# STAINLESS STEEL AND WELDING FUME

## – A STATUS REPORT

## STAINLESS STEEL AND WELDING FUME

This Status Report provides information on the physical characteristics and chemical composition of fume generated during arc welding of stainless steels. It reviews the hazard that welding fume may represent and the evidence of risk that is posed for welders and those working in their vicinity. Regulatory requirements and appropriate working practices are outlined.

This is an introduction to a very complex topic. Moreover, "fume" may have formal legal definitions, which will vary in different jurisdictions and might be narrower than the general definition used for the purposes of this paper. Thus any decision on a program for worker protection should be based on expert advice and have reference to relevant national codes and practices.


## SUMMARY

The fume generated when welding stainless steels includes respirable particles, the composition of which particularly with the flux-shielded welding processes - suggests a potential to cause cancers. However, epidemiological analyses have not identified any actual risk specific to stainless steels but have shown a slight excess of lung cancers among welders as a whole, *i.e.*, both welders of non-alloyed steels and welders of stainless steels, compared with the general population. The cause of this excess has not been identified but may be connected with factors incidental to welding. Nevertheless, appropriate precautions to avoid exposure to welding fume of all kinds are advisable and indeed necessary if regulatory limits are to be observed.


### Arc Welding Processes

The range of arc welding processes used for welding stainless steels can be divided into two categories: those employing a flux for protection of the weld pool- manual metal arc, flux cored arc and submerged - arc processes - and the gas-shielded processes - tungsten inert gas, metal inert/active gas, and plasma arc. All these processes generate fume although submerged-arc and tungsten inert gas do so at significantly lower levels.

### Welding Fume Generation

Fume can be defined as the airborne particles and gases produced during welding. Because of the very high temperatures generated by the arc (in the order of thousands of degrees Celsius), metal – primarily a fraction of the filler metal being transported into the weld pool - is vaporized and condenses, forming generally spherical particles. Although these are of very small diameter, up to about 0.1 mm, many of them link up to form aggregates ranging up to about 1 mm in length. It is inevitable that most of these particles will undergo chemical reactions with the surrounding atmosphere in the course of formation.

### Welding Fume Composition

While gases such as carbon monoxide and dioxide and nitrogen oxides are formed by flux decomposition and arc reactions, the most significant gas in fume is ozone, which is generated by the action of ultraviolet radiation from the arc on oxygen in the atmosphere. The reaction is most evident in the gas-shielded processes, since ozone rapidly decomposes when formed in the flux-shielded processes due to catalytic decomposition with particulate fume and atmospheric reactions.

The base metal plays little part in the formation of particulate fume. The chemical composition of particles formed in flux processes reflects reactions between constituents of the filler metal and the minerals forming the flux. For example, fume from a stainless steel manual metal arc electrode depositing weld metal containing about 19% chromium and 10% nickel is typically found to contain 5% chromium and less than 1% nickel. Closer examination reveals that these fractions are largely contained in particles of complex constitution, virtually none being a pure chemical compound. Chromium is partly present as a potassium -iron chromate, while nickel appears in a mixed oxide with iron, but all particles typically include a range of other elements, such as silicon and manganese.

### Process Differences

The tungsten inert gas process produces little particulate fume but ozone is formed. The rate at which fume is generated by the metal inert/active gas process is dependent, *inter alia*, on the current (which governs metal transfer mode) and the composition of the shielding gas. Fume generation rate rises with increasing current, as the transfer mode changes from short-circuiting to globular, but it then drops to a minimum when spray transfer is initiated. Pulsed-arc processes offer the possibility of maintaining lower fume generation rates, particularly when droplet transfer is closely controlled by power source electronics. Mixtures of inert gas and active gas such as the argon-oxygen mixtures and the more complex commercial blends often used for welding stainless steels produce more fume than the inert gas alone. The constituents of particulate fume produced by the metal inert/active gas process reflect the chemical composition of the filler metal but their proportions vary due to differences in the vapour pressure of individual elements; for example, the manganese content of stainless steel fume may be several times that of the filler wire.

### Chromium

There is an important difference, however, between the chemical forms of chromium in fume from the flux processes and from the gas-shielded processes. In the former group, most of the chromium is present in hexavalent form (chromates), while almost all chromium in fume produced by the gas-shielded processes is in the trivalent form and hexavalent compounds are only present in very small proportions. The relevance of this difference is that, without reference to welding, hexavalent chromium compounds are classified as carcinogenic to humans (Group I) by the IARC* while trivalent chromium compounds are unclassifiable as to carcinogenicity to humans (Group 3). Nickel compounds are also classified in-Group I by the IARC.

### Occupational Health of Welders

There has been a continuing concern that the inhalation of fume by welders (and also ancillary workers) when stainless steel is welded could give rise to cancers, particularly lung cancer. This fear is based on the chemical composition of the fume, especially that produced by the flux processes, and the very small size of particles, which puts them in the respirable range, *i.e.,* capable of penetration down to the level of the lung alveoli.

### Epidemiological Studies

This possibility has been explored in a number of epidemiological studies of welders, categorized according to the materials with which they worked and typically extending over periods of more than 20 years since first exposure. The most extensive of these was the IARC study, which pooled data for more than 11,000 welders in nine European countries, separating data for shipyard welders, mild steel welders and stainless steel welders. Overall there was an excess mortality from lung cancer but this could not be related to duration of employment or cumulative exposure to total fume, total chromium, hexavalent chromium or nickel. As a result, IARC classified welding fume in Group 2B, that is possibly carcinogenic to humans.

* International Agency for Research on Cancer particularly lung cancer. This fear is based on the chemical composition of the fume, especially, that produced by the flux processes, and the very small size of particles, which puts them in the respirable range, *i.e.*, capable of penetration down to the level of the lung alveoli.

### Mild vs Stainless Steel Welding

In a number of other, national, studies, stainless steel welders have been compared with mild steel welders or a control group of non-welders. It has not been possible to show a consistent pattern of excess lung cancers attributable to stainless steel fume from these studies. Indeed there have been indications that the incidence of lung cancer is less among stainless steel welders than in mild steel welders. It has been speculated that stainless steel welders are more highly qualified and remunerated and therefore generally healthier than their mild steel welder counterparts. However, there remains the slight excess of lung cancers which has been found for welders as a whole, for which no fully satisfactory explanation has been advanced.

Because, they are necessarily historical, epidemiological studies have to rely on data for exposure which are not based on contemporary measurements and are to some extent anecdotal. Furthermore, allowance has to be made for the effects of smoking, so far as is practicable, and also for the possible exposure to asbestos which was associated with welding environments in the past, especially, in shipyards. Some investigators have claimed that this last factor can account partly or even wholly for the excess of lung cancers.

## INTERNATIONAL INSTITUTE OF WELDING

The Health and Safety Commission of the International Institute of Welding reviewed the available evidence and issued a statement in 1993, endorsed periodically since then, which noted that welders as a group have a slightly greater risk of developing lung cancer than the general population. The Commission pointed out that studies do not show that welding processes in general or of a specific type are a definite cause of the excess but recommended that prudent action should be taken by those responsible for the health and safety of welders to reduce exposure to welding fume.

The statement also advocates that exposure to chromium and nickel compounds 'known to have caused lung cancer in processes other than welding' should especially be reduced. Thus an analogy is drawn to compounds which are not identical to the complex compounds which constitute welding fume particles. This same difficulty confronts regulators who must define permissible exposure levels or maximum exposure limits in the absence of causal links from epidemiological studies of welders.

### Other Occupational Diseases

It is also necessary to consider the overall health of welders for whom respiratory diseases less serious than lung cancer are still debilitating. Even here, the evidence is somewhat confusing : *for example*, differences in pulmonary function values between welders (mostly of mild steel) and non-welders were only found where the welders were also smokers or worked without respiratory protection. In another study, the 'healthy worker' effect was adduced to explain good respiratory health among stainless steel welders. Nevertheless, cumulative effects have been suggested over the long term.

### Good Practice

It is clearly sensible to minimize contact with welding fume, whatever its composition, and regulations in industrialized countries specify a concentration limit for total welding fume, *e.g.*, 5 mg/m$^3$ as an 8-hour time-weighted average (TWA). Within that overall value, limits are identified for particular fume constituents, expressed as metal concentration. Currently, the Occupational Safety and Health Administration of the United States (OSHA) prescribes a permissible TWA exposure limit (PEL) of 0.1 mg/m$^3$ for CrVI compounds, while the United Kingdom sets a maximum exposure limit of 0.05 mg/m$^3$. A technical guidance concentration (TRK) is specified in Germany, 0.1 mg/m$^3$ for the manual metal arc process and 0.05 mg/m$^3$ for other processes. Limits are also prescribed for other constituent elements of stainless steels, such as nickel and manganese, and for ozone and other gases.*

Measurements can be made in the workplace to determine both the total fume concentration and the concentration of individual fume constituents. Sampling devices are available to measure exposure in a welder's breathing zone and also to determine the overall level of fume in the workshop. Detailed analyses are laborious and expensive and can show variations with time under nominally uniform conditions. For control purposes, it may be more convenient to determine whether an individual element

* All figures were accurate at the time of writing but should not be considered as authoritative as regulations are subject to change.

limit has been exceeded by calculation, using the total fume measurement. Where consumable manufacturers publish or supply data sheets containing typical fume compositions, these can be used to estimate individual element concentrations. Conversely, it is also possible to calculate the maximum allowable fume concentration at which no constituent limit will be exceeded.

Although fume emission may be minimized by selection of an appropriate welding process, the choice is usually restricted by technical and economic factors. It is therefore necessary to control risk by reducing exposure to fume: often this is achieved by general ventilation of the workplace but local ventilation systems that remove fume near its source are more effective and desirable. In this approach, contaminated air is exhausted by fixed or movable extraction units and may be filtered before emission to atmosphere or returned to the workshop. Some metal inert/active gas welding torches are also designed with integral extraction hoses. While personal protective equipment such as an air-fed helmet may also safeguard the wearer, it should only be considered for special situations - welding in a confined space, for example – when alternatives to reducing exposure are not possible or not effective.

## References


1. Characterisation of Welding Fume. American Welding Society, February 1983.
2. A historical prospective study of European stainless steel, mild steel, and shipyard welders. L. Simonato, *et al., British Journal of Industrial Medicine,* 1991, 48, 145–154.
3. A mortality study among mild steel and stainless steel welders. J.J. Moulin, *et al. British Journal of Industrial Medicine,* 1993, 50, 234–243.
4. Incidence of cancer among Norwegian boiler welders. E. Danielsen, *et al., Occupational and Environmental Medicine,* 1996, 53, 231–234.
5. Cancer mortality among arc welders exposed to fumes containing chromium and nickel. N. Becker. *JOEM,* 1999, 41, 294–303.
6. On the subject of cancer risk in arc welding. W. Zschiesche. *Welding in the World,* 1993, 31, 124–125
7. Respiratory symptoms and pulmonary function among stainless steel welders. A. Sobaszek, *et al., JOEM,* 1998, 40, 223–229.
8. Assessment of exposure to fume from welding and allied processes. Guidance Note EH54, Health and Safety Executive, UK.
9. Manufacture, Processing and Use of Stainless Steel: A Review of the Health Effects. H.J. Cross, *et al.* European Confederation of Iron and Steel Industries, 1999.


*(Contd. from Page 35)*

# CORROSION OF STAINLESS STEELS

A special form of crevice corrosion is called deposit corrosion. This is when the corrosion is found under non-metallic deposits or coatings on the metal surface.

Steels with good resistance to pitting corrosion have also good resistance to crevice corrosion.

### STRESS CORROSION CRACKING (SCC)

Stress corrosion cracking, SCC, is a corrosion attack on a metal subjected to a tensile stress and exposed to a corrosive environment.

During stress corrosion cracking the metal or alloy can remain virtually unattacked on most of its surface, while fine cracks progress through it.

For austenitic stainless steels the risk for SCC is especially, big in solutions containing chlorides or other halogenides. The risk increases with increasing saltconcentration, tensile stress and also increased temperature. SCC is seldom found in solutions with temperatures below 60°C.

The resistance of the austenitic stainless steels is improved by increased Ni content. The ferritic Cr steels totally without Ni are under normal conditions unsensitive for SCC as well as steels which are ferritic-austenitic.