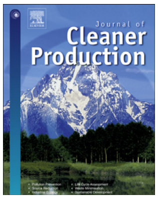
Journal of Cleaner Production xxx (2015) 1–14

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro



Welding fume reduction by nano-alumina coating on electrodes – towards green welding process

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ARTICLE INFO

Article history:
Received 28 September 2014
Received in revised form
27 June 2015
Accepted 28 June 2015
Available online xxx

Keywords:
Welding fumes
Nano-alumina coating
Response surface methodology
Physical properties
Metallographic studies

ABSTRACT

Fume reduction from the welding process is important from the perspective of environmental pollution and protection to the health of the welder. A novel method of reducing welding fumes at source towards green welding process has been worked out after nano coating of conventional electrodes. This method involves the dipping of a core welding wire, prior to its flux coating, in a sol containing aluminium isopropoxide, to obtain a thin film of nano alumina coating. The nano-coated electrodes did reduce the concentration of fumes up to 62% in the welder's breathing zone, when tested vis-à-vis the concentration from uncoated counterpart. A substantial reduction in the concentration of metallic constituents in the fumes of coated electrodes was noted too. Central Composite Design matrix of response surface methodology was applied in designing these experiments and investigating the effect of coating process parameters on the welding fumes at the breathing zone of the welder. The reduction was found to be more for a homogenous deposit with lower crystallite size. Metallographic studies of the weld from nano-alumina coated electrodes showed fine grained acicular and widmanstatten ferrites with increased hardness. This is one of the first studies that verified experimentally the role of parameters such as crystallite size, specific heat capacity and latent heat of fusion through nano coating of electrode wire, in reducing the concentration of airborne particulates in welding fumes.

1. Introduction

Rapid advancements in technology and industrialization happening during the last few decades have also increased the risk of exposure to toxic fumes and gases. The development of environmentally friendly/green processes with reduced emissions of such hazardous materials is the need of the hour. Welding is one such industrial process viewed as environmentally vulnerable due to its energy intensive nature, exposure hazards and environmental burden (Vimal et al., 2015).

Welding fumes are small particles formed by the condensation of metals and metal oxides that become volatile due to the intense heat of the arc. It poses great health risks to the people in its proximity. The reduction of fume emissions during welding is necessary in order to reduce the exposure risk level to welders and thus provide a safe and healthier work environment. Attaining such an improvement is a tedious task which requires the development of new eco-friendly materials and welding techniques which can replace the conventional toxic ones (Albuquerque et al., 2015). The mass rate at which these fumes generated depends on the following: base material, filler metal, welding process adopted and chemical composition of the shielding gas mixture. The acute and chronic health effects arising due to welding fumes depends on the duration and severity of exposure (Quimby and Ulrich, 1999). During the welding operation, the welder is the one who gets exposed to the fumes first. Hence, it is warranted to characterize the exposure risk associated with welding fumes, especially in the operator's breathing zone (Goller and Paik, 1985). Among the various welding processes, Manual Metal Arc Welding (MMAW) or Shielded Metal Arc Welding (SMAW) is the most prosaic. In terms of fume production they are rated next to Flux Cored Arc Welding (FCAW) (Sowards et al., 2008).

Control of welding fumes and gases has been a matter of serious concern, with studies on the safety aspects of fumes

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http://dx.doi.org/10.1016/j.jclepro.2015.06.132
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Please cite this article in press as: Sivapirakasam, S.P., et al., Welding fume reduction by nano-alumina coating on electrodes – towards green welding process, Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.06.132

initiated back in the mid-twentieth century. Traditional control measures implemented had resorted to enclosure and local exhaust ventilation (LEV) supplemented by the use of respiratory protective equipment (RPE). Additional reduction strategies merely focused on modification of process parameters such as current, voltage (Pires et al., 2006) and shielding gas composition (Pires et al., 2007). However, due to its adverse effect on the weld quality and production, it was not a feasible solution. It was later realized that the control of fumes at the source by modification of consumables would be the best possible strategy.

The welding fume emissions were determined to chiefly depend on two major factors. The first factor is a result of the fume prediction models proposed by Dennis et al. (2001) and Redding (2002). According to these authors, welding fume emissions were related to the evaporation from droplets, which in turn was depended on the physical properties of welding wire.

The second factor, which plays a deterministic role in fume emissions, was the ionization potential of arc atmosphere. The use of low ionization potential materials in the welding process improves arc stability, yields better weld properties and reduced fume formation. Reichelt et al. (1980) compared two shielding gases having different ionization potential and found that the one having lower ionization potential resulted in stable arc and better weld properties. Dennis et al. (1996) reported a significant decrease in the fume emissions with addition of Al, a low ionization potential material to the welding wire.

With further advancement of nanotechnology, studies on the effect of addition of nano particles on the quality aspects of weld were initiated. Chen et al. (2009) reported that the arc stability and weld properties were improved when the conventional marble was replaced by nano-marble in the electrode flux. Further, Fattahi et al. (2011) reported that the addition of nano sized TiO_2 to the welding electrode reduced the ionization potential of arc atmosphere and in turn offered better arc stability. The nano particle additions in the welding wire and its effect on the fume emissions are yet to be investigated. Commercial production of welding wire using nano particles imposes limitations such as risk of exposure, hazard during handling, high procurement cost and the heterogeneity of distribution.

The present work focuses on the development of an eco friendly welding process by coating the bare welding wire with a thin film of nano alumina prior to its flux coating. The main objective of this work is to investigate the effect of coating process parameters on the airborne particle concentration of welding fumes. The other objectives of this investigations are: (a) to optimize coating process parameters for reduced airborne particulate concentration in the breathing zone (b) Comparative studies on the metallic constituents from coated and uncoated electrodes and (c) metallographic studies of the weld to determine its quality aspects.

2. Materials and methods

The core welding wire purchased from a local electrode manufacturer was used as the coating substrate. The wire made of low carbon steel (IS 2062) had 4 mm diameter and was 450 mm long. These were polished with different grades of emery paper and then cleaned with acetone. Square pieces of dimension 10 × 10 × 5 mm were cut from the same grade material for structural and morphological characterization of the resultant coating. The weld was deposited on low carbon steel plates (IS 2062) of dimension 300 × 120 × 10 mm. The chemical composition of the core wire and the base metal are presented in Table 1.

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

Material	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

The coating was achieved by the sol–gel dip coating method, which compared to other coating techniques appeared economical and more efficient. The procedure consisted of dipping and withdrawing a substrate from a fluid sol followed by gravitational draining and solvent evaporation. This procedure resulted in the deposition of a solid film (Brinker et al., 1991). The properties of the deposit such as its crystallite size and morphology depend on several coating process parameters such as the molar concentration of sol, dipping time and sintering temperature. Independent studies by Farroq and Kamran (2012), Lazos et al. (2009) and Davood and Taha (2009) revealed that the crystallite size of the deposit increased with an increase in molar concentration of sol, dipping time and sintering temperature. Based on initial experimental trials in the laboratory, the range of these parameters were fixed as follows: Molar concentration of alumina sol – 0.005–0.04 M, dipping time – 2–300 min and sintering temperature – 300–500 °C.

Because of the complex interaction of these parameters, a 'one variable at a time' approach would not give a clear understanding of the correlation between them and their effect on the output. In such cases, Design of Experiments (DoEs), fuzzy logic and Artificial Neural Networks can be employed. Among these, DoE is the most versatile technique used to evaluate the main effects and interaction of process parameters on an output response with minimum number of experiments (Sivapirakasam et al., 2011). In the present work, the response surface methodology of Central Composite Design (CCD), a standard technique of DoE was employed to incorporate the variation of process parameters at five different levels (Khuri and Cornell, 1996).

The Central Composite Design contains an imbedded factorial design with center points that is augmented with a group of 'star points'. Fig. 1 shows the CCD for studying three factors. It consists of 8 factorial points (colored black), six axial points (colored gray) and three to five center points (colored white). The center points are usually replicated in order to get an unbiased estimate of pure error and to improve the precision of the experiment (Montgomery, 2004).

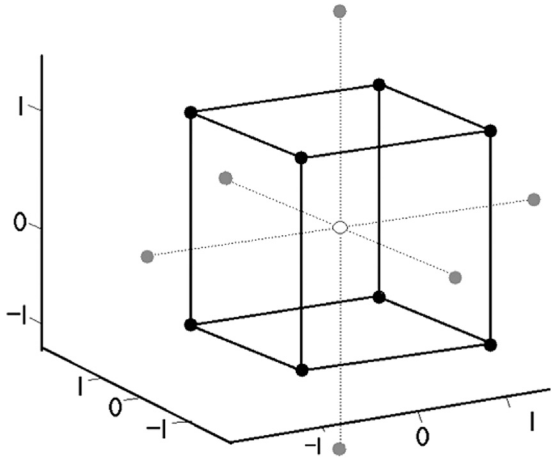

Fig. 1. A schematic representation of the Central Composite Design of three factors.

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