It has been asserted that employment as a welder is associated with an excess risk for the neurological disorder of manganism and the development of Parkinson's disease at an earlier than usual age. It has been suggested that this may be due to absorption of manganese in emissions from welding processes. In this two-part paper, sources of exposure to manganese, its role in human health and its toxicological potential are considered, then, in Part 2, published reports on the incidence of manganism and Parkinson's disease in welders and of a possible causal link between this and occupational exposure to manganese compounds are reviewed critically and evidence-based conclusions are drawn.

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1 Introduction

It has been asserted that employment as a welder is associated with an excess risk for developing clinical and subclinical forms of the neurological disorder of manganism and that it may promote the development of Parkinson's disease so that it is manifest-
ed at an earlier age than would be expected from the experience of the general population of industrialised countries.

Information supporting, challenging and countering these hypotheses and the suggestion that the risk is associated with the absorption of manganese in emissions from welding processes has been presented in the scientific literature in epidemiological and case study reports – and the validity and relevance of some of these papers has been challenged. Uncertainty continues and the debate smoulders on, particularly in the United States of America, causing anxiety and uncertainty in the industry and in health and safety regulators.

This paper seeks to provide sufficient understanding of the role and function of manganese in human health and disease, its sources and factors which may affect its absorption to assist the reader evaluate evidence on the occurrence of manganism and Parkinson’s disease in welders. This evidence will be critically re-viewed in Part 2 in the next issue of “Welding and Cutting”.

2 Manganese in health

Trace amounts of manganese are essential to the normal functioning of the human body. It acts across a broad spectrum of activities including a range of reactions in the central nervous system which affect mood, posture and movement.

Manganese may be absorbed into the body through the gastrointestinal tract and the lung, the latter being the usual route for occupational exposures. Man does not seem to share to any appreciable extent the direct route from the nose to the brain which has been demonstrated in mice, rats and pike.

In its bio-available forms, several carrier systems are used to transport manganese across the alveolar membrane and other cell membranes, including the blood-brain barrier, and in the blood. Iron competes with manganese for space on at least some of these systems. Manganese leaves the brain by diffusion.

The balance between the concentration of manganese which has been absorbed into the blood from the lungs and upper digestive tract and the body’s requirement for it is maintained principally by the liver. Some 96% of excess amounts of manganese are excreted in the bile for disposal in faeces. The balance of daily intake is excreted in urine. Concentrations of manganese in biological samples such as blood and urine do not correlate sufficiently with exposure to permit reliable individual biological monitoring but have been shown to be sufficient to distinguish exposed and unexposed groups.

3 Non-occupational sources of exposure to manganese

Food is the prime source of manganese for those who are not occupationally exposed. The highest concentrations are found in grains, nuts, fruits and leafy green vegetables. Exceptionally, exposure may also result from the ingestion of drinking water containing high levels of manganese compounds from natural sources or polluted by used batteries or pesticides. Rarely, errors in medical treatments have resulted in excess manganese being absorbed by patients.

Soil erosion is the most common natural source of airborne exposure. The principal man-made non-occupational airborne sources are combustion of fossil fuels and discharges from industrial processes into the air breathed by the local community.

4 Occupational sources of exposure to manganese

Occupational sources of exposure to inorganic manganese-containing dusts or fumes include:
- mining, sorting, milling and refining ore;
- milling and bagging refined manganese metal for transport;
- producing, crushing or milling ferro- and silicon manganese alloys;
- producing carbon and high-temperature steel;
- processing steel by welding, cutting, grinding and polishing;
- manufacture of a range of products including dry cell batteries, ceramics, amethyst glass, porcelain and glass-bonding materials and glazes.

5 Risk assessment of the occupational exposure of welders to manganese

Risk assessment of the occupational exposure of welders to manganese requires clear and precise appreciation of the activities that are to define “welder”;
- sources of occupational exposure to manganese other than welding processes;
- toxicological potential of exposure to manganese in welders’ workplaces;
- pathological, experimental, clinical and epidemiological information about adverse health effects which have been attributed to that occupational exposure.

This should allow a meaningful assessment of the risks attached to welding and, additionally, to the total work package which may involve the welder in cutting, grinding, polishing metal and working in the vicinity of others who are welding or using these allied and related processes.

6 Activity definition of a welder

In this paper, a welder is defined as a worker who is employed solely or principally in joining metal components by the application of heat from an electric arc to melt the abutting surfaces thereby creating a weld pool which, when cooled, creates a metallic joint. The arc is struck between the metal to be joined and an electrode.

7 Other processes with risk of exposure of welders to manganese

Hardfacing, where layers of high manganese alloys are bonded by an arc to, for example, rail track “frogs” (crossing areas) or the teeth of excavator buckets to increase resistance to wear, is classified by some authorities as a form of arc welding. Typically it generates higher concentrations and quantities of manganese-containing fume than when welding is used as a joining process on steels containing lower proportions of manganese.

It is thought prudent to classify hardfacing and other high fume producing processes allied to welding, such as gouging/cutting high manganese steels, separately for the purpose of risk assessment and that has been done in this review. That said, these processes must not be ignored when assessing overall exposure in the workplace.

The same considerations should be applied to processes related to welding such as grinding and polishing metal as these
may also be sources of airborne manganese-containing particles in the air of the workplace. While some of these particles may be respirable they are likely to be significantly different from particles created during welding in their chemical composition and structure and thus in absorbability and potential for causing health effects.

Care must also be taken to consider workplace contamination when assessing the exposure of welders to manganese compounds. An extreme example is fume emitted from or contaminating manganese refinery apparatus which is then repaired by a welder fitting a new electrode in place. In such situations the air may already be replete with manganese compounds before welding starts and fume arising from the welding process and weld site will be enriched by the manganese contamination on the base metal.

Exposures to emissions from all these sources other than welding should be clearly identified and health effects ascribed to the processes from which they arise as otherwise false conclusions may be drawn.
8 Toxicological potential of airborne manganese in welders’ workplaces

Formation, emission and composition of particles in welding fume and the composition of the welding fume as a whole are subject to the effects of many influences and vary between and within processes. Due to the complex thermodynamic conditions during generation of welding fume, a chemical element can form different compounds depending on the percentage of the element in the weld components and the presence of other chemical elements in the fume.

Particles in welding fume are formed by vaporisation of the filler and base metals in the intense heat and energy of the arc and ejection of hot metal as large spatter from the weld pool or micro-spatter from the narrowed area of the rod or wire during metal transfer – all followed by oxidation, and sometimes re-oxidation, in the ambient air then condensation as they cool. More than 90% of the particles derive from the source of filler metal.

The toxicological potential of airborne manganese-compound-containing particles in welders’ workplaces depends largely on dose received (exposure concentration × time) and their chemical composition, size, structure and resulting bioavailability.

9 Exposure and dose

Unless adequate risk control measures are in place, and used correctly, welders may be exposed to excessive amounts of fumes from their own welding or generated by others working in the same place. External features, notably ventilation and the position of the welder’s head in relation to the plume, have been shown to result in marked differences in exposure, even in those doing the same welding task. It may be necessary for personal respiratory protection equipment to be used.

Despite the widespread use of welding there is a relative paucity of published information on exposure levels and doses received and much of this is derived from samplers which have not been placed in the breathing zone behind the welding handheld shield or helmet. The information which has been published suggests that exposures are relatively low in welding as a joining process on carbon steel, except on inadequately ventilated confined spaces, but may be much higher when repairing or recycling high manganese-containing rail tracks or manganese refining equipment. Some examples of welders’ exposure levels measured in workplaces in Germany are shown in Table 1.

10 Chemical composition

The chemical composition of the particles is fairly uniform within emissions from a single process. Depending on the manganese content in the covering or filling and the extent of selective distillation occurring in the heat of the arc, the proportion of manganese in fume may be much greater than in the filler wire or rod.

Due to the complex thermodynamic conditions during formation of the welding fume, a chemical element may form different compounds in the welding fume, as a function of the proportion of this element and the presence of other chemical elements in the welding fume. The manganese content is not found in elemental form but as simple oxides such as MnO and commonly as complex oxides called spinels which include oxygen with other metals, for example MnFe2O4. Examples of the composition of welding fume emitted from a range of processes and base metals are given in Tables 2 and 3 [2].

11 Particle size

The size of the particles is critically important in assessing the bioavailability of manganese as the lung is the principal potential route of entry. An important characteristic is the particle diameter (aerodynamic diameter for particles > 0.1 μm, diffusion equivalent diameter for particles < 0.1 μm) which places most particles in welding fume in the respirable category (with many classed as ultratine) so they may reach the deepest areas, the alveoli, where air is separated from the blood, and thus hazardous materials from absorption, by only a narrow cellular boundary [4].

12 Structure

The morphology of the particles may play an important part in determining the absorbability and thus toxicological potential of manganese in welding fumes. Spherical particles in welding fume, especially the larger ones, may have a core and shell [1; 3; 5]. Cores generally consist of a complex amalgam of iron-rich oxides containing iron, manganese, potassium, chromium and oxygen in different ratios depending on the type of consumable. The metal oxide core of these particles is surrounded by a relatively impervious shell rich in silicon oxide containing other compounds such as iron and manganese fluoride depending on the composition of the flux of the wire.

13 Solubility and absorption

The solubility and absorption of manganese compounds in the particles are vitally important in determining the effective dose received. Most reported studies which provide results of changes in manganese levels in biological fluids support the belief that manganese in welding fume is absorbed in that there are significantly higher concentrations in groups of workers who have been exposed

Table 3. Chemical compounds in welding fumes during the welding of high-alloy steel [1, 3].

<table>
<thead>
<tr>
<th>Element</th>
<th>Chemical compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr(III)</td>
<td>CrO3, FeCrO4, KCrO4, (Fe, Mn, Ni)CrO4, CrCl, CrO2, CrO3</td>
</tr>
<tr>
<td>Cr(VI)</td>
<td>K2CrO7, Na2CrO4, K2Cr2O7, FeCrO4</td>
</tr>
<tr>
<td>Mn</td>
<td>MnO, Mn3O4, MnO2, Mn2O3, Mn2O5</td>
</tr>
<tr>
<td>Fe</td>
<td>KFeO4, K2FeO4, Fe3O4, Fe2O3</td>
</tr>
<tr>
<td>Si</td>
<td>SiO2 (am), SiO2 (am)</td>
</tr>
<tr>
<td>F</td>
<td>K2FeF6, K2MnF6, KFeF6, KF, NaF</td>
</tr>
<tr>
<td>K</td>
<td>K2CrF7, K2MnF6, K2MnO2, K2MnF6, K2Mn2O7, KF, NaF</td>
</tr>
<tr>
<td>Na</td>
<td>Na2FeO4, Na2CrO4, K2NaCrO4</td>
</tr>
<tr>
<td>Ca</td>
<td>CaF2, K2CaF4</td>
</tr>
</tbody>
</table>

1) Manual metal arc welding; 2) metal active gas welding.
to fumes compared to unexposed controls [6...13]. Two investigations reported no difference between welders and controls in concentrations of manganese in the biological fluids studied [14; 15].

Iron is present in great abundance in welding fume and is absorbed. It competes with manganese for the transport mechanism into and within the body. A possible protective role for iron present in welding fume against the absorption of co-existing manganese has been suggested but not confirmed [16].

Overall, in this situation of conflicting and absent evidence, while there seems to be more published evidence in support of absorbability, with this varying between processes and electrode compositions, there is insufficient good quality information to arrive at a firm conclusion on the bioavailability and thus the toxicological potential of manganese in welding fume. The topic must not simply be brushed aside on the grounds that manganese is not absorbable thereby seeking to dismiss the possibility of it having an adverse effect on the health of those exposed to the fumes in sufficient doses. Given the widely remarked upon variation in chemical compounds in welding fume between and within processes, it would not be surprising to find that the solubility of manganese in compounds varied between processes and with the composition of the welding electrode. These differences could affect the biological responses to manganese after the inhalation of welding fumes. More and better research is required to clarify bioavailability unambiguously.

(To be continued)

Literature