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Original Article

Characterization of Total and Size-Fractionated Manganese Exposure by Work Area in a Shipbuilding Yard

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ABSTRACT

Background: Shipbuilding involves intensive welding activities, and welders are exposed to a variety of metal fumes, including manganese, that may be associated with neurological impairments. This study aimed to characterize total and size-fractionated manganese exposure resulting from welding operations in shipbuilding work areas.

Methods: In this study, we characterized manganese-containing particulates with an emphasis on total mass ($n = 86$, closed-face 37-mm cassette samplers) and particle size-selective mass concentrations ($n = 86$, 8-stage cascade impactor samplers), particle size distributions, and a comparison of exposure levels determined using personal cassette and impactor samplers.

Results: Our results suggest that 67.4% of all samples were above the current American Conference of Governmental Industrial Hygienists manganese threshold limit value of 100 μg/m^3 as inhalable mass. Furthermore, most of the particles containing manganese in the welding process were of the size of respirable particulates, and 90.7% of all samples exceeded the American Conference of Governmental Industrial Hygienists threshold limit value of 20 μg/m^3 for respirable manganese.

Conclusion: The concentrations measured with the two sampler types (cassette: total mass; impactor: inhalable mass) were significantly correlated ($r = 0.964$, $p < 0.001$), but the total concentration obtained using cassette samplers was lower than the inhalable concentration of impactor samplers.

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1. Introduction

Shipbuilding refers to the construction of ships and other floating vessels. It normally takes place in a specialized facility known as a shipbuilding yard. Welding is a major task in shipbuilding yards that generates welding fumes. Owing to the condensation of the high-temperature metal vapor released into the air from the welding arc, welding fume is generated during transfer of molten metal from the electrode to the base metal. The constituents of the welding fume and its contents depend on welding type, welding condition, materials being fused, and filler materials. A significant amount of welding in shipbuilding yards is performed on steel. Inevitably, manganese (Mn) is present in the base metals being joined and the filler wire being used, and, hence, in the fumes to which workers are exposed.

Manganese is an essential element and is required for adequate functioning of the human central nervous system. However, high, long-term occupational exposure to manganese can result in manganism, a severe neurological disorder characterized by movement disturbances and cognitive deficits [1,2].

In 1985, the first case of occupational disease due to exposure to manganese was reported at a welding rod manufacturing company in Republic of Korea [3]. Prior to 2002, a total of 10 cases of occupational disease due to manganese were reported: three workers involved in crushing materials containing manganese, one metal assembly line worker, and six welders [3]. Thus, minimizing the concentration of manganese that welders are exposed to is very important for protecting their health.

Currently, the Occupational Safety and Health Administration [4] in the USA has a permissible exposure limit for welding fume as individual metals or total particulate mass. The permissible exposure limit for manganese is 5,000 μg/m^3, set as a ceiling for total fume and dust, while for iron oxide fume it is 10,000 μg/m^3, set as an 8-hour time-weighted average (TWA) [4]. The Ministry of

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Table 1
ACGIH TLV changing history for manganese

Substance type	Year	TLV (μg/m^3)
Manganese	1948–1959 1960–1962 1963–1969	TWA: 6,000 TWA: 5,000 Ceiling: 5,000
Manganese and compounds	1970–1981	Ceiling: 5,000 as Mn
Manganese fume	1977 proposed 1979–1994	TWA: 1,000 as Mn TWA: 1,000 as Mn STEL: 3,000 as Mn
Manganese dust and compounds	1982–1987 1986 proposed 1988–1994	Ceiling: 5,000 as Mn TWA: 5,000 as Mn TWA: 5,000 as Mn
1.1. Manganese, element, and inorganic compounds	1.1. 1992 proposed 1.1. 1995–2012 1.1. 2009 proposed 1.1. 2013–present	1.1. TWA: 200 as Mn 1.1. TWA: 200 as Mn 1.1. TWA: 100 (I), 20 (R) as Mn TWA: 100 (I), 20 (R) as Mn

ACGIH, American Conference of Governmental Industrial Hygienists; I, inhalable fraction; Mn, manganese; R, respirable fraction; STEL, short-term exposure limit; TLV, threshold limit value; TWA, time-weighted average.

Employment and Labor (MoEL) in Republic of Korea also has an occupational exposure standard (OES) of welding fume as individual metals or total particulate mass. Currently, the OES for manganese is 1,000 μg/m^3, set as an 8-hour TWA [5]. The National Institute for Occupational Safety and Health considers welding fumes carcinogenic and recommends that the exposure be maintained at the lowest feasible level [6].

Until 2004, the threshold limit value (TLV) of the American Conference of Governmental Industrial Hygienists (ACGIH) for welding fume generated from stick welding or oxy-gas welding of iron, mild steel, or aluminum was 5,000 μg/m^3 as total particulate mass. However, in 2004, this value was withdrawn based on the consideration that welding fumes are variable in composition and require more study. The TLV–TWA for manganese was set at 6,000 μg/m^3 during 1948–1959, 5,000 μg/m^3 in 1960–1962, 1,000 μg/m^3 in 1979, and 200 μg/m^3 in 1992 [7]. After studying the element since it first appeared on their Notice of Intended Change List in 2009, the ACGIH recently adopted changes to the TLV for manganese in 2013. The manganese TLV of 200 μg/m^3 was lowered to 20 μg/m^3 for respirable particulate matter and to 100 μg/m^3 for inhalable particulate matter with a note indicating that the TLV is based on neurobehavioral and neuropsychological changes [8]. Table 1 summarizes the historical ACGIH's TLVs for manganese by the exposed substance types.

The regional deposition pattern of particulates in the respiratory tract affects the pathological potential of inhaled particles. The human respiratory tract can be divided into three main regions based on size, structure, and function, namely, the head, the tracheobronchial region, and the gas-exchange region. Recently, many studies have suggested that the neurological impairment of welders during welding operations is associated with exposure to manganese in welding fumes [1,2,9,10]. In addition, the ACGIH has recently adopted a new stricter limit for manganese-containing respirable particulates. However, no studies on concentrations of manganese exposure in welders by particle size in shipbuilding yards could be found. Related papers present the total manganese concentration containing all airborne sizes.

Here, we present the results of a study on manganese exposure of welders by work area in a shipbuilding yard. The objective of this work was to characterize manganese exposure associated with work areas and manganese concentration distribution by particle size, and to compare the mass concentrations obtained using a three-piece cassette sampler (total particulates) and a size-selective impactor sampler (inhalable, thoracic, and respirable particulates).

2. Materials and methods

All samples were collected from the main work areas at one shipbuilding yard in Republic of Korea. The job contents, welding types used, and number of workers sampled in the work areas were as follows. In steel cutting, steel plates are cut into the parts that will form the hull and deck sections of a ship typically using a thermal plasma cutting technique, and 10 workers were sampled in this work area. In the block assembly, the cut steel is assembled into smaller blocks. Almost 95% of the work in this work area was CO_2 arc welding, and the remainder was grinding. A total of 32 workers in this work area were sampled. In block erection, smaller blocks are assembled into larger sections that are mounted together, which finally becomes a complete ship. All work in this area was CO_2 arc welding. We sampled 21 workers in this work area. Ships should be outfitted with support equipment, such as plumbing, electrical installation, etc. There are two major processes for outfitting: outfitting preparation and outfitting installation. The CO_2 arc welding workload of outfitting preparation and installation was smaller than that in the other work areas (preparation: 80%; installation: 90%). However, these work areas used tungsten inert gas (argon) welding (preparation: 20%; installation: 10%). We sampled seven (preparation) and 16 (installation) workers in these work areas.

2.1. Personal air sampling and analysis

A total of 86 samples of air particulates were collected from employees in five main processes using a closed-face 37-mm cassette sampler, and the total manganese was analyzed. All cassette samples were collected on mixed cellulose ester substrates at a flow rate of 2.0 L/min using personal air sampling pumps (Gilian BDX-II; Sensidyne, St Petersburg, FL, USA). Each 37-mm cassette sampler was positioned in the personal breathing zones of employees during their normal work activities.

In the same employees, 86 impactor samples were collected using eight-stage cascade impactor samplers (Marple Series 290; MSP Corporation, Shoreview, MN, USA), which were also positioned in employees' personal breathing zones and analyzed for manganese.

All impactor samples were collected on Mylar substrate (from Stage 1 to Stage 8) and polyvinyl chloride substrate (backup stage) at a flow rate of 2.0 L/min, using personal air sampler pumps (Gilian BDX-II; Sensidyne). The aerodynamic diameter cut points for the impactor samplers at a flow rate of 2.0 L/min were > 21.3 μm (Stage 1), 14.8 μm (Stage 2), 9.8 μm (Stage 3), 6.0 μm (Stage 4), 3.5 μm (Stage 5), 1.55 μm (Stage 6), 0.93 μm (Stage 7), 0.52 μm (Stage 8), and < 0.52 μm (final backup stage). All impactor samples were collected on the substrates, which were sprayed with silicone to minimize particle bounce during sampling.

Manganese content analyses were performed by inductively coupled plasma/mass spectrometry according to the National Institute for Occupational Safety and Health analytical method 7302, which has a limit of detection of 0.02 μg/sample [11].

2.2. Data analysis

The concentration of manganese in air was determined by dividing the sum of analyte masses on all filters in a sample by the volume of sampled air. The inhalable, thoracic, and respirable mass concentrations of manganese on the impactor samples were calculated using the ACGIH/International Organization for Standardization dust criteria [12]. Size-selective mass concentrations were calculated using Simpson's rule in a tabular–graphical approach to estimate the contribution of each impactor stage to the

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