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Fume and gas emission during arc welding: Hazards and recommendation

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ABSTRACT

Welding is the principal industrial process used for joining metals, but at the same time, it's the significant source of toxic fumes and gases emission. With the advent of new types of welding procedures and consumables, the number of welders exposed to welding fumes is growing constantly in spite of the mechanisation and automation of the process. Having in mind that, in some cases, toxic fumes and gases can be over the respective limits for toxic substances, one of the most important requirements for chosen welding procedure is its harmlessness to the environment. The health aspects associated with welding are complex and the industry is continuing its research to evaluate the effects of the welder's exposure to typical constituents of welding fumes and gases, as well as its impact on what concerns climatic changes. The aim of this paper is to estimate the influence of the type of filler material on the emission of toxic substances, and to show the potential hazards. In order to determine that effect, microalloyed steel has been welded using two different filler materials (metal cored wire and self-shielded wire). The concentrations of emitted total dust, CO_2, CO, SO, Mn, Ni, Al, Cr, Cr(VI), Ca and P were measured. By comparing results for both filler materials, it was established that the special attention must be paid to the high concentration of manganese and CO in metal cored wire, as well as high concentrations of phosphorus and aluminum in self-shielded wire. Also, conducted experimental measurements of emission of certain elements did not show higher toxicity of self-shielded wire compare to metal cored wire, what is in the contrast with previous studies.

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1. Introduction

Welding is the principal industrial process used for joining metals. It's a particular technology in the sense that it is needed in almost all kinds of metallic constructions [1]. In this sector; there are about 730 000 full time and 5.5 million welding related jobs in

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Europe. Worldwide, industry lays down an estimated one million tons of weld metal annually. Based on an average fume production of 0.5% of weld metal, an estimated five thousand tons of fume are produced annually. With the advent of new types of welding procedures and consumables, the number of welders exposed to welding fumes is growing constantly in spite of the mechanisation and automation of the process. Presently, some 3 million persons from different professional backgrounds are directly subjected to welding fume and gas action. Most welding processes, by their operation mode and the technological equipment used, have a major impact on the environment and pollution is not in the least negligible [2]. Various fumes and gases can be generated during welding. Welding fumes are metal-containing aerosols consisting of particles formed through complex vaporisation–condensation–oxidation processes during welding. Welding fume gets into the welder's body mainly through the breathing organs, because welding fume particles are among the most respirable ones. The 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, to long-term lung damage and neurological disorders, such as lung cancer and Parkinson's disease. Gas phase pollutants are also generated during welding operations; known gaseous pollutants include carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and ozone (O_3).

The main goal in every advancement of welding processes throughout the years was first, to improve the integrity of the weld, and second, to improve upon the process-to make it faster, more efficient, and more cost effective through higher productivity [3]. Finally, in nowdays, one of the most important requirements is the health aspects associated with welding and cutting and the industry is continuing its research to evaluate the effects of the welder's exposure to typical constituents of welding fumes and gases and its impact on what concerns climatic changes.

The reasons for estimating emissions dictate the level of effort required, the data quality objectives and the resources required. The most important step in the emission estimation process is to define the end use and identify potential users of the data. For example emission estimation required to demonstrate compliance with regulatory standards may require more accurate and costly methods than those intended for the purpose of national inventory reporting [4]. New environmental, health and safety legislation, both in the EU and in the USA, is driving the need for the study of new welding processes, and the selection of the operational procedures that will reduce fume emissions and will promote a healthier, safer and more productive work environment [5]. While the developed countries have set that goal, a great number of developing countries, including Serbia, are still striving to identify such procedures and provide the fundamental preconditions for their more intensive utilization in the future.

2. Welding fumes and gas emission and potential hazards

Welding fumes are very small particles that are formed when the vaporized metal rapidly condenses in air and are typically too small to be seen by the naked eye, but collectively, form a visible plume. Welding fumes consist of metal oxide particles and gases that are formed during welding and they are easily inhaled. The chemical composition of the particles and the amount of fumes produced during welding depend on the welding procedures, the chemical composition of the shielding gases, the filler and the base material, the presence of coatings and the time and severity of the exposure [6].

The primary source of information when determining the components likely to be in the fume is the material safety data sheet of the consumable welding electrode/wire. About 90–95 percent of the fumes are generated from the filler metal and flux coating/core of consumable electrodes. Since the base metal weld pool is much cooler than the electrode tip, the base metal contributes only a minor amount of the total fumes. The only case when the base metal may be a significant factor of the fume exposure if the metal or surface residue contains a highly toxic substance (lead, cadmium, etc.). In addition to the welding technique, studies have shown that the fume generation rate is also influenced by the following factors: electrical current, arc voltage, wire diameter, shielding gas, welding speed and steady/current pulsed current welding [7,8].

Welding fume can be present in different morphologies [9]. Individual spherical particles less than 20 nm are formed by vapor condensation, while aggregates of 20 nm particles are formed by the collision of primary particles. Welding fume particle size can be divided into three groups: ultrafine ($0.01 < d < 0.1$ μm), fine ($0.1 < d < 2.5$ μm), and coarse ($d > 2.5$ μm) [10]. There are several mechanisms by which welding fume can originate. Fig. 1 shows the various methods of fume formation.

When heating of the liquid metal occurs rapidly, metal alloy droplet expulsion occurs and the result is small droplets being forced off of the parent metal droplet. When this metal droplet cools and solidifies outside the presence of oxygen, as in an inert argon or helium atmosphere, mostly metallic particles with a slight oxide layer will occur (Fig. 1a). In cases where inert gas shielding is not used, such as with SMAW (Shielded Metal Arc Welding) or FCAW-S (Self-shielded Flux Cored Arc Welding), the liquid droplet is in direct contact with oxygen and will readily oxidize, Fig. 1b. For inert processes, such as GMAW (Gas Metal Arc Welding) or GTAW (Gas Tungsten Arc Welding), oxygen may be incorporated from the surrounding atmosphere or may be an inherent component in the gas mixture, as in $Ar–O_2$ mixtures or even $Ar–CO_2$ mixtures. If heating of the liquid metal is sufficient, vaporization of the metal will occur. Inert atmospheres facilitate fume formation through vaporization and condensation of elemental material with some light oxidation. Fume formed from FCAW and SMAW results from vaporization, condensation, and subsequent oxidation of elemental and lower oxide species, and the vaporization/condensation of oxide and fluoride flux species and compounds, Fig. 1c and d. The chemical composition of fume is, therefore, highly dependent on flux composition since a significant amount of low melting point components are contained within the flux and wind up in the fume particles themselves [9].

The combination of the molten metal with the compounds in the flux or electrode coating can cause chemical reactions that can change the composition of the fume particles. Fume particle morphology and composition are therefore a product of the electrode composition and shielding atmosphere. The characterization of welding fume depends on what the investigator hopes to determine. The materials typically found in welding fume include aluminum, beryllium, cadmium oxides, chromium, copper, fluorides, iron oxide, lead, manganese, molybdenum, nickel, vanadium, and zinc oxides. Each of these elements has harmful effect to human health, but will continue to be listed just some of them.

Manganese: Inhalation of fumes with high concentrations of manganese and its oxides may bring "metal fume fever". Symptoms of metal fume fever are chills and fever, dryness of the throat, weakness and aching of the head and body. Symptoms often occur several hours after exposure to fumes and usually last for only a day. Prolonged or repeated exposure to manganese has long been associated with central nervous system effects which are similar in nature to Parkinsonism. Manganese can cause a degeneration of CNS function that gets progressively worse after symptoms first appear [12].