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Emission of airborne ultrafine particles during welding of steel plates

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Abstract

The present study is focused on the characterization of ultrafine particles emitted in welding of steel using mixtures of Ar+CO_2, and intends to analyze which are the main process parameters which may have influence on the emission itself. It was found that the amount of emitted ultrafine particles (measured by particle number and alveolar deposited surface area) are clearly dependent from the distance to the welding front and also from the main welding parameters, namely the current intensity and heat input in the welding process. The emission of airborne ultrafine particles seem to increase with the current intensity as fume formation rate does. When comparing the tested gas mixtures, higher emissions are observed for more oxidant mixtures, that is, mixtures with higher CO_2 content, which result in higher arc stability. The later mixtures originate higher concentrations of ultrafine particles (as measured by number of particles by cm^3 of air) and higher values of alveolar deposited surface area of particles, thus resulting in a more hazardous condition regarding worker's exposure.

Keywords: arc welding; welding fumes; ultrafine particles; alveolar deposited surface area.

1. Introduction

Arc welding is extensively used in metallic construction worldwide. However, it can produce dangerous fumes that may be hazardous to the welder's health [1] and it is estimated that, presently, 1-2% of workers from different professional backgrounds (which accounts for more than 3 million persons) are subjected to welding fume and gas action [2]. These authors also showed a correlation between processing parameters in metal active gas (MAG), that is, metal transfer modes, and the quantity of fumes formed expressed as fume formation rate. Additionally, the gas mixtures have also an influence on fumes (quantity and composition), since the higher the oxygen content of the gas, the higher the fume formation observed. 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 mechanization and automation of the processes [3]. Simultaneously, the number of publications on epidemiologic studies [4] and the devices for welders' protection is also increasing. Apart from that, the influence of ultrafine particulate, lying in the nano range, on human health has been pointed to be of much concern [5-7] as airborne ultrafine particles can also result from macroscopic common industrial processes such as welding [8-9]. The detrimental health effects of inhaling ultrafine aerosols were recognised long ago and various attempts have been made to minimise exposure, as the issuing of specific regulations on emissions and objectives for air quality in working microenvironments.

When considering human exposure to airborne pollutants the exposure to airborne particles, and specifically to its finer fractions, such as sub micrometer particles, is of particular interest. Current workplace exposure limits, that have been established long ago, are based on particle mass, but this criteria

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could not be completely adequate in what concerns nano sized particles as these materials are, in fact, characterized by very large surface areas (considering the same volume, nano sized particles have larger surface areas than micro sized particles, for instance), which has been pointed out as the distinctive characteristic that could even turn out an inert substance into a toxic one, but having the same chemical composition, and exhibiting very different interactions with biological fluids and cells [10-11]. As a result, assessing workplace conditions and personal exposure based on the measurement of particle surface area is of increasing interest. It is well known that lung deposition is the most efficient way for airborne particles to enter the body and potentially cause adverse health effects. If ultrafine particles can deposit in the lung and remain there, have an active surface chemistry and interact with the body, then, there is potential for exposure and dosing. Oberdörster [12] showed that surface area plays an important role in the toxicity of nanoparticles and is the measurement metric that best correlates with particle-induced adverse health effects. Therefore, in order to be able to assess exposure, it is important to have an estimation of the surface area of emitted ultrafine particles, as they are potentially able to deposit in the lower parts of the lung, such as the alveoli and clog them, or even being transferred to the blood circulation system with resulting distribution in several end organs [13].

In 1996, the International Commission of Radiological Protection (ICRP) developed a comprehensive lung deposition model for radioactive aerosols. Several parameters are required to construct the model including breathing rate, lung volume, activity, nose/mouth breathing, etc., and the obtained deposition curves (for tracheobronchial and alveolar deposition) derived from the model can vary according to these parameters. For industrial hygiene applications, ACGIH [14] developed a definition of a reference worker, in order to derive the corresponding deposition curves for tracheobronchial and alveolar lung deposition, based on the ICRP model: the tracheobronchial deposition curve represents the fraction of aerosol that deposits in the tracheobronchial region of the lung, while the alveolar deposition curve represents the fraction of the aerosol that deposits in the alveolar region of the lung. For exposure assessment applications it is common to sample aerosols relevant to their deposition in a specific region of the human lung thus depending on the aerosol being sampled. In what concerns ultrafine particles, due to its very fine dimensions, the health effects would be related to the deposition deep in the alveolar regions of the lung, so the respirable fraction of the aerosol is the metric of interest, as it is interesting to assess the potential surface of the alveoli to be clogged by the presence of these ultrafine particles.

This work comes in line with preliminary work from these authors that demonstrated the presence of ultrafine particles in welding processes such as metal-active gas (MAG) [4, 15], and aims to assess the emissions of ultrafine particles emitted from welding of steel and try to correlate these with operational parameters and, thus, molten metal transfer modes. Similar studies have also been made for welding fumes generated in other processes, such as manual metal arc welding (MMA), metal inert gas welding (MIG) and tungsten inert gas welding (TIG) for stainless steel electrodes [16]. Also, previous studies have not been assessing the deposited surface area of emitted particles.

2. Experimental

MAG welding tests were performed in laboratory using an experimental set-up consisting of an automatic welding machine Kemppi, model ProMig 501, controlled, which assured a stable electric arc, a constant welding speed and, therefore, repeatability of the welding process.

Bead on plate welds were performed on 3 mm thick mild carbon steel plates S235 JR with the chemical composition shown in table 1. Tests were also performed on austenitic 10 mm thick stainless steel plates AISI 304 having the chemical composition also shown in table 1. Welding consumables used were a solid wire AWS 5.18 ER79S-6, with a diameter of 1 mm for carbon steel and a solid wire AWS ER316 LSi, with a diameter of 0.8 mm, for stainless steel. Both solid wire compositions are shown in table 2.

The operating parameters used are depicted in table 3 for carbon steel and in table 4 for stainless steel. Different conditions were tested for welding, varying the gas protection mixture and current intensity and voltage in order to produce short-circuit, globular and spray metal transfer modes. The welding voltage was adjusted automatically by the welding machine in accordance with the feeding wire speed. Each test condition was replicated twice. Between each test, time intervals were provided in order to allow for some dissipation of aerosol in the closed atmosphere of the sampling location.