



## Welding fumes reduction by coating of nano-TiO<sub>2</sub> on electrodes



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### ABSTRACT

The coated electrodes were used to deposit bead on plate welds on IS 2062 low carbon steel plates and the fumes in the breathing zone of the welder were collected using the personal air sampler. The experiments were designed using the Taguchi methodology. The experimental electrodes exhibited 80% reduction in breathing zone concentration of fumes compared to commercially available uncoated counterparts. Further, constituent analysis revealed a tangible reduction in the concentration of Fe, Mn, Si, Ni, Cr and Ti in the fumes. Metallographic analysis confirmed that the weld obtained from coated electrodes exhibited a higher depth of penetration, fine-grained microstructure and higher hardness values.

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### 1. Introduction

Exposure to welding fumes is a well-known occupational hazard. The extent of environmental depreciation is vis-à-vis the rate and concentrations at which these contaminants are released into the atmosphere. The reduction of fumes at the source and in the breathing zone is important, as both general and local extraction systems are found to be inadequate in effectively controlling the fumes.

The magnitude and composition of these fumes depends on several factors such as: (a) the type of welding process adopted; (b) the welding power supply characteristics; (c) the type of shielding gas mixture; (d) the composition of the base metal and electrode; (e) arc stability and (f) spatters.

In the recent past, intense research activities are seen in modifying any of the aforementioned factors to reduce the fumes (Pires et al., 2006; Shane, 2002). There are different types of welding processes currently in practice, such as Manual Metal Arc Welding (MMAW), Gas Metal Arc Welding (GMAW), Flux Core Arc

Welding (FCAW) and Gas Tungsten Arc Welding (GTAW) and solid state welding processes like Diffusion Welding (DW) and Friction Stir Welding (FSW). FCAW is the highest fume producer while FSW is the lowest. MMAW being the most versatile process, is also the second largest fume producer (Sowards et al., 2008). Changing the welding process can lower emissions. Yet, this is not a feasible solution, since each welding process has its own sphere of application and it is difficult to substitute one for the other.

An increase in the welding power supply characteristics such as the welding current and voltage, will cause an increase in the emission of fumes. A tangible reduction in fumes can be achieved by suitably lowering the welding current and voltage (Pires et al., 2006). However, this becomes difficult due to high current machines and the general trend in the industry to improve productivity of the process.

The next possible method for reduction is by the proper selection of shielding gas mixtures. Shielding gases protect the weld pool from oxidation. Investigations by Carpenter et al. (2009) showed that the fumes increased with an increase in the percentage of CO<sub>2</sub> and O<sub>2</sub> in the shielding gas mixtures. This meant that a substantial reduction in fumes was possible by lowering the percentage of CO<sub>2</sub> and O<sub>2</sub> in the shielding gas mixtures. Dennis et al. (2002) observed a reduction in hexavalent chromium when a secondary shielding gas containing reducing agents like NO and C<sub>2</sub>H<sub>4</sub> were used. However this practice is not applicable to all types of processes, and suits more to the automatic welding processes such as externally

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shielded FCAW, GMAW and GTAW where there was a provision for changing the shielding gas and not for self-shielded processes like MMAW.

The last two factors, arc stability and spatters are more or less interrelated. Arc stability, which is a measure of the average voltage variation around the set potential during welding depends on the following factors: (a) composition of flux, (b) arc length, (c) power supply characteristics, and (d) oxidation potential of the shielding gas. The welding flux consists of a mixture of low melting materials known as arc stabilizers, which produce vapors with a low ionization potential and result in an overall improvement in the arc stability. According to [Indacochea and Olson \(1983\)](#), there exists a strong correlation between the arc stability and ionization potential of the arc atmosphere.

Arc length and power supply characteristics (current and voltage) are other key factors influencing arc stability and are essentially interrelated. A short arc length could lead to a highly erratic and unstable arc, due to the high voltage incurred at the electrode tip ([Modenesi and Nixon, 1994](#)).

Arc stability also depends on the oxidizing potential of the shielding gas. [Modenesi and Nixon \(1994\)](#) demonstrated that the high oxidizing potential of the shielding gas minimized the arc wander, allowed more efficient transfer of heat and so improved the arc stability. [Schwemmer et al. \(1979\)](#) stated that the presence of oxidizing atoms in the flux could enhance the cathode emission characteristics and improve the arc stability.

Once arc stability is attained, spatter formation and, consequently, fume formation will also reduce. This can be identified as the most promising solution to deal with fumes. [Dennis et al. \(1996\)](#) experimentally demonstrated this by adding 1% Al to the core of a metal cored arc welding wire and found a significant reduction in fumes. A landmark in these studies took place when [Chen et al. \(2009\)](#) observed an improvement in arc stability and mechanical properties of the weld when the conventional micro scale marble in the flux coating of a D600R surfacing electrode was replaced by nano-sized marble. Similarly, [Fattahi et al. \(2011\)](#) found that the addition of TiO<sub>2</sub> nanoparticles to the welding electrode increased the arc stability, which the author attributed to nanoparticles reducing the ionization potential of the arc atmosphere. The direct addition of nanoparticles to the welding electrode has certain weaknesses such as the risks involved in handling, non-uniform distribution and high procurement cost.

The present study has many fold objectives. The key objective being the reduction of the fume evolution in the breathing zone of the welder. Firstly, introducing nano-TiO<sub>2</sub> particles to the welding electrode by coating them over the bare welding wires using the sol-gel dip coating method. Other objectives of this investigation are to: (a) evaluate the effect of each coating process parameter on the concentration of fumes in the breathing zone; (b) constituent analysis of the collected aerosol from the coated electrodes using the Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES) and compare it with that from the commercially available uncoated electrode; and (c) investigate the weld quality by conducting macro and micro analysis, SEM/EDS analysis and micro hardness test on the resultant weld.

## 2. Materials and methods

### 2.1. Materials

Titanium Tetra Butoxide (98% pure; Sigma–Aldrich) was used as the precursor of TiO<sub>2</sub>. The weld plate was made of low carbon steel (IS 2062) and cut into dimensions of 300 mm × 120 mm × 10 mm. It was cleaned with a wire brush prior to welding to remove any traces of rust. Core welding wires having a diameter of 4 mm and a length

**Table 1**  
Chemical composition of the core wire and the base metal.

| Material      | Composition (%) |      |      |       |      |       |      |
|---------------|-----------------|------|------|-------|------|-------|------|
|               | Fe              | Mn   | Si   | P     | C    | S     | CE   |
| Welding rod   | 95.99           | 1.50 | 0.40 | 0.05  | 0.23 | 0.05  | 0.42 |
| Base material | 98.68           | 1.50 | 0.40 | 0.045 | 0.22 | 0.045 | 0.41 |

of 450 mm purchased from a local electrode manufacturer were used as the coating substrate. Besides, square pieces of dimension 10 mm × 10 mm × 5 mm were cut from the same grade material to study the structural and morphological characteristics of the resultant coating. They were polished with different grades of emery paper and cleaned with acetone prior to coating. The surface morphology of the coated specimens was examined using the Scanning Electron Microscope (TESCAN, VEGA SBH), while, the phase analysis of the coating was carried out by X-Ray Diffraction Analysis using a computer controlled X-Ray Diffractometer (Rigaku Ultima III) under Cu-K $\alpha$  radiation ( $\lambda = 1.54 \text{ \AA}$ ). After coating, the core wires were taken back to the electrode manufacturer for flux coating. The flux formulation used was of E-7018 iron powder – low hydrogen electrode. [Table 1](#) presents the chemical composition of the core wire and the base metal and [Table 2](#) shows the composition of flux.

The welding power supply used was of constant current type (ARC 400, RILION) DC rectifier. The emitted fumes during welding were collected using a personal air sampler (SKC model No. 224-PCXR8), one end of which was outfitted with a preloaded filter cassette. The flow rate of the sampler was calibrated using a soap bubble meter. A Whatman GF/A filter paper having a diameter of 37 mm and pore size of 1.6  $\mu\text{m}$  was used to collect the particulates. The weight of the filter paper was measured using a sensitive precision weighing balance (accuracy  $\pm 0.01$  mg, Shimadzu model AUW220D) both prior to and after sampling. Constituent analysis of the collected aerosol was carried out by using the Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES, Perkin Elmer model OPTIMA 5300DV). The macro and microstructures of the weld were observed under an optical microscope (Olympus BX61). Energy dispersive X-ray spectroscopy (EDS) (JEOL model JED 2300) was carried out using a high magnification scanning electron microscope (SEM) (JEOL model 6390 LV) for local elemental chemical analysis of the weld. Further, the oxygen content in the weld was analyzed by employing an oxygen analyzer (Make Eltra, Model ONH-2000). The micro hardness of the weld was tested using a Vicker's Micro Hardness testing machine (Zwick ZHV30) with a square based diamond pyramid indenter.

**Table 2**  
Ingredients of flux.

| Ingredients   | Wt.% |
|---|------|
| Iron  | 15   |
| Titanium dioxides (as Ti)                               | 10   |
| Limestone and/or calcium carbonate                      | 5    |
| Silicates and other binders                             | <5   |
| Manganese and/or manganese alloys and compounds (as Mn) | <5   |
| Mineral silicates                                       | <5   |
| Aluminum oxide and/or bauxite                           | <5   |
| Fluorides (as F)  | 1    |
| Silicon and/or silicon alloys and compounds (as Si)     | 1    |
| Titanium and/or titanium alloys (as Ti)                 | 0.5  |
| Aluminum and/or aluminum alloys (as Al)                 | <0.5 |
| Lithium compounds (as Li)                               | <0.5 |

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