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THE EFFECTS OF ARC WELDING HAZARDS TO WELDERS AND PEOPLE SURROUNDING THE WELDING AREA

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ABSTRACT

Arc welding is a family of fusion welding processes that utilizes heat of an electric arc for the purpose of welding. In every arc welding method, safety should be the paramount consideration. It requires the most protection of the face, body and welding area during welding to reduce the welding hazards to welders and non-welders. The intensity of the arc produces strong ultraviolet and infrared radiation, fumes and dusts. Any person exposed during the welding process can be affected.

This paper is adapted from different publications to provide an overview of welding hazards, health effects and safety measures. The review describes information currently available from different published research works. It involves the group of people that can be affected by arc welding hazards including arc welders, the crafts constitute the subset of welding group, passerby, bystanders and residents near the welding shop.

It has been revealed from different studies that the profession is very hazardous and most of the stakeholders involved possess limited knowledge of welding hazards and hence to avoid these hazards, it is advised to abide to all safety measures.

Key words: Arc Welding Processes, Welding Hazards, Health Effects, Safety Measures.

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1. INTRODUCTION

Welding is a process of joining two metal parts together by applying intense heat between them, which causes the parts to intermix after melting. Welding processes are widely used for the manufacture of shipyards, civil engineering structures, mining industry, transportation means, petrochemical industry, and metallurgy [1].

Workplace is an important part of human environment. The health and efficiency of workers in any organization get influenced in large extent by conditions in their work environment. It is an established fact that no occupation exists without risk of hazard [2]. Arc welders and other

people surrounding the welders have potential exposure to a number of hazards [3]. Arc welding is a safe process when sufficient measures are taken to protect the welder from potential hazards and when proper operating practices are followed [2, 4]. According to World Health Organization (WHO), there are about 250 million cases of work-related injuries per year worldwide. One of the jobs that contribute to these occupational injuries is the welding process, especially in developing countries [2, 5]. Welding is common indispensable procedure in engineering works and is associated with varied health hazards apart from injuries. Welding operations lead to production of gases and small solid particles, together known as welding smoke. Most of this is produced during arc welding [1, 2]. Major hazards welders can encounter if these dangers are overlooked include fumes and gases, arc rays and sparks, and electric shock [6]. The thermal effects can cause agglomeration of the particles into particle chains and clusters that can be deposited in the human respiratory tract. Most of the fume particles are less than 1micron in diameter when produced, but they tend to grow in size with time due to agglomeration [1]. Arc welding produces the full spectrum of ultraviolet radiation (UVR). It is possible that welders are at greater risk of developing skin cancer than the general population. Furthermore, thermal burns from hot metal can occur when welding and contribute to increased risk of developing actinic skin and ocular damage [7]. Electric shock from welding and cutting equipment can result in death or severe burns. Additionally, serious injury can occur if the welder falls as a result of the shock [8].

2. ARC WELDING HAZARDS

Normally operations are not hazardous but a completely safe work-place is something non-existent in the world. Because welding generally requires the use of electric current (including high frequency high voltage current) and compressed gases as well as it involves burning of fluxes, coatings, and gases therefore it may lead to accidents due to negligence and thus prove hazardous [9]. The profession is regarded as the most hazardous and not all welders are aware of all the Hazards [10]. The hazards which are more or less peculiar are: fumes and gases; arc radiation; fire and explosion; electric shock; and compressed gases [9, 11].

2.1. Welding Fumes and Gases/Dust

Shielded Meatal Arc Welding (SMAW), Submerged Arc Welding (SAW), Gas Tungsten Arc Welding (GTAW), and Gas Metal Arc Welding (GMAW), cause very small particles that are formed when the vaporised metal rapidly condenses in air, and are typically too small to be seen by the naked eye, but collectively, form a visible plume. These fumes can be harmful if inhaled through the nose and mouth of the welder. The content of the fumes may be either asphyxiating or toxic [12, 8].

The electric arc welding processes generate dust and particulate fumes, which when inhaled regularly over long periods can result in serious effects of the welder's health. The fumes and dust generated during arc welding may be carried into the zone around the welder's face by convection currents rising from the arc. Metallic vapours, mostly oxides and silicates of metals, react with atmospheric oxygen resulting in the formation of fine dust. Especially dangerous are the oxides of zinc, lead, cadmium, beryllium, and copper formed during welding copper, brass and bronze [9].

Also during arc welding, the atmosphere surrounding the welder is contaminated with manganese compounds, nitrogen oxides, ozone, carbon monoxide, and fluorides. Some fluxes on melting give off oxides of manganese in dust form as well as hydrogen chlorides and fluorides. In carbon dioxide (CO_2) welding, carbon monoxide may be produced by decomposition of CO_2 in the shielding gas or of carbonates in flux cored wire [9].

Some of the effects of fumes on welder and surrounding people including irritation of the respiratory tract resulting in dryness of the throat, coughing, chest tightness, and breathing difficulties. In this respect cadmium fumes have the worst effect. It can also result, in acute influenza-like illness called metal fever. Continuous exposure to metallic fumes and dust can lead to systematic poisoning and fibrosis causing the formation of fibrous or scar tissues in the lungs [9, 13]. Therefore, health effects associated with metal fumes depend on the specific metals present in the fumes, but there is a concern that these may range from short-term illnesses, such as metal fume fever (i.e. flu-like symptoms), to long-term lung damage and/or neurological disorders, such as lung cancer and/or Parkinson's disease [8].

Fine particles are more hazardous than coarse particles because they can pass through the nose and throat and lodge in the lungs, causing lung damage and premature death in persons with heart or lung disease [14]. The most breathable particles are of sizes from 0.1 to 5 μm; particles with more than 5 μm in size are deposited in the upper respiratory tract and those with less than 0.1 μm in size are mainly removed from the body by exhalation [15]. Thus, welding fume particles are among the most breathable ones. Fig. 1 shows particle sizes for a number of familiar pollutants [1, 8, 15].

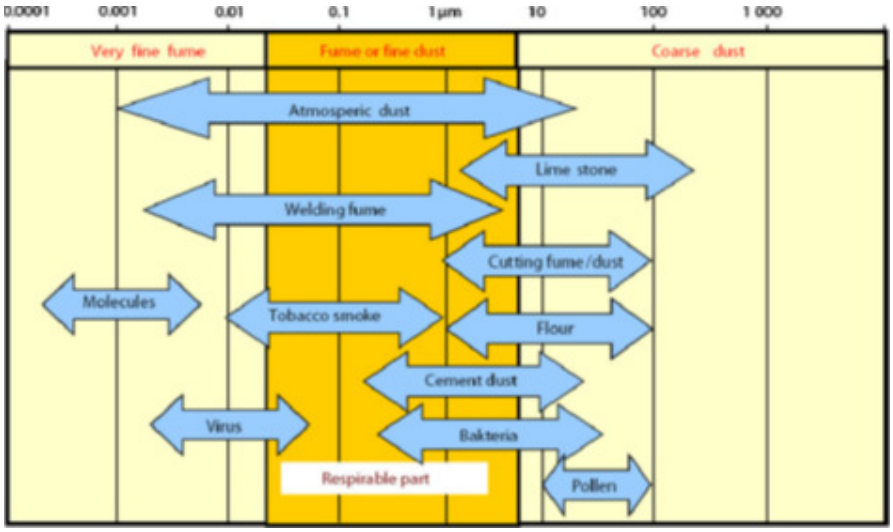

Figure 1 Particle sizes for different pollutants

Fig. 2 shows the concentration of respirable particulates in breathing zone of welders and non-welders. The average concentration of respirable particulates in the breathing zones of welders was four times as high as in the breathing zones of non-welders [1,16].

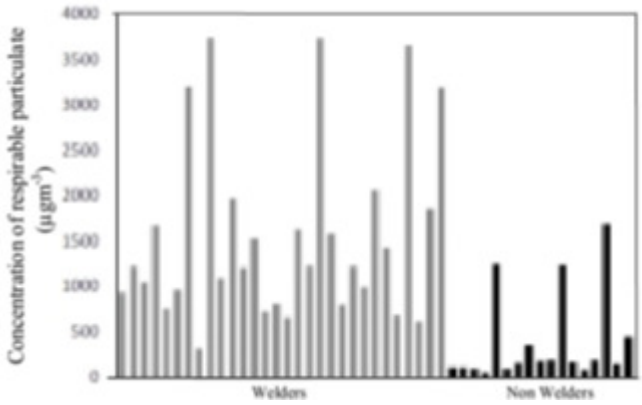

Figure 2 Concentration of respirable particulates in breathing zone of welders and non-welders [1, 16].

Fumes and gases are minimized by: working in a well ventilated area; wearing proper respirator when necessary; using materials and welding process which generate fewer fumes; Keeping the head out of the fumes, and avoiding breath the fumes [12, 17].

2.2. Electric Arc Radiation

An electric arc gives off visible light (wavelength 0.4 to 0.75 μm) of high intensity with a brilliance 10,000 times the safe glare level of the eyes. The intensity of emitted light depends upon the current level, and the presence of flux [9, 12]. The welding arc also emits ultra violet (UV) and infra-red rays [7, 9, 12] with wave length less than 0.4 μm and higher than 0.7 μm respectively [9]. UV rays can damage both eyes and skin. Even an accidental exposure to UV light from an arc can cause a condition known as arc eyes. This is characterized by painful gritty feeling as if sand has gone under the eye lids. This painful condition does not develop immediately after exposure and may take 4 to 8 hours and normally takes 24 to 48 hours to disappear [9, 18, 19].

Radiation in the visible and near infrared spectrum (400-1400 nm) penetrates the eye, to be absorbed by the retina where, given sufficient intensity and duration, causes thermal or photochemical damage which may be permanent and sight threatening [18].

Welders' face shields are fitted with shaded lenses that help to protect their eyes from ultraviolet (UV) radiation, which prevent arc eye or welder's flash. Unfortunately, some other crafts do not have the protecting gears and many passerby and residents leaving near the welding shops do not even know that the arc's bright light can burn their eyes in just a few seconds. In fact, many welding-related eye injuries each year are to bystanders, passerby and residents who are watching someone that welds. [3, 12]. A summary of actinic UVR hazards are posed to persons working around electric arc welding processes as follows [20]:

- **Hazardous Exposure.** The level of hazardous exposure affecting welders' helpers and other personnel forklift and overhead crane operators, for example) located in the vicinity of open arc welding can now be determined. The intensity and wavelengths of nonionizing radiant energy produced depend on many factors such as the process type, welding parameters, electrode and base metal composition, fluxes, and any coating or plating on the base material.
- **Exposure Time.** Exposure to actinic UVR is considered to be cumulative with each exposure over an 8 hours workday and within a 24 hours period. Therefore, two 5 min exposures during a workday could be considered as a single 10 min exposure.
- **Reflections.** Actinic UVR can reflect significantly from some common surfaces and these reflections might also create potentially harmful exposure to unprotected personnel. Unpainted metals (particularly aluminium) and concrete floors readily reflect actinic UVR. On the other hand, lightly coloured paints often use pigments of zinc oxide or titanium oxide and have a low reflectance of actinic UVR.
- **Safety Information.** Welders, welders' helpers, and their supervisors should periodically include a discussion of actinic UVR hazards in normal safety reviews and within written safety procedures. Concern for actinic UVR is especially important to discuss with new employees and personnel who work in the vicinity of open arcs.
- **Nearby Persons.** Persons in the vicinity of welding operations can be protected from exposure to actinic UVR by use of screens, curtains, or adequate distance from aisles, walkways, etc. Welders' helpers, overhead crane operators, and forklift operators who have a line of sight to any open arcs should consider wearing appropriate safety equipment such as safety glasses with side shields or even a clear, full-face shield and long-sleeved shirts.
- **Skin Protection.** While standards exist for welders and their helpers, skin protection has not been uniformly prescribed for other personnel who work in the vicinity of open arcs. Fabric measurements have shown that natural materials (leather, cotton, wool) are better for absorbing

actinic ultraviolet radiation than synthetic materials (polyester, nylon). Incidental personnel should consider wearing a long-sleeved shirt.

- **Warning Signs.** Warning signs are useful when persons unfamiliar with actinic UVR and other welding hazards are nearby. Such warnings are especially important to have on portable welding screens that can be used at field sites near the general population. A suitable sign could simply state "Danger" or "Warning" and be posted conspicuously at entry points or doors to welding areas. Such signs might also include the warning "Avoid Exposure of Eye and Skin to Arc and Harmful Ultraviolet Emissions."

2.3. Fire and Explosions

Fire in a welding area can be caused by the ignition of inflammable or combustible materials lying in the vicinity of the welding zone, and also due to electrical short-circuit. Electric arcs, hot metal, slag, sparks and spatter are sources of ignition and explosion if precautionary measures are not followed. A safe distance for welding in the general area of combustible materials is normally considered to be 10.7 m. Many of industrial fires have been caused by sparks that can be flying to a certain area with combustible materials [9, 12, 21]. Sparks and molten metal can travel greater distances when falling. Sparks can pass through or become lodged in cracks, clothing, pipe holes, and other small openings in floors, walls, or partitions. Typical combustible materials inside buildings include: wood, paper, rags, clothing, plastics, chemicals, flammable liquids and gases, and dusts. Parts of buildings such as floors, partitions, and roofs may also be combustible. Typical combustible materials outside buildings include dry leaves, grass, and brush. Welding can cause explosions in spaces containing flammable gases, vapors, liquids, or dusts. Special precautions are needed for any work on containers [21]. The following measures have to be taken to avoid fire and explosion hazards [21, 9, 12]:

Remove combustible materials for a minimum radius of 35 feet (10.7 metres) around the work area or move the work to a location well away from combustible materials. If relocation is not possible, protect combustibles with covers made of fire resistant material. If possible, enclose the work area with portable, fire-resistant screens. Cover or block all openings, such as doorways, windows, cracks, or other openings with fire resistant material. Do not weld material having a combustible coating or internal structure, such as in walls or ceilings, without an appropriate method for eliminating the hazard. After welding, make a thorough examination of the area for evidence of fire. Keep appropriate fire extinguishing equipment nearby, and know how to use it. Do not weld in atmospheres containing reactive, toxic, or flammable gases, vapours, liquids, or dust. Do not apply heat to a workpiece covered by an unknown substance or coating that can produce flammable, toxic, or reactive vapours when heated. Do not apply heat to a container that has held an unknown substance or a combustible material unless container is made or declared safe. Provide adequate ventilation in work areas to prevent accumulation of flammable gases, vapours, or dusts. No smoking should be allowed in the welding area where inflammable goods are being used.

2.4. Electric Shocks

Electric shock is defined as a sudden violent response to electric current flow through any part of a person's body. *Electrocution* is death caused by electric shock. *Primary electrical injury (230, 460 V)* is tissue damage produced directly by electrical current or voltage. *Secondary injuries (20 – 100 V),* such as falls, are common [4, 13, 22]. Electric shock may occur in welding if current happens to pass through the welder's body; the magnitude of the current depends upon the resistance offered by the body. A current of 0.1 A or above, be dc or ac, is taken to be lethal to humans. Since the human body resistance is a maximum of 600 ohms, the lethal current is provided by voltage of 60 V (V = IR). In human body the maximum resistance is offered by the skin, however, wet skin has lower resistance than the dry skin. Generally, it is taken that

current up to 0.002 A do not produce pain, those between 0.002 and 0.05 A do so and are dangerous, and those higher than 0.05 A cause heavy shock and can be lethal [9].

To avoid electric shocks, Read all instructions, labels, and installation manuals before installing, operating, or servicing the equipment and train all personnel involved in welding operations to observe safe electrical work practices also touching the live electrical parts should be avoided. Have all installation, operation, maintenance, and repair work performed properly and only by qualified people and input power cord for damage or bare wiring should be inspected and replaced immediately if damaged. Further, do not work alone where there are electrically hazardous conditions. Wear dry, hole-free, insulating gloves in good condition and protective clothing. Do not touch the electrode with a bare hand. Insulate yourself from the workpiece and ground using dry insulating mats or covers big enough to prevent any physical contact with the work or ground and the electrode holder has to be well insulated and dry. Do not allow the electrode holder or electrode to come in contact with any other person or any grounded object and not wrap cables carrying electric current around any part of the body. Special care must be taken when welding in confined spaces like inside a boiler, tanks or pipes which usually have ample contact with the ground; due to low contact resistance even a low open circuit voltage (OCV) of the welding power source may become dangerous to the operator. Extra precautions are also needed when welding outdoors after rain or snow. In all these cases it is imperative to use protective means like dielectric gloves and rubber mats atc [22, 24].

2.5. Compressed Gases

Gases used in arc welding processes are the shielding gases. Shielding gases used in arc welding are argon, helium, and carbon dioxide [9]. The gases have a remarkable effect on the overall performance of the welding system. The main function of these gases is to protect the weld pool from adverse reactions with atmospheric gases. Oxygen, nitrogen and water vapour present in ambient air can cause weld contamination. Weld shielding, always involves removal of potentially reactive gases from the vicinity of the weld, preventing the detrimental effects on the molten metal of the surrounding atmosphere. Shielding gases can also stabilize the arc and enhance the metal transfer mode in arc welding processes. The shielding gas also interacts with the base and filler metal and can thus change basic mechanical properties of the weld area, such as strength, toughness, hardness and corrosion resistance. Shielding gases moreover have important effects on the formation of the weld bead and the penetration pattern. The application of different shielding gases can result in different penetration and weld bead profiles [25]. However, apart from all these important effects the gases have to be handled with care. These gases are stored in compressed gas cylinders which are potentially hazardous because of the possibility of sudden release of gas by removal or breaking off of the valve. High pressure gas escaping from such a cylinder causes it to be like a rocket which may smash into people and properties [9]. In storage, transport and operation of compressed gas cylinders it is imperative to observe the following rules [9]:

Whether in use or stored, the cylinders should be kept vertical and secured to prevent falling by means of chains and clamps. Hammers or wrenches should not be used to open cylinder valves. Proper trolley should be used for moving cylinders from one point to another in the workshop. The cylinder should never be carried on shoulders because in case it falls it can not only injure the person but may also explode. Compressed gas should not be exposed to sunlight or heat as this may lead to increase the pressure leading to explosion. The temperature of gas cylinder should not be allowed to exceed 54 ^{o}C. Cylinder valve should be opened gradually without jerk otherwise it may damage the regulator diaphragm. Cylinders should be provided with their caps during storage and transport.

Figure 3 Welders at work using only sunglasses without protecting gears during welding (a) in Nepal [10], (b and c) in Tanzania [12]

3. REMARKS FROM DIFFERENT RESEARCHERS

To minimize ocular injury and promote eye health among industrial welders, it is recommended that work safety intervention programs should be carried out by eye care providers through leaflets, posters, and television and radio advertisements [6].

The education and training of employers and employees on Occupational Health and Safety (OHS) issues, a great European challenge, needs to be expanded in order to address also the highly demanding field of radiation. Radiation experts can play a critical role in highlighting the characteristics, hazards and protection approaches required to deal with this field [26].

Health and safety in welding are very important issues that need to be addressed worldwide. Europe is strongly investing in clarifying the long term impact of the use of welding technologies in the human body [15].

Suitable means of protection from UVR exposure while arc welding include wearing protective gloves together with clothing that covers the arms and forearms down to the gloves. However, the radiant heat from welding can be quite uncomfortable, and welding on a hot day compounds the problem. Discarding heavy welders' clothing and gloves in favour of short-sleeved shirts (unbuttoned at the top) exposes the hands, forearms, neck and manubrium to a considerably increased level of UVR. Wearing protective clothing while welding is a hindrance not only for full-time welders. Other tradespeople who perform welding occasionally (e.g. motor mechanics) find it inconvenient to put on protective clothing, while sculptors and tradespeople doing highly intricate work also experience difficulty in achieving fine detail when wearing heavy clothing and thick gloves. Furthermore, while welders are invariably trained in health and safety issues, assistants or other workers in the vicinity may not be aware of the possible risks [7].

Welders have been advised to minimize the chance of overexposure to welding fume using adequate ventilation and keeping heads out of the plume. However, welding requires close observation and many workers tend to put their head where ever necessary to see the work. This may include putting the head in the plume if required [27].

In order to effectively protect welders from combined exposure to welding fumes and gases, use of the supplied air respirator, or combined use of a half-facepiece dust respirator and a local exhaust system, is recommended [28].

There is need for proper education of this economically viable group on workplace hazards, the types and proper use of different protective devices in order to safeguard their health. Similarly, training in ergonomics could contribute toward reduction of work-related accidents [5].

To minimize integumentary disorders, such as skin cancer, can be prevented by the use of suitable face screen during welding activity; respiratory, gastric, and cardiac disorders, such as lung and stomach cancer and cardiac arrhythmias, can be prevented by the use of a respirator,

doing physical activities in order to facilitate gas exchange, and washing hands after working with weld to prevent ingestion of metals [29].

4. CONCLUSION

This review has shown that welding profession is very hazardous however, not all welders are aware of all the hazards. This is even worse to those who surround the welding area that are not dealing with welding works. In this respect, some welders and other people are affected by welding hazards only because they are not aware of welding hazards. To avoid the arc welding hazards, this paper has suggested some safety measures to be taken during welding activities.

REFERENCES

[1] Pankaj, K. Impact of Welding Processes on Environment and Health. International Journal of Advanced Research in Mechanical Engineering & Technology, 1(1), 2015, pp. 17–20.

[2] Chauhan, A. Anand, T. Kishore, J. Danielsen, T. E. and Krishna, G. I. Occupational hazard exposure and general health profile of welders in rural Delhi. Indian Journal of Occupational and environmental Medicine. 18(1) 2014, pp. 21-26.

[3] Emmet, E. A. Buncher, R. R. Suskind, R. B. Rowe, K. W. Skin and Eye Diseases Among Arc Welders and Those Exposed to Welding Operations. Journal of Occupational Medicine. 23(2), 1981, pp. 85-90.

[4] Lincoln Electric. Safety Practices in Welding, Arc Welding Safety. Guide for Safe Arc Welding. pp. 23. http://www.lincolnelectric.com/assets/us/en/literature /e205.pdf

[5] Sabitu, K. I. Z. Dauda, M. M. Awareness of occupational hazards and utilization of safety measures among welders in kaduna metropolis, Northern Nigeria. Annals of African Medicine (Journal). 8(1), 2009, pp. 46-51.

[6] Fiebai, B. Awoyesuku, E. A. Ocular injuries among industrial welders in Port Harcourt, Nigeria. Clinical Ophthalmology. 5, 2011, pp. 1261-1263.

[7] Dixon, A. J. and Dixon, B. F. Ultraviolet radiation from welding and possible risk of skin and ocular malignancy. The Medical Journal of Australia. 181(3), 2004, pp. 155-157.

[8] Pires, I. & Quintino, L. Amaral, V. and Rosado, T. Reduction of fume and gas emissions using innovative gas metal arc welding variants. International Journal of Advanced Manufacturing Technology. 50, 2010, pp. 557-567.

[9] Parmar, R. S. Welding Processes and Technology. Second Edition. Delhi: Khan Publishers, 2007, pp. 760.

[10] Budhathoki, S. S. Singh, S. B. Sagtani, R. A. Niraula, S. R. Pokharel, P. K. Awareness of occupational hazards and use of safety measures among welders: a cross-sectional study from eastern Nepal. http://bmjopen.bmj.com/content/4/ 6/e004646.short.

[11] Amza, G. Rontescu, C. Cicic, D. – T. Apostolescu, Z. Pică, D. Research on Environmental Pollution When Using Shielded Metal Arc Welding (SMAW). 72(3), 2010, pp. 73-88.

[12] Kadinda, D. J. Assessment of Arc Welding Hazards to Welders and Residents Surrounding Welding Workshops in Tanzania- Case Study of Dar es Salaam. Senior Project Report. Bachelor of Mechanical Engineering. 2007, pp. 65.

[13] Rongo, L. M. B. de Haan, S. Barten, F. Msamanga, G. I. Dolmans, W. M.V. van Naerssen, T. Heederik, D. Felt Occupational and Environmental Health Hazards Among Workers in Small Scale Industries in Dar es Salaam, Tanzania: Focus Group Discussion Study. East African Journal of Public Health. 2(1), 2005, 21-26.

[14] Brugge, D. and Dhar, A. Residential Health near Major Construction Projects: Unexplored Hazards. Review of Environmental Health, 23(1), 2008, 75-81.

[15] Quintino, L. Hourmat, B. Pires I. Health and Safety in Welding in the European Union, ABS, XXXV CONSOLDA – Congresso Nacional de Soldagem. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.533.1926&rep=rep1&type=pdf

[16] Nastiti, A. Pramudyastuti, D.Y. Oginawati, K. and Santoso, M. Determination of Informal Sector as Urban Pollution Source: Fume Characterization of Small-scale Manual Metal Arc Welding using Factor Analysis in Bandung City. Atom Indonesia. 38(1), 2012, pp. 35-42.

[17] Metal Fume Fever. Safety and Health Fact Sheet. American Welding Society. 25. 2014, https://app.aws.org/technical/facts/FACT-25_2014.pdf.

[18] Brittain, G. P. H. Retinal burns caused by exposure to MIG-welding arcs: report of two cases. British Journal of Ophthalmology. 72, 1988, pp. 570-575.

[19] Sultan, A. M. Thamir, Al-K. Health Hazards of Welding Fumes. Occupational risk of welding fumes. pp. 25. http://repository.ksu.edu.sa/jspui/bitstream/123456789/ 3358/1 /HEALTH% 20HAZARDS%20OF%20WELDING%20FUMES.pdf

[20] Lyon, T.L. AWS Safety and Health Fact Sheet Bundle for Fabricators. Knowing the Danger of Actinic Ultraviolet Emission. Welding Journal. 2002, pp. 28-30. https://app.aws.org/safety/safety/FACTbundle_construction.pdf.

[21] Fire and Explosion Prevention. Safety and Health Fact Sheet No. 6. American Welding Society. 2006, pp. 3. https://app.aws.org/technical/facts/fs6-806.pdf

[22] Electrical Hazards. Safety and Health Fact Sheet No. 5. American Welding Society. 2006, pp. 3. https://app.aws.org/technical/facts/fs5-806.pdf

[23] Raymond, M. F. and Leslie A. G. Conduction of Electrical Current to and Through the Human Body: A Review.

[24] Guide for Safety at Work Electric Shock Hazard of Manual Electric Arc Welding Work. Occupational Safety and Health Branch Labour Department. 2008, pp. 8. http://www.labour.gov.hk/eng/public/os/C/arc_welding.pdf

[25] Kah, P. and Martikainen, J. Influence of shielding gases in the welding of metals. International Journal of Advanced Manufacturing Technology. 64, 2013, pp. 1411-1421.

[26] Gourzoulidis, G. A. Achtipis, A. Topalis, F.V. Kazasidis, M.E. Pantelis, D. Markoulis, A. Kappas, C. Bourousis, C.A. Artificial Optical Radiation photobiological hazards in arc welding. European Journal of Medical Physics. Elsevier. 32(8), 2016, pp. 981-986.

[27] Harris, M. K. Ewing, W. M. Longo, W. DePasquale, C. Mount, M. D. Hatfield, R. and Stapleton, R. Manganese Exposures During Shielded Metal Arc Welding (SMAW) in an Enclosed Space. Journal of Occupational and Environmental Hygiene. 2, 2005, pp. 375-382.

[28] Dr. V. V. Satyanarayana, J. Jagadesh Kumar, D. Pratibha and A. Pooja. Application of Dual Response and Tolerance Analysis Approaches For Robust Design of Spot Welding Process, International Journal of Mechanical Engineering and Technology, 7(1), 2016, pp. 05-10.

[29] Seayon S. Dmello, Jebin Biju, Shashank S. Hegde and Anand V. Ganoo, Design and Fabrication of Automated 2-Axis Welding Machine. International Journal of Mechanical Engineering and Technology, 8(3), 2017, pp. 209–218

[30] Syambabu Nutalapati, Dr. D. Azad and Dr. G. Swami Naidu, Effect of Welding Current on Welding Speed and Ultimate Tensile Strength (UTS) of Mild Steel. International Journal of Mechanical Engineering and Technology, 7(5), 2016, pp. 156–176.

[31] Saito, H. Ojima, J. Takaya, M. Iwasaki, T. Hisanaga, N. Tanaka, S. and Arito, H. Laboratory Measurement of Hazardous Fumes and Gases at a Point Corresponding to Breathing Zone of Welder during a CO2 Arc Welding. Industrial Health. 38, 2000, pp. 69-78.

[32] Bonow, C. A. Cezar-Vaz, M. R. de Almeida, M. C. V. Rocha, L. P. Borges, A. M. Piexak, D. R. and Vaz, J. C. Risk Perception and Risk Communication for Training Women Apprentice Welders: A Challenge for Public Health Nursing. Nursing Research and Practice. 2013, pp. 11.