they can cause inflammation and damage. (Fikayo *et al*., 2023) In addition to the respiratory effects, welding fumes can also cause other health problems, such as cardiovascular disease and neurological disorders. The gases in welding fumes can also be harmful and can lead to asphyxiation if they displace oxygen in the air. Several things can be done to protect welders from the health risks of welding fumes. (Roach, 2018)The most important is to use a respirator that is designed to filter out the fine particles in welding fumes. Other protective measures include good ventilation, wet grinding, and minimizing fume generation techniques. The respiratory assault doesn't end there. Studies by Osanloo *et al*. (2020) have linked chronic fume exposure to a heightened risk of pulmonary fibrosis, a scarring of lung tissue that impairs breathing. Meanwhile, research by Antonini and colleagues (2015) suggests welders may face a two-fold increased risk of developing lung cancer, fueled by the complex cocktail of carcinogens within fume particles. The threat extends beyond the lungs, too. Manganese, a common component of welding fumes, has been linked to neurological disorders like Parkinson's disease, according to studies by Racette *et al*. (2017). This ominous picture reinforces the critical need for comprehensive protection. Respiratory protective equipment (RPE) remains the frontline defense, demanding proper selection, fit-testing, and regular maintenance. Beyond RPE, ventilation systems tailored to specific welding processes can significantly reduce airborne fume concentrations. Implementing wet grinding techniques and choosing low-fume consumables further minimize exposure. Moreover, fostering a culture of safety through welder education and training empowers individuals to actively safeguard their health. (Dehghan & Mehrifar, 2019) Despite its vital role in fabrication, welding exposes workers to hazardous fumes containing elements like manganese and chromium, raising concerns about respiratory diseases and potential cancer. This study aims to measure fume and gas exposure in various welding processes to prioritize control measures and protect the 5 million welders in Europe alone. Each precaution, meticulously followed, becomes a brick in the wall against the invisible enemy - a testament to the unwavering commitment to protecting the lungs that give life to every weld.

METAL FUME FEVER

Metal fume fever (MFF), a flu-like illness caused by inhaling metallic oxides like aluminum and zinc in welding fumes, can easily be mistaken for a common cold. (Aminian *et al*., 2019) Diagnosis relies heavily on a welder's work environment and reported symptoms, which typically appear 24-48 hours after exposure and include chills, headache, muscle aches, cough, and breathlessness. Studies by Ross and El-zein *et al*. confirm this pattern, highlighting the increased risk of respiratory issues after 15-18 months of welding. (Dueck *et al*., 2021)The smaller the fume particles (less than 1mm) and their concentration (over 500 mg/m3 for 2 hours), the greater the health hazard. While 1500-2000 MFF cases occur annually in the US, managing symptoms with antipyretics, analgesics, and oxygen therapy is possible. (Borská *et al*., 2003)Ultimately, preventing the effects through proper ventilation, respirators, protective gear, and welder awareness remains crucial for safeguarding health in the welding industry. (Wanjari & Wankhede, 2020) A flu-like illness affects 1,500-2,500 people annually in the U.S. [Blanc *et al*., 1993]. This self-limiting, yet uncomfortable condition strikes with lightning speed, mimicking influenza within 4-8 hours. Nicknamed "Monday morning syndrome," "foundry fever," and "welder's ague," the illness manifests with chills, thirst, fever, and a metallic taste in the mouth [Martin *et al*., 1997]. Though short-lived, often resolving within 24-48 hours, it arises from inhaling zinc oxide fumes generated during welding galvanized steel [Sferlazza and Beckett, 1991]. Interestingly, repeated exposure breeds tolerance, leading to symptom-free Mondays after weekend breaks [Martin *et al*., 1997]. Despite its prevalence, metal fume fever remains shrouded in mystery. Research suggests lung inflammation triggered by pro-inflammatory cytokines like TNF-a, IL-1, and IL-6 plays a role, paving the way for further investigation into this common occupational ailment. This is a temporary flu-like illness caused by inhaling welding fumes, typically containing zinc but also other metals like copper, magnesium, and cadmium. Occurring around 4 hours after exposure and resolving within 1-2 days, it affects roughly 500-2000 welders yearly in the US, with nearly a third experiencing at least one episode. (Wardhana & Datau, 2014) While self-limiting, it carries potential consequences. Studies suggest it might predict the future development of welding-related asthma. Furthermore, research identifies the inflammatory mediator IL-6 as a potential early biomarker of exposure to zinc and copper welding fumes, (Wanjari & Wankhede, 2020) offering a tool for monitoring welder health and preventing more serious lung diseases. Despite its short-lived nature, it should not be ignored, as it warrants further investigation and proactive management to protect the health of welders(Schoonover *et al*., 2011).

WELDING FUME COMPONENTS AND ASSOCIATED HEALTH EFFECTS

It is observed acute systemic inflammatory responses following occupational exposure to high levels of fine particulate matter in a cohort of welders without overt cardiovascular diseases. Peripheral WBC counts, particularly neutrophils, increased immediately, but this acute effect was noted only among non-smokers. Sixteen hours post-exposure, a significant rise in CRP levels was observed in both smokers and non-smokers. The clinical significance of these acute changes in WBC and CRP levels due to welding fume exposure warrants further investigation(Kim *et al*., 2005). data on various negative health effects from welding fumes at low-to-moderate exposure levels are available, underscoring the urgent need for a health-based Occupational Exposure Limit (OEL) for welding fumes. This OEL should be based on a comprehensive evaluation of all health impacts of welding, considering the different welding methods. Some countries, such as Denmark (0.5–1.7 mg/m^3 depending on the welding process and material) and The Netherlands (1 mg/m^3), have already introduced such OELs. A general OEL for welding fumes does not eliminate the need for specific OELs for components like chromium, nickel, aluminium, lead, and manganese, which vary with the welding technique and material. Combining a general OEL with specific OELs helps ensure safe levels for various welding types. Additionally, setting an OEL is insufficient on its own; other measures, such as local exhaust ventilation and fresh-air respirators, are necessary. Health risks and ventilation measures must be clearly communicated, for instance, in safety data sheets accompanying welding electrode packages. Furthermore, welders over the age of 50 may be advised to vaccinate against pneumococcal pneumonia(Sjögren *et al*., 2022). Welding, a crucial process in modern industry, poses significant occupational health and safety hazards. Despite extensive research on welding fumes, particularly emission factors (EFs) and fume generation rates, substantial knowledge gaps remain. Easily accessible, comprehensive, and standardized EFs could greatly aid in managing welding fume hazards. This data allows occupational hygienists and welders to assess fume formation hazards more accurately and implement effective control strategies. EFs, being more accessible and directly related to work done, may be more practical than fume generation rates. Addressing future research recommendations systematically could enhance

Table 1. Common health risks, welding fume metal oxide compounds, gases, and exposure limits

Elements/ Compound	Health Risks	Control Measures	Exposure Limits (OEL's)	Concentration In Fumes/Units	References
Chromium (Cr)	DNA damage, cancer, respiratory issues	Use of protective gear (masks, gloves), ventilation	0.5 mg/m³ (as Cr VI)	Varies with the method, typically 0.5–1.5%	(Kim *et al.*, 2005)
Nickel (Ni)	DNA damage, cancer, respiratory issues	Protective equipment, proper ventilation	1.5 mg/m³ (inhalable fraction)	Varies with the method, typically 0.5–2.5%	(Kim *et al.*, 2005)
Lead (Pb)	Toxicity affecting multiple body systems	Protective gear, workplace hygiene	0.05 mg/m³	Trace amounts, typically <0.1%	(Chadha & Singh, 2013)
Manganese (Mn)	Neurological effects	Use of respirators, proper ventilation	0.2 mg/m³ (inhalable fraction)	Varies with the method, typically 1–5%	(Chadha & Singh, 2013)
Aluminium (Al)	Respiratory issues, metal fume fever	Use of protective equipment, proper ventilation	1 mg/m³ (respirable fraction)	Varies with the method, typically 1–3%	(Chadha & Singh, 2013)
Zinc (Zn)	Metal fume fever	Ventilation, use of masks	5 mg/m³ (as ZnO fume)	Varies with the method, typically 1–10%	(Rahul *et al.*, 2019)
Ultraviolet Radiation	Skin cancer (especially neck area)	Use of appropriate safety gear	N/A	N/A	(Rahul *et al.*, 2019)
Ozone (O_3)	Respiratory issues, eye irritation	Ventilation, use of respiratory protection	0.1 ppm (0.2 mg/m³)	Generated in arc welding, ppm range	(Sjögren *et al.*, 2022)
Carbon Monoxide (CO)	Headaches, dizziness, cardiovascula r effects	Proper ventilation, CO detectors	25 ppm (29 mg/m³)	Generated in arc welding, ppm range	(Sjögren *et al.*, 2022)
Iron Oxide (Fe_2O_3)	Respiratory issues, metal fume fever	Ventilation, use of masks	5 mg/m³	Major component, up to 50%	(Spear, 2004)
Molybdenum (Mo)	Respiratory issues, eye, and skin irritation	Use of protective equipment, proper ventilation	10 mg/m³ (inhalable fraction)	Trace amounts, typically <1%	(Sjögren *et al.*, 2022)

the use and reliability of welding fume EFs, potentially improving exposure modeling tools. Consistent and standardized methods are crucial for reliable EFs, and integrating emission factor calculations into ISO standards would further improve these procedures(Quecke *et al.*, 2023). Welders are exposed to complex compounds produced by industrial processes, resulting in elevated levels of trace metals like Cr, Ni, Pb, and Mn in their blood. Studies indicate that this exposure increases health hazards, including DNA damage, which can lead to serious conditions like cancer. Additionally, welders show elevated MDA levels, indicating oxidative stress. The risk is compounded by insufficient protective equipment and a lack of health awareness. To mitigate these risks, welders should use protective gear such as face masks, gloves, and light filters, and work in well-ventilated environments. Regular health checks are essential to reduce occupational health risks in the iron-based industry(Chadha & Singh, 2013). Flux-Cored Arc Welding (FCAW) produces the highest fume generation rate for mild steel welding, followed by SMAW, GMAW, and GTAW. Efforts to develop "low-fume" consumables have focused on reformulating flux-cored wires with low-carbon materials and fewer mineral compounds. When assessing exposure, consider the welding process, material composition, and specific factors such as task, workpiece position, and ventilation. High alloy materials often contain metals with lower occupational exposure limits, such as chromium and nickel(Spear, 2004). Welding fumes contain carcinogenic elements that may lead to chronic health issues upon prolonged exposure. Fume reduction is the primary strategy to avoid such issues. Exposure to ultraviolet radiation causes skin cancer in welders, particularly affecting the neck area due to insufficient safety gear. Welding fume fever is an acute health issue that can lead to long-term respiratory problems. Identifying symptoms of welding diseases requires checking the previous work history of welders. The addition of reactive metals like alumina, zinc, and titanium to welding electrodes has been found to mitigate fumes and their harmful constituents when tested in the Shielded Metal Arc Welding (SMAW) process. Additionally, nanosized calcite improves arc stability and weld deposition more effectively than its microsized counterpart(Rahul *et al*., 2019).

SAFETY MEASURES

Coastal South India assessed the awareness and practice of safety measures among welders. It revealed low awareness of hazards and safety measures, with limited utilization of protective devices. Factors like low education, lack of institutional training, and economic conditions contributed to inadequate safety practices among welders. The findings emphasize the need for intervention and improved safety measures in welding occupations, especially in developing countries facing challenges in implementing regulatory measures(Conte-devolx *et al*., 2019). The safety of laser beam welding in the context of pyrotechnic actuator manufacturing for AP1000 nuclear power plants is crucial. The analysis considers potential dangers, such as the risk of ignition during welding due to high-pressure hot gases and splashing melted metal. Safety measures include workshop improvements, equipment enhancements, design modifications like special fixtures, and specific welding techniques. These precautions aim to prevent accidents, ensuring the safety and integrity of the pyrotechnic actuator welding process, particularly in handling Sulfur-Free Black Powder, a sensitive material used in the actuator(Zhang *et al*., 2012). Ensuring safety in welding is paramount to prevent accidents and protect workers. Safety measures cover mental and physical readiness, proper use of personal protective equipment, ventilation for fume control, and precautions in confined spaces. (Fauzi *et al*., 2023)Additionally, guidelines address safe welding area practices, hot work permits, cutting container safety, oxyfuel gas welding precautions, proper ventilation, training, and electrical safety (Fig.4). The conclusion emphasizes collective responsibility, proper attire, and adherence to safety rules to mitigate the risk of accidents and injuries in welding environments(Tukur & Zhoude, 2013). Welders were exposed to fumes, sparks, and toxic gases, which could lead to health problems. It was recommended that welders should wear personal protective equipment (PPE) to protect themselves from these hazards(Alexander *et al*., 2016), Belmoro & Gumasing, 2023).

Welding, a vital craft shaping metal into marvels, demands unwavering vigilance for both body and mind(Hoefer *et al*., 2023),(Quecke *et al*., 2023). Invisible fumes whisper insidious

Fig. 4. Safety Measures

threats, molten sparks sear, and unseen currents crackle with danger. This dance with risk is amplified in developing nations, where shadows of inadequate education and lax regulations lurk(Ojima, 2023). Yet, hope blazes bright. (Hassim & Rozali, 2022)Training illuminates the path, equipping minds with hazard awareness and skillful hands with safe practices.(Pramitasari *et al*., 2022) Enhanced equipment shields bodies from harm, while strengthened regulations act as the steel beam of worker protection. (Reinhold & Pallon, 2014)From the delicate dance of laser beams in nuclear reactors to the sun-drenched workshops of coastal South India, the mantra remains the same: collective responsibility, unwavering adherence to safety protocols, and the right gear for the job. (Z 'gambo, 2015)Remember, a welder's safety is not just a personal shield, it's the guarantor of integrity in every weld, every bridge, and every machine that hums to life, a testament to the human spirit forged in the fires of vigilance. (Budhathoki *et al*., 2014)So let us raise a banner not just for the finished product, but for the unseen heroes who wield the torch, their safety woven into the very fabric of our world.

Welders in this study faced hazardous working conditions, which exposed them to numerous health and safety risks. Despite being aware of these occupational hazards and the personal protective equipment (PPE) needed, most welders did not use the recommended PPE, with none consistently using all required PPE. They frequently experienced acute health issues such as eye, nasal, and respiratory problems, metal fume fever, and cuts and burns on their hands and arms. The protective measures they used were insufficient against the hazards encountered. Education improved awareness of hazards and PPE usage, and older, more experienced welders were more likely to use PPE(Z 'gambo, 2015).

Several hazards were identified in some welding workshops, including unsafe gas cylinders and poorly organized workplaces. The use of homemade acetylene gas posed a risk of back flame and potential cylinder explosions. Welders were aware of common hazards such as bright light, welding fumes, and flying sparks and particles. Despite being aware of welding PPE, many welders did not use it. Common health impacts reported included burns, conjunctivitis, and irritation of the eyes, nose, and airways. Proper use of PPE could protect against acute health effects, but the study showed these effects were present among welders who used PPE sporadically or not at all. Coughing was the most reported symptom, followed by sneezing, stuffy nose, and runny nose, linked to exposure to welding fumes and dust(Panduragan *et al*., 2022). Physical hazards associated with welding activities in Embakasi include electric shocks, sharp objects, bright light, and excess heat. Factors such as hours worked, work experience, and PPE use significantly influence welders' knowledge of these hazards. Most welders reported experiencing cuts, burns, and electric shocks regularly. While safety goggles and insulated gloves were commonly used, the use of other PPE like face shields, respirators, and helmets was low, leading to increased eye and respiratory issues, along with cuts and burns. The study faced limitations due to recall bias and the transient nature of SME workers, along with social desirability bias in self-reporting. To mitigate these hazards, measures such as improved training on physical hazards, regular inspections by health and safety agencies, work safety intervention programs, and the establishment of a strong welder's union are recommended(Odhiambo *et al*., 2020). In January 2012, 285 respondents were interviewed. Among them, 6 (2.1%) had tertiary education, 136 (47.7%) had secondary education, and 126 (44.2%) had primary education. Nearly all respondents, 284 (99.6%), had apprenticeship training. However, 185 respondents (64.9%) had poor knowledge of the health effects of welding smoke. There was a statistically significant relationship between knowledge of welding smoke's health effects and the use of face masks during welding (p=0.0000), but not with the use of eye goggles (p=0.4558). Of the 23 respondents who used face masks, 43.5% always used them, 34.8% used them often, and 21.7% used them occasionally. Among the 273 respondents who used eye goggles, 51.3% always used them, 23.1% used them often, and 23.6% used them occasionally

(Adewoye *et al*., 2013). Welding is a hazardous profession that exposes workers to numerous physical and chemical risks, particularly without the proper use of personal protective equipment (PPE). Unprotected exposure can result in various health issues among welders. While using recommended PPE consistently can minimize these risks, many welders in eastern Nepal are unaware of the hazards and the necessary PPE. Instead of using respirators and welding goggles, they often rely on inadequate masks and sunglasses. Most welders are self-taught and lack formal training, leading to a weak culture of occupational safety and health (OSH). This study highlights the gap between welders' awareness of hazards and their actual PPE usage. To address this, interventions are needed to promote PPE use, with support from labor organizations and public health agencies to prioritize OSH in policy making(Budhathoki *et al*., 2014). The purpose of this activity is to reduce accidents and occupational diseases and to enhance workers' understanding of Occupational Safety and Health (OHS), particularly the use of PPE. Counseling on OHS can significantly improve workers' comprehension and motivation to use PPE correctly during welding, cutting, and smoothing processes. Over two months, PPE usage and proper equipment operation improved, leading to a 69.44% reduction in work accidents, with complete elimination of spark-related skin injuries. There were also notable decreases in hot flashes (82.86%), respiratory issues from welding fumes (72.73%), scratches (62.50%), and watery red eyes (43.24%). Continuous implementation and periodic monitoring of such activities are recommended for sustained safety improvements, not only at the SME welding workshop Dinoyo but also at other similar workshops. These programs can extend to other sectors requiring similar safety measures(Putri & Tjahjono, 2022).

RESULTS AND DISCUSSION

The investigation into the health effects of metal fumes from welding in a shipyard has unveiled significant dangers associated with welding occupations. (Lai *et al*., 2016) Welders of 300 in numbers in the districts of Jhapa, Morang, and Sunsari, were affected by the adverse effects of welding materials and conditions on particle sizes, compositions, and dispersion patterns. These factors pose health risks to workers who may inhale hazardous particles, underscoring the importance of protective gear and alternative welding techniques. (Kirichenko *et al*., 2018) The research demonstrated the need for enhanced safety precautions by highlighting common occupational health problems among welders, including respiratory ailments and injuries. A strong correlation was found between age, length of employment, and daily welding hours,(Budhathoki *et al*., 2016) further emphasizing the importance of understanding and mitigating risks associated with welding occupations. Focus was extended to 52 boilermakers exposed to welding fumes, revealing alterations in metabolites linked to inflammation. These findings suggest potential biomarkers (Krajnak, *et al*, 2017). Thomas & Benjamin M. Davis, Glen F. Rall, 2017)for occupational risks that could be utilized for health monitoring, although additional investigation and validation are required (S. *et al*., 2018)to establish their reliability. Despite inconsistent symptoms among welders exposed to mild steel welding fumes, subclinical inflammatory effects were observed in blood, nasal lavage, and exhaled breath condensate, particularly in those experiencing work-related symptoms. This indicates potential respiratory risks(Roach, 2018), necessitating further research to explore mechanisms and early biomarkers of airway effects in welders(Dierschke *et al*., 2017). It was understood that the effects of mild steel welding fumes on mice's lungs, revealing that these fumes promoted lung tumors even in the absence of known carcinogenic metals(Rehman *et al*., 2018). This suggests possible risks for welders and raises concerns about welding safety, speculating on the potential immune system and epigenetic impacts(Bakri *et al*., 2020). Despite only inducing mild lung inflammation, welding fumes high in iron and manganese were shown to stimulate the growth of lung cancers in mice. (Yang, Lin, Lin, *et al*., 2018)Welders often get hurt on the job because they don't use safety equipment or because their workplaces are unsafe. Welders who work with stainless steel are at risk of cancer from exposure to chromium and nickel in the fumes. (Wardhana & Datau, 2014)Metal fume fever is a temporary flu-like illness caused by inhaling metal fumes, usually zinc oxide from welding. It is treated with rest and avoiding future exposure Employers should use source control and ventilation to reduce exposure, and provide respirators if necessary,(Yang, Lin, Young, *et al*., 2018) Welding fumes are mostly coarse particles containing iron, aluminum, and zinc. These metals can dissolve in lung fluids and potentially cause harm. They need more training and better equipment to stay healthy. (Amani *et al*., 2017)This highlights worries about the safety of welding practices and underscores the need for comprehensive safety measures and guidelines. (Awosan *et al*., 2017)Welders are aware of the dangers of their job and how to prevent them, but they often don't use safety gear because it's not available or uncomfortable. A large welding study finds elevated cancer risk for lungs, mesothelioma, bladder, and kidneys. (MacLeod *et al*., 2017)This leads to a lot of preventable injuries. Fe2O3 is a lung tumor promoter in vivo and may be the primary metal oxide responsible for the carcinogenic effect of SS fume. (Erdely *et al*., 2011) Furthermore, the research indicated that long-term exposure to welding fumes led to pulmonary inflammation and reproductive changes. In contrast, short-term exposure to varying levels of manganese affected rats' neuroendocrine function and sperm production. These findings suggest potential neurotoxic effects and emphasize the potential value of circulating prolactin as a biomarker for assessing the impact of welding fumes on reproductive health. (Hariri *et al*., 2012)Toenails are a promising non-invasive biomarker for long-term heavy metal exposure due to their ease of collection, stability, and protection from contamination. Welding fumes and gases can be dangerous, giving welders health problems like lung issues, brain problems, and even cancer. Welders should wear safety gear to protect themselves(Chadha & Singh, 2016). To inform occupational health programs, further research with a larger sample size is needed, along with an investigation into the long-term effects on the aging pulmonary system of welders exposed to mild steel welding fumes, particularly those exhibiting work-related symptoms. Safety measures like masks, helmets, shielding glasses, and aprons are to be made mandatory in the safety protocol (Fig.5).

SUMMARY

In summary, this comprehensive review illuminates the multifaceted nature of welding fume exposure and its potential health implications. The trend of articles published from the year 2001 to 2024 is presented in Fig.6. Fig.7 indicates countries that contributed to the study of the welding fumes and safety issues. The choice of welding parameters, shielding gases, and

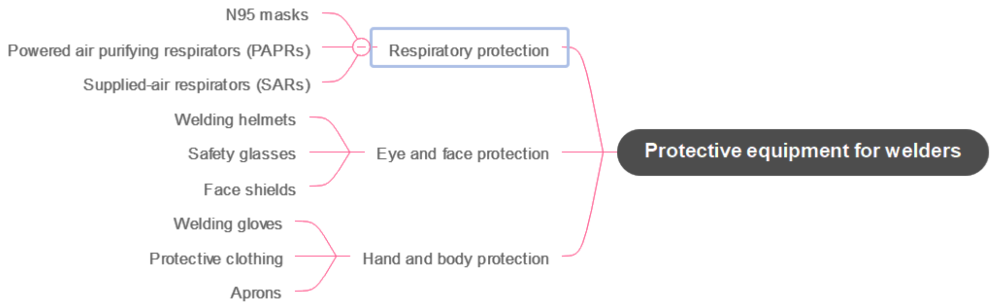

Fig. 5. Protective Equipment

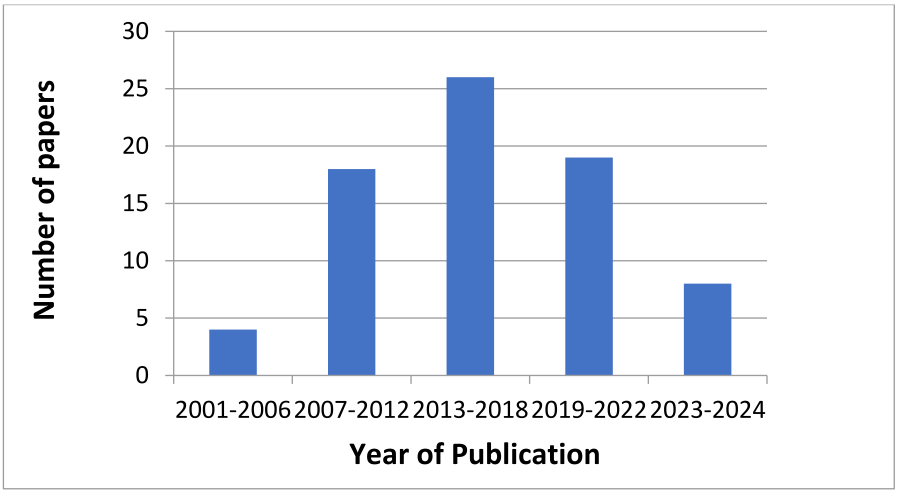

Fig. 6. Distribution of papers considered based on the year of publication

materials significantly influences the composition and characteristics of fumes, highlighting the need for nuanced risk assessment strategies. The inadequacy of general exhaust ventilation in controlling welding fumes advocated for the implementation of local exhaust ventilation systems. Notably, the identification of increased lung damage and inflammation from MMAW-HS fume, with its potential neurotoxic effects, underscores the importance of targeted research to quantify associated risks. Similarly, the complexity of minimizing Cr VI exposure in stainless steel welding is highlighted, suggesting a prioritized hierarchy of engineering controls. There is a potential link between welding fume exposure during pregnancy and adverse birth outcomes, necessitating further research for confirmation. Neurological problems faced by Bay Bridge welders emphasize the critical need for proper ventilation and worker protection in confined spaces. The immediate inflammatory response in non-smokers due to welding fumes, along with elevated CRP levels, warrants further investigation into the long-term health impacts. The diverse and complex nature of welding fumes, necessitating a combination of imaging and analysis techniques for comprehensive characterization was witnessed. The identification of specific welding processes that significantly reduce Cr VI exposure offers practical insights for safeguarding pulmonary health. Overall, this extensive compilation of findings not only advances our understanding of the health risks associated with welding fume exposure but also underscores the imperative for continued research, targeted prevention measures, and improved worker protection strategies. The collaboration of researchers, industrial practitioners, and policymakers is crucial to addressing the identified knowledge gaps and ensuring the well-being of welders worldwide. Figure 8 depicts the various occupational diseases caused by welding

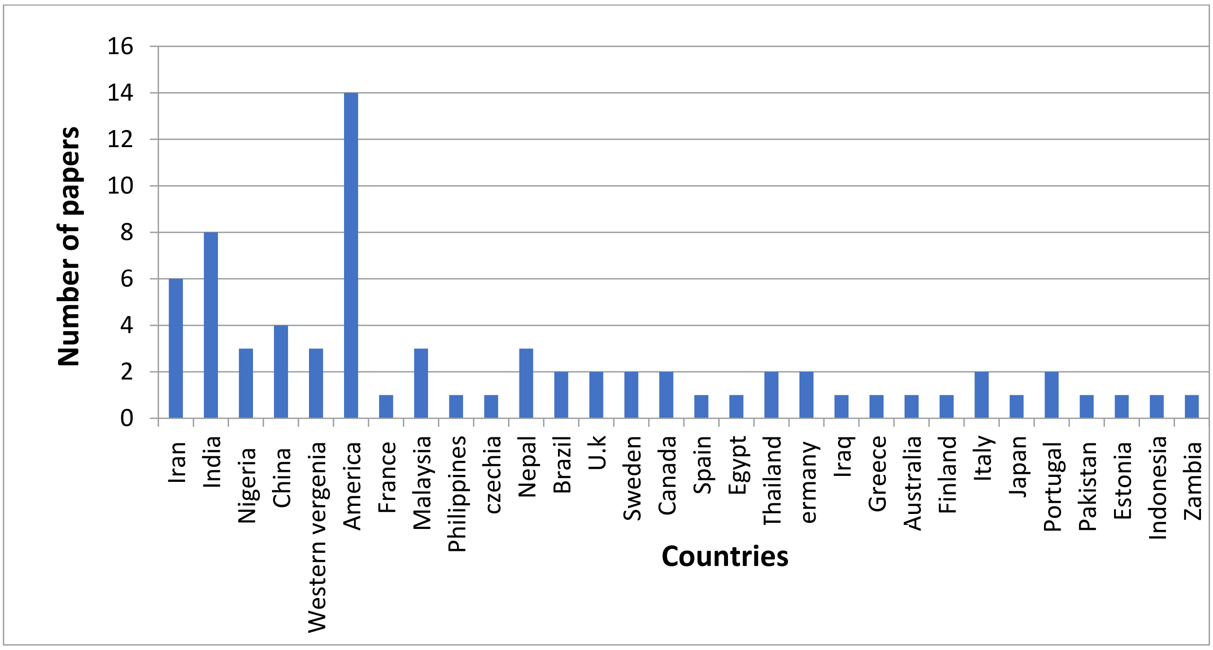

Fig. 7. Distribution of papers based on Country

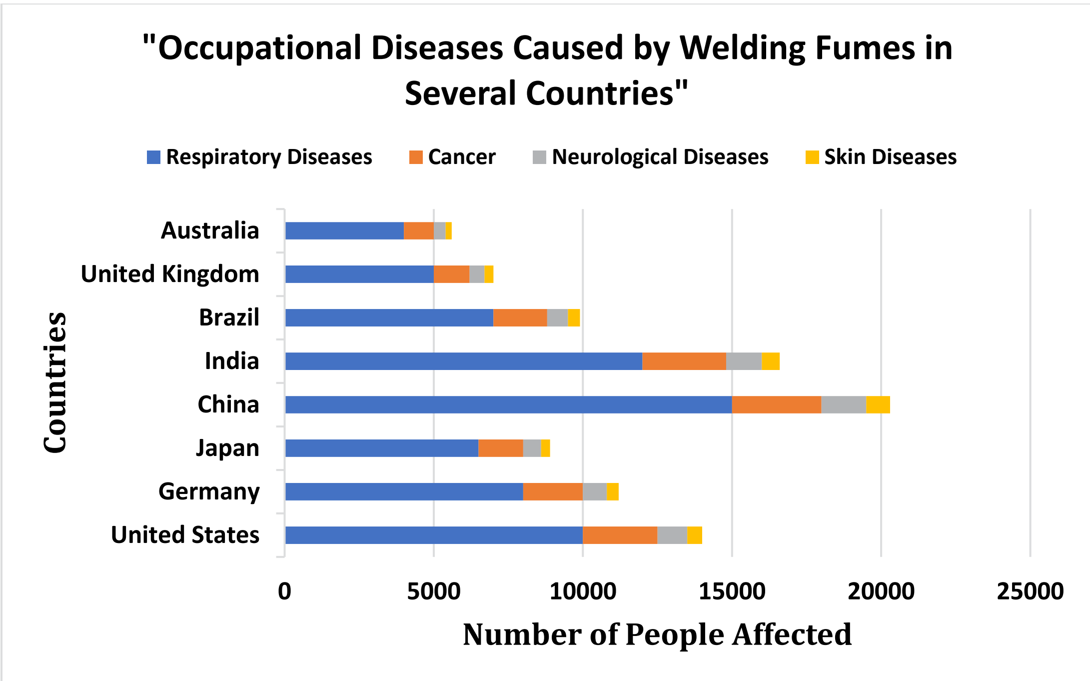

Fig. 8. Occupational diseases across various countries

fumes spread across various countries. It is visible that China is most affected by the respiratory diseases and cancer. The least affected is Australia. But we also should consider the population of the countries.

CONCLUSIONS

The occupational hazards associated with welding fumes encompass a spectrum of respiratory ailments.

Welders exhibit a [43%] heightened risk of developing lung cancer compared to the general population, emphasizing the urgent need for protective measures. Moreover, their susceptibility to respiratory infections is evident, with welders facing an increased likelihood of infection.

Metal fume fever, another concern, affects welders disproportionately, with a higher incidence rate than individuals in non-welding occupations. Additionally, welders experience an elevated risk of developing asthma, underscoring the imperative for proactive measures.

According to the Bureau of Labor Statistics (1999), more than half a million welders in the world either die or get injured every year. Nearly 3 million workers die every year due to work-related accidents and diseases as stated by International Labour Organization (2023)

To mitigate these risks, stringent ventilation systems, adherence to safety protocols, and consistent use of respiratory protective equipment are paramount, safeguarding the respiratory health of welders and promoting a safer work environment.

It is recommended that adequate ventilation, the use of personal protective equipment, the application of engineering controls, providing training and awareness to all employees, hygiene practices, and regular monitoring are followed to avoid the effect of welding fumes.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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