A REVIEW ON OPERATIONAL HAZARDS OF WELDING PROCESSES

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Abstract: Welding operations are characterised by high levels of uncertainty due to the nature of their challenging field of operations. Given that welding projects presents a variety of potential hazards including exposure to welding fumes, radiations, particulates and gases, analysing the welding operations requires experience of professionals who understands the processes of welding and their various hazards. Modelling of welding accident hazards indicates that the multitudes of stakeholders involved in fabrication/welding operations are faced with dynamic environmental factors which often lead to breached in safety and causing disruption of operations. Therefore, the safety of welders and other stakeholders involve in welding project is very important. This review is focused on the background study of welding processes, analysis of common and special hazards in fabrication/welding environment, potential hazards associated with welding operations, risk governance in fabrication, welding safety and management programs in support of welding operations. It is envisaged that sufficient knowledge and attention to hazards in welding projects will be a safeguard to business losses.

Keywords: Accident, environment, fabrication, hazards, operations, safety, welding, workshops

Introduction

Welding is a fabrication process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the work pieces and sometimes adding a filler material to form a pool of molten material (the *weld pool*) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld.

This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the pieces to form a bond between them, without melting the work pieces. Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. Welding can be done in many different industrial environments, including open air, under water, and in outer space (D'Amato and McCullion, 2013).

Experience has shown that welding remains one of the most hazardous operations and precautions must be taken to avoid welding hazards such as burns, electric shock, eye damage, and exposure to chemical fumes and ultraviolet light. Due to the increase in technological advancement, welding related operations and services are being performed in numerous industries, including shipbuilding, construction, fabrication shops, railroads and aerospace amongst others. Also, the type of welding to be used in these industries can be based on a number of considerations, including the type of base metal used, the quality of the weld required, and other variables.

It is also observed that many distinct factors influences the strength of welds and the material around them, including the welding method, the amount and concentration of energy input, the weldability of the base material, filler material, and flux material, the design of the joint, and the interactions among all these factors. Research conducted by Verma and Taiwade, (2017) reviewed the effect of welding processes and conditions on the microstructure, mechanical properties and corrosion resistance of duplex steel weldments; Raja and Hexley (2012) presented a review on optimisation of welding processes; Rahmani *et al.*, (2016) presented an assessment of the effect of welding fumes on welders' cognitive failure and health-related quality of life; Regina *et al.*, (2015) presented a study that assessed the risk communication concerning welding fumes for the primary preventive care of welding apprentices in Southern Brazil and Mgonja (2017) highlighted the effects of arc welding hazards to welders and people around the welding area. This paper therefore reviews the operational hazards associated with welding processes in a typical welding workshop.

Common types of welding processes

Based on research, different welding processes have different fumes generation rates (FGR). One must have a basic understanding of these processes and their relative FGR in order to assess the risk of exposures to welding fumes, radiations and gases. Based on the research conducted by Draugeiates and Bouaifi (1992); Fiore, (2006); Colwel and Layo, (2008); Spear, (2010); John and Omorodion, (2017), the following welding processes were highlighted.

Shielded metal arc welding (SMAW) or Metal Manual Arc Welding (MMAW) or "Stick welding") is commonly used for mild steel, low-alloy steel and stainless steel welding. In SMAW, the electrode is held manually, and the electric arc established between the electrode and the base metal. The electrode is covered with a flux material, which provides a shielding gas for the weld to help minimize contamination. The electrode is consumed in the process, and the filler metal contributes to the weld. SMAW can produce high levels of metal fume and fluoride exposure; however, SMAW is considered to have little potential for generating ozone, nitric oxide and nitrogen dioxide gases (Spear, 2010; John and Omorodion, 2017).

Gas metal arc welding (GMAW) is popular in the group as metal inert gas (MIG) welding. GMAW is typically used for most types of metal and is faster than SMAW. This process involves the flow of an electric arc between the base metal and a continuously spool-fed solid-core consumable electrode. Shielding gas is supplied externally, and the electrode has no flux coating or core. Although GMAW requires a higher electrical current than SMAW, it produces fewer fumes since the electrode has no fluxing agents. However, due to the intense current levels, GMAW produces significant levels of ozone, nitrogen oxide and nitrogen dioxide gases (Booth *et al.*, 2006; Spear 2010; John and Omorodion, 2017)

Flux-cored arc welding (FCAW) is commonly used for mild steel, low-alloy steel and stainless steel welding. This process has similarities to both SMAW and GMAW. The consumable electrode is continuously fed from a spool and an electric arc is established between the electrode and base metal. The electrode wire has a central core containing fluxing agents and additional shielding gas may be supplied externally. This process generates a substantial amount of fumes due to the high electrical currents and the flux cored electrode. However, FCAW generates little ozone, nitric oxide and nitrogen dioxide gases (Maruyama *et al.*, 1994; Colwel and Layo, 2008; Weibe *et al.*, 2011).

Gas tungsten arc welding (GTAW) is also popular in the group as tungsten inert gas (TIG) welding. GTAW is used on metals such as aluminum, magnesium, mild steel, stainless steel, brass, silver and copper-nickel alloys. This process uses a non-consumable tungsten electrode. The filler metal is fed manually and the shielding gas is supplied externally. High electrical currents are used which causes this process to produce significant levels of ozone, nitric oxide and nitrogen dioxide gases. However, GTAW produces very few fumes (Fiore, 2006; John and Omorodion, 2017).

Submerged arc welding (SAW) is a common welding process used to weld thick plates of mild steel and low-alloy steels. In this process, the electric arc is established between the base metal and a consumable wire electrode; however, the arc is not visible since it is submerged under flux granules. This flux keeps the fumes low since the arc is not visible. Little ozone, nitric oxide and nitrogen dioxide gases are generated. The major potential airborne hazard with SAW is the fluoride compounds generated from the flux (Fiore, 2006; John and Omorodion, 2017).

Plasma arc welding (PAW): It is an arc welding process similar to gas tungsten arc welding (GTAW). The electric arc is formed between an electrode (which is usually, but not always, made of sintered tungsten) and the work piece. The key difference than GTAW is that in PAW, by positioning the electrode within the body of the torch, the plasma arc can be separated from the shielding gas envelope. Plasma arc welding is advancement over the GTAW process. This process uses a non-consumable tungsten electrode and an arc constricted through a fine-bore copper nozzle. PAW can be used to join all metals that are weldable with GTAW (i.e., most commercial metals and alloys) (Draugeiates and Bouaifi, 1992; Spear, 2010; HSE, 2016; John and Omorodion, 2017).

Oxy-fuel welding: The most common is oxyacetylene welding, Oxy-welding, or gas welding in the US and oxy-fuel cutting are processes that use fuel gases and oxygen to weld and cut metals, respectively. Pure oxygen, instead of air (20% oxygen/80% nitrogen), is used to increase the flame temperature to allow localized melting of the work piece material (e.g., steel) at a room environment. A common propane/air flame burns at about 3630 °F (2000 °C), a propane/oxygen flame burns at about 4530 °F (2500 °C), and an acetylene/oxygen flame burns at about 6330 °F (3500 °C). Oxy-fuel is widely used for welding pipes and tubes, as well as for repair work. It is also frequently well suited, and favoured, for fabricating some types of metal-based artwork. The process is commonly used in industry, especially for large products and in the manufacture of welded pressure vessels. Other arc welding processes include atomic hydrogen welding, electro-slag welding, electro-gas welding, and stud arc welding (Spear, 2010; HSE, 2016; John and Omorodion, 2017).

Types of gas and their properties

During welding operations, welders may purge air from behind the weld using the same gas supply at the welding gun. This process may be a proprietary mix such as argon/ helium or argon/ helium/ CO2. Mixed gases tend to be significantly more expensive than pure argon, as a result larger scale purging operations tend to use argon. Although metal active gas (MAG) welding does not use a true inert gas (often carbon dioxide or a mixture of gases) the gases used do not contain sufficient oxygen to sustain life. Similarly nitrogen is not a true inert gas as it can chemically react with metal at welding temperatures and may be used to purge air, particularly if large quantities of gas are needed to purge a large void (HSE, 2007; D'Amato and McCullion, 2011; HSE, 2016).

Table 1: Physical properties of welding gas

Gas	Colour	Odour	Relative density
Argon	None	None	1.38
Helium	None	None	0.14
Nitrogen	None	None	0.97
Carbon dioxide	None	None	1.53
Oxygen	None	None	1.11
Propane	None	Natural gas	1.21
Acetylene	None	Garlic-like	0.28

Source: HSE (2016)

As presented in Fig. 1, acetylene and propane have distinctive smells, the other gases are colourless, odourless and their direct measurements are difficult. However, detection tubes are available for some, and the flammable gases can be detected with suitably calibrated flammable gas-detection equipment. The most appropriate detection method when checking oxygen levels is the use of a suitably calibrated oxygen meter (HSE, 2007; D'Amato and McCullion, 2013). Gases denser than air whose density is one (1) can accumulate in tank bottoms, vessels, pits and other low-lying areas. In very still air conditions the denser gases, e.g. argon, can act almost like a liquid and will form dense, low-lying layers which will disperse only slowly. Lighter gases may collect in high-level spaces which could pose a risk if this is at head level. Although dense gases will tend to sink, and light gases rise, the movement is easily disrupted. For example a pressurised gas leak or intentional release of a jet of gas will entrain the surrounding air and may form a homogenous mixture or concentration 'gradient' within a confined space. Similarly the movement of people, plant or convection currents can cause sufficient air turbulence to disrupt the natural tendency of a particular gas to rise or sink (HSE, 2007, 2016).

Common and special hazards in industrial environment

Industrial facilities such as fabrication yards are said to have common hazards and special hazards. Common hazards are those hazards that are found in many facilities regardless of the occupancy or the product being manufactured while special hazards are hazards which are associated with a specific industry (Beattie, 2014).

Given that almost all welding facilities have electricity, the hazards associated with the power distribution of electricity are considered common hazards because they are common to all industries. The application of compressed air in industries is another example of a common hazard because many facilities have air compressors and compressed air is used for a number of different purposes.

To help keep welders safe, organizations such as the Health and Safety Executive (HSE), American Welding Society (AWS), The Welding Institute (TWI) amongst others offer safety guidelines to help control, minimize or help employers and workers avoid welding hazards and workers are encourage to comply with the following important guidelines in the workplace (Petrkovsek, 2016; John and Omorodion, 2017):

- Read and understand manufacturer's instructions for equipment
- Carefully review material safety data sheets
- Follow the company's internal safety practices

It is important to note that awareness of the most common welding hazards and knowing how to avoid them ensures a safe, productive work environment for all. Some of the hazards associated with welding engineering project include electric shock, fumes and gases, fire and explosions, arc radiation, hot parts, flying sparks, spatter, metal or dirt, electric and magnetic field (EMF), noise, moving part, gas cylinders, falling equipment and surface coatings and containments amongst others.

Special hazards are primarily associated with specific sector such as the welding and manufacturing industries. Also, conducting a proprietary process which involves combustible materials with an ignition source nearby may be a special hazard at a facility. Therefore flammable liquids are considered special hazards because they represent a high hazard and they are usually specific to the occupancy of that facility. However, experience has shown that what may be a common hazard for most industries can become a special hazard in a particular industry. An example may be hot work in welding and manufacturing operations which includes such things as electric arc and gas welding, chipping, grinding, cutting, abrasive blasting, brazing and soldering. Hot work can produce heat from flame, spark or other source of ignition with sufficient energy to ignite flammable vapours, gases, or dust (Spear, 2010; Beattie, 2014; Petrkovsek, 2016; John and Omorodion, 2017).

Safety potential hazards associated with welding operations

Safety is a critical consideration for any welding project. Arc welding is probably the most common type of welding done today and is a safe occupation when proper precautions are taken. But, if safety measures are ignored, welders face an array of hazards which can be potentially dangerous with long term consequence. The following are some potential hazards associated with welding operations.

Electric shock

The main electrical hazard is electric shock or electrocution. 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. All of the following are electrically energized when the power is "on": the welding circuit (including the electrode and work piece), input power and machine internal circuits, the wire, reel of wire, drive rolls, and all other metal parts touching the energized electrode (Singh and Anand, 2013; Kim *et al*. 2011). It's important to remember never to touch the electrode or metal parts of the electrode holder with skin or welding clothing and insulate yourself from the work and ground.

Fumes and gases

Overexposure to welding fumes and gases can be hazardous to welder's health. Welding fume contains potentially harmful complex metal oxide compounds from consumables, base metal and the base-metal coatings. The specific potential health effects which relate to the welding consumable product being used can be found in the Health Hazard Data section of the Safety Data Sheet available from welder's company or employer and the consumable manufacturer. Welding areas require adequate ventilation and local exhaust to keep fumes and gases from the breathing zone and the general area. In most situations, employers will provide a ventilation system- such as a fan, and an exhaust system or fixed or removable exhaust hoods- to remove fumes and gases from the work area (Beattie, 2014).

Fire and explosions

The welding arc creates extreme temperatures, and may pose a significant fire and explosions hazard if safe practices are not followed. While the welding arc may reach temperatures of 10,000 degrees Fahrenheit, the real danger is not from the arc itself, but rather the intense near the arc heat, sparks and spatter created by the arc. This spatter can reach up to 35 feet away from the welding space. To prevent fires from welding operations, it is important to weld, inspect the work area for any flammable materials and remove them from the area. Flammable materials are comprised of three categories: liquid, such as gasoline, oil and paint; solid, such as wood, cardboard and paper; gas, including acetylene, propane and hydrogen.

Knowing where the fire alarms and extinguishers are located, and checking the extinguisher's gauge to make sure it is full will significantly help in reducing likelihood of fire scenarios in welding operations. If an extinguisher is not available, be sure to have access to fire hoses, sand buckets or other equipment that douses fire. And, know the location of the nearest fire exit.

Injuries from lack of sufficient PPE

Personal protective equipment (PPE) helps to keep welding operators free from injury, such as burns – the most common welding injury – and exposure to arc rays. The right PPE allows for freedom of movement while still providing adequate protection from welding hazards. Thanks to their durability and fire resistance, leather and flame-resistant treated cotton clothing is recommended in welding environments. This is because synthetic material such as polyester or rayon will melt when exposed to extreme heat. Welding leathers are especially recommended when welding out of position, such as applications that require vertical or overhead welding (Petrkovsek, 2016). When wearing a helmet, always wear safety glasses with side shields or goggles to prevent sparks or other debris from hitting the eyes. Leather boots with 6-to-8-inch ankle coverage are the best foot protection; metatarsal guards over the shoe laces can protect feet from falling objects and sparks. It will not be pleasant if a hot piece of spatter finds its way inside your clothing or shoes. Heavy, flame-resistant gloves should always be worn to protect from burns, cuts and scratches. As long as they are dry, they also should provide some protection from electric shock. Leather is a good choice for gloves (D 'Amato, 2013 and Petrkovsek, 2016).

Helmets with side shields are essential for protecting eyes and skin from exposure to arc rays. Make sure to choose the right shade lens for your process – use the helmet's instructions to help select the right shade level. Begin with a darker filter lens and gradually change to a lighter shade until you have good visibility at the puddle and weld joint but it is comfortable and does not irritate your eyes. Helmets also protect from sparks, heat and electric shock. Welder's flash from improper eye protection may cause extreme discomfort, swelling or temporary blindness, so don't take any risks – wear a helmet at all times during welding (Petrkovsek, 2016). It is important to note that in order to protect ears from noise; welders must wear hearing protection such as ear plugs or muffs if working in an area with high noise levels. Doing so will protect their ears, as well as prevent metal and other debris from entering the ear canal.

Other safety considerations

Welders should also be aware of other safety considerations within the work environment such as the working in a confined space or in an elevated area. They should also pay close attention to safety information on the products being used and the material safety data sheets provided by the manufacturer and work with their employer and co-workers to follow appropriate safe practices for their workplace. Also, when opening a can of electrode, welders are expected to keep hands away from sharp edges, remove clutter and debris from the welding area to prevent tripping or falling. And never use broken or damaged equipment or PPE (Petrkovsek, 2016 and John, 2018).

Special hazards particular to welding workshops

Research has shown that the best ways to identify special hazards at a facility is to take audit of the facility by looking at specific processes and equipment in use. During the process of the auditing, a comprehensive hazard review of the workshop will be beneficial to stakeholders as it may reduce the probability of occurrence of any undesired event happening and the severity of any consequence to operators of the workshop. Regular review of welding workshops will help to ensure that it is in compliance with current regulatory standards. Based on the type of application, there are several hazard identification techniques; these include (John *et al*, 2014; Wang and Trbojevic, 2007):

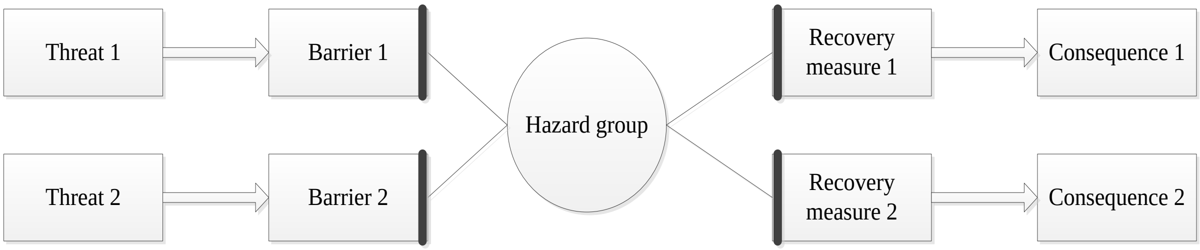
- What if /Checklist Analysis
- Hazard and Operability Studies (HAZOP)
- Failure Mode Effect and Criticality Analysis (FMECA)
- Fault Tree Analysis (FTA)
- Event Tree Analysis (ETA)
- Cause-Consequence Analysis and Bow-tie Analysis

Each of these methods provides insight on the hazard associated with a particular system. The hazard evaluation provides a sense of direction toward the risk assessment process. Based on the risk assessment outcome, decisions may be undertaken on the common and special hazards in the facility with respect to the harm on human life. Once the assessment is completed and any changes are implemented in the system, plant documentation can be updated to help with any future work to be done on the facility. The process will help to bring management and employees together to evaluate and solve common problems to their facility/workshop in a reliable and systematic fashion (John and Nwaoha, 2016).

Risk governance of fabrication and welding processes

Governance refers to the review and oversight of all activities in any phase of a system's life cycle, which may be in the form of peer reviews, design reviews and independent reviews, especially during the development phase of a technological system (Jackson, 2010). Most safety researchers and analysts agree that risk governance in critical infrastructure systems is a key aspect of systems resilience.

Risk governance in a broad context, as defined by International Risk Governance Council (IRGC) (2005), is the identification, assessment, management and communication of risks. Based on the IRGCs definition, the basic elements of Bow-tie can be presented in Fig. 1.



Source: Wang and Trbojevic (2007)
Fig. 1: Risk assessment Bow-tie

Figure 1 shows the bow-tie diagram. The starting point on the left hand side is a hazard which is defined as a situation or condition with the potential to cause harm. Based on Wang and Trbojevic (2007), these conditions or situations can be technical, organisational or human factor related and can be in any of the following:

- Hazardous elements such as hydrocarbon under pressure, explosives etc.
- Initiating event causing the hazard to occur.
- Threat and target, personnel or a system that is vulnerable to an attack.

A hazard can be triggered by one or several threats (e.g. mal-function, excess pressure, corrosion, design fault, etc.) which if not checked would lead to an initiating event or loss of control situation (as shown by a circle perimeter in Fig. 1). To prevent this, resiliency measures or barriers are put in place. The left hand side of the bow-tie is also called the causation part and requires causation analysis in the risk governance process (hazard analysis, failure mode and effect analysis, fault tree analysis etc.). A barrier system based on Fig. 1 is to reduce the probability of release of hazards with the aim of buffering the system from major external and internal disruptions, thereby absorbing shocks and reducing system uncertainty. These barriers may include monitoring systems enabled with sensors, connections, feedback loops, action capabilities, etc. The same is true about the recovery measures or resiliency measures at the right hand side, which can include actions in the form of procedures' inspections, and drills that can be standardized as various policies based on the evaluation of the system using event tree analysis, consequence analysis and so on (Mansouri *et al*., 2010; Wang and Trbojevic, 2007).

The right hand side of the bow-tie depicts the escalation or outcome analysis which could take place if all barriers are breached and the initiating event is released. This event could then escalate to different outcomes, each of which would have specific consequences such as loss of life, fire/explosion, etc. In light of the above, a risk management system can be envisaged as a critical and key aspect for improving safety in complex systems operations by maintaining barriers and recovery measures.

Management programs in support of welding safety

Due to the dynamic nature of welding projects, management programs are critical in controlling hazards and ensuring safety of personnel. Based on experience, management involvement and commitment to safety in industrial facilities has helped in reducing risks in complex projects to As Low As Reasonably Practicable (ALARP). Hence, the following management programs may be utilised to enhance safety of welding projects (Beattie, 2015).

- Emergency planning and response
- Evacuation plan
- Self-inspection for fire safety items and fire protection equipment
- Housekeeping inspection program
- Robust business continuity and recovery plan
- Hot work permit program
- Lock out tag out (LOTO)
- Fire extinguisher inspection and maintenance program
- Fire protection inspection testing, and maintenance programs
- Alarm system and illegal entry inspection and testing programs
- Electrical inspection programs
- Accident investigation program
- Safety committee and safety training program
- Hazard analysis program

Conclusion

Dealing with common and special hazards in welding and fabrication workshops requires experience of professionals in the industry who may employ advanced methodologies to tackles various risks scenarios in a flexible manner. Knowledge and attention to hazards associated with welding operations is a critical safeguard to enhancing business operations in a systematic manner. The research has established that welding operations is dependent on factors encompassing technical, operational, security, organisational and external issues. Thus, this necessitates the development of a generic model that can be used to model disruption scenarios in a straightforward manner to enhance the safety of welders. Further review of literature revealed that collaboration amongst the multitudes of stakeholders involved in welding/fabrications operations would help to achieve efficiency and ensure safety of welders. It is worth noting that the ability of fabrication operators to maximize performance depends on the availability of the right information, which could be quantitative or qualitative. The quantitative information needs to be complemented by the qualitative information to provide a broader view of welding hazards in order to propose strategies aimed at improving safety in a typical welding workshop.

References

Abdolrasoul R, Farideh G, Somayeh FD, Adel M & Arash A 2016. Assessment of the effect of welding fumes on welders' cognitive failure and health-related quality of life, International Journal of Occupational Safety and Ergonomics, 22(3): 426-432.

American Welding Society (AWS). Fumes and Gases in the Welding Environment and other welding related safety and health publications, published by the American Welding Society, 550 NW LeJeune Road.

Beattie WS 2015. Fire Protection for Common and Special Hazards American Society of Safety Engineers' Professional Development Conference and Exposition, 7-10, 15-506.

Booth GS, Jones RL & Threadgill PL 2006. Recent Developments In Welding Technology, The Sixteenth International Offshore and Polar Engineering Conference, 28 May – 2 June, San Francisco, Califonia, USA.

Colwel RL & Layo W 2008. Flux-core Welding in Refinery Services. NACE International Corrosion 2008, 16-20 March, New Orleans, Louisiana, p. 16.

Regina MC, Bonow CA & Cezar-Vaz J 2015. Risk communication concerning welding fumes for the primary preventive care of welding apprentices in Southern Brazil. *Int. J. Envtal. Resource and Public Health*, 12(1): 986-1002.

D'Amato V & McCullion M 2013. The "science" of the welding process and exposure assessments. American Society of Safety Engineers (ASSE) Professional Development Conference and Exposition, 24-27 June, Las Vegas, Nevada USA. Document ID-13-680.

D'Amato V & McCullion M 2011. Welding and Industrial Hygiene: The "Science" of the Welding Process, American Society of Safety Engineers (ASSE) Professional Development Conference and Exposition, 12-15 June, Chicago, Illinois, USA. Document ID. ASSE-11-782.

D'Amato V & Michael M 2012, Atrium Environmental Health and Safety Services, LLC SMACNA, American Society of Safety Engineers (ASSE) Professional Development Conference and Exposition, 12-531 September, Califonia, USA. Document ID. ASSE-13-963.

Fiore SR 2006. Reducing exposure to hexavalent chromium in welding fumes. *Welding Journal*, 85(8): 38-42.

Health and Safety Executive 2007. A guide to the Gas Safety (Management) Regulations 1996 Guidance on Regulations. ISBN 978-0-7176-1159-1.

John A, Riahi R, Paraskevadakis D, Bury A, Yang Z & Wang J 2014. A New Approach for Evaluating the Disruption Risk of a Seaport System. Safety and Reliability: Methodology and Application. Nowakowski et al. (ed.) 1st edn. Tailor and Francis Group, London, p. 301.

John A and Omorodion OA 2017. Modelling of Welding Hazard in and Industrial Workshop Using FFTA Method, International Journal of Scientific & Engineering Research 8(7): 781.

Jackson S 2010. Architecting Resilient Systems, Accident Avoidance and Survival and Recovery from Disruptions. Vol. 1, 1st, John Wiley and Sons, New Jersey, USA, pp. 39-53.

Mansouri M, Nilchiani R & Mostashari A 2010. A policy making framework for resilient port infrastructure systems. *Marine Policy*, 34: 1125-1134.

Maruyama T, Ogawa T, Nishiyama S, Ushijima A & Yamashita K 1994. Gas Metal Arc Welding of Duplex Stainless Steel Using Flux Cored Wire. The Fourth International Offshore and Polar Engineering Conference, 10-15 April, Osaka, Japan.

Mgonja CT 2017. The effects of arc welding hazards to welders and people surrounding the welding area. *Int. J. Mech. Engr. & Techn.* (IJMET), 8(3): 433–441.

Petrkovsek J 2016. Be Prepared: Five Potential Welding Safety Hazards to Avoid. https://www.lincolnelectric.com/en-us/support/welding-solutions/Pages/Five-potential-welding-safety-hazards.aspx Accessed on 23/June/2018.

http://www.hse.gov.uk/welding/asphyxiation-hazards.htm, Accessed on 10/09/2016

Raja E & Hexley J 2012. A review on optimisation of welding process. *Int. Conf. on Modelling, Optimisation and Comp., Procedia Engr.*, 38: 544-554.

Spear JE. 2010. Welding safety, assessing and controlling exposure to hexavalent chromium. *American Society of Saf. Eng*., 55(9): 22 – 31.

Verma J & Taiwade RV 2017. Effect of welding processes and conditions on the microstructure, mechanical properties and corrosion resistance of duplex stainless steel weldments—A review. *Journal of Manufacturing Processes*, 25(1): 134-152.

Wang J & Trbojevic VM 2007. Design for Safety of Marine and Offshore Systems. Vol. 1, 1st edn. Institute of Marine Engineering, Science and Technology (IMarEST), London, UK, pp. 1- 403.

Weibe J, Schelle W, Bruns C & Schmidt T 2011. Impact of FCAW On the Mechanical Properties of Seamless Line Pipe Steels of Grades X65 And X80. The Twenty-first International Offshore and Polar Engineering Conference, 19-24 June, Maui, Hawai, USA.