Chromium in Stainless Steel Welding Fumes

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1. Introduction

Chromium may occur in several valence states: chromium in metallic form (valence state 0), trivalent form (Cr III), and hexavalent form (Cr VI). Trivalent chromium (Cr III) occurs widely in nature and is an essential nutrient required by the human body to promote the action of insulin in body tissues. Chromium as a pure metal has no reported human or environmental toxicity effects. Both acute and chronic toxicity of chromium are mainly caused by hexavalent chromium compounds (Cr VI).

Fume particles from the welding of stainless steel may contain trivalent chromium (Cr III), and hexavalent chromium (Cr VI) compounds.

Welding designates a joining operation that ensures the continuity of the metallic state between two pieces to be joined. The main electric arc methods which are employed for welding stainless steels are :

- Gas Tungsten Arc Welding (GTAW),
- Plasma Arc Welding (PAW),
- Gas Metal Arc Welding (GMAW),
- Flux-Cored Arc Welding (FCAW),
- Shielded Metal Arc Welding (SMAW),
- Submerged Arc Welding (SAW).

Various gases and fumes can be generated during welding. Welding fumes are metal-containing aerosols consisting of particles formed through complex vaporisation-condensation-(oxidation) or vaporisation-(oxidation)-condensation processes during welding. The fumes are therefore complex in their composition and their structure. That means their toxicity on man must be examined according to the principle of ***speciation,*** which must take into account the following aspects Chemical speciation, physical speciation, biochemical speciation in relation with welding processes, workplace exposures, and existing regulations.

The composition of the welding fumes and their generation rate will depend largely on the welding process employed and the filler material (if any) used which is the major source of fumes and which has an influence on metal speciation in the fumes.

The rate of generation of fumes during arc welding of stainless steel depends on various factors:

- welding current (current density)
- arc voltage (arc length)
- type of metal transfer (type of filler material and/or welding process)
- shielding gas or welding atmosphere

These factors are interdependent and generally have a substantial effect on the generation of fumes.

2. Electric Arc Processes for Welding of Stainless Steel

2.1 Gas Tungsten Arc Welding: GTAW

The GTAW process is also known as the TIG (Tungsten Inert Gas) or WIG (Wolfram Inert Gas). In this process, the energy necessary for melting the metal is supplied by an electric arc struck and maintained between a refractory electrode and the work piece under an inert or slightly reducing atmosphere. If a filler metal is employed, it is in the form of either rods or coiled wire for automatic welding.

The inert gas flow, which protects the arc zone from the ambient air, enables a very stable arc to be maintained. Depending on the base material, shielding gases consist mainly of mixture of argon (Ar), helium (He) and hydrogen (H_2). The common work piece thickness range is 0.5 to 4.0 mm.

2.2 Plasma Arc Welding: PAW

Plasma arc welding is similar to GTAW. The significant difference is that the arc plasma is constricted by a nozzle to produce a high energy plasma stream, in which temperatures between 10.000 and 20.000° C are attained. Since the plasma jet is extremely narrow, it cannot provide adequate protection for the weld pool, so that it is necessary to add a larger diameter annular stream of shielding gas.

The gases used both for this purpose and for forming the plasma are similar to those employed in GTAW, namely pure argon (Ar), Ar-hydrogen (H_2) up to 20%, Ar-helium (He) – H_2.

In manual plasma welding, where the torch is hand-held, the so-called "micro-plasma" and "mini-plasma" processes are employed for current between 0.1 and 15 amperes and the "non-emergent jet" technique for currents between about 15 and 100 amperes. By increasing the welding current (above 100 amperes) and plasma gas flow, a very powerful plasma beam is created which can achieve full penetration of the work piece. During welding, the hole progressively cuts through the metal with the weld pool flowing in behind to form the weld.

The common workpiece thickness range is 0.1 to 1.0 mm for micro-plasma and mini –plasma processes, 1.0 to 3.5 mm for the non-emergent jet technique and 3.5 to 10.0 mm for the key hole process (in a single pass).

2.3 Gas Metal Arc Welding: GMAW

In the GMAW process, also known as the MIG (Metal Inert Gas) process, the welding heat is produced by an arc struck between a continuously fed metal wire electrode and the work piece. Contrary to the GTAW and PAW processes, the electrode is consumable, an arc being struck between the fusible filler wire and the work piece under a shielding gas.

GMAW requires a shielding gas to prevent oxidation in the welding arc. Argon with 2% oxygen (O_2) gives a stable arc and is suitable for most applications. Argon with 3% carbon dioxide (CO_2) gives about the same result. The welding speed and penetration can be increased when helium (He) and hydrogen (H_2) are added to the argon + O_2 or argon + CO_2 shielding gas mixtures. However, in the GMAW / MIG process, a low percentage of oxygen (O_2) or carbon dioxide (CO_2) is often needed in the shielding gas (argon) to improve both arc stability and wetting by the molten metal. Higher levels of O_2 or CO_2 give excessive oxidation of chromium (Cr), manganese (Mn) and silicon (Si) and excessive pick-up of carbon (C) in the weld pool. For single V joints and square butt joints welded in one run, the common work piece thickness range is 1.0 to 5.0 mm.

Confusion often arises between MIG (Metal Inert Gas) and MAG (Metal Active Gas) welding process. In fact in the MIG process applied for stainless steels, the oxidising nature of the shielding gas is negligible, whereas it is deliberately enhanced in the MAG.

2.4 Flux Cored Arc Welding: FCAW

A variant of the GMAW process is the FCAW (Flux Cored Arc Welding) process, in which the electrode wire consists of a stainless steel sheath filled with a solid flux, whose role is similar to that of the electrode covering in the SMAW (Shielded Metal Arc Welding) process. The core provides deoxidisers and slag forming materials and may provide shielding gases in the case of self-shielded FCAW electrodes.

The gas, which can be added extraneously serves as a gas shielding to avoid the harmful effects of the oxygen in the air. Argon with 3% CO_2 can be used for this welding process.

The FCAW technique combines the advantages of the SMAW method with the high productivity of an automatic or semi-automatic process due to the possibility of continuously feeding the cored wire. Compared to a conventional solid electrode, the flux provides a slag cover.

Both FCAW and GMAW have similar bead sizes. For single V joints and square butt joints, welded in one run, the common thickness range is 1.0 to 5.0 mm.

2.5 Shielded Metal Arc Welding (Covered Electrode): SMAW

Although the SMAW process, also known as the MMA (Manual Metal Arc) process is very old, since the first applications were reported by Kjelberg in 1907, it remains widely employed due to its great flexibility and simplicity of use.

The electrode consists of a metal core covered with a layer of flux . The core is usually a solid stainless steel rod. The covering, which plays an essential role in the process, is extruded on the core, and gives each electrode its specific "personality". It serves three main functions : electrical, physical and metallurgical. The electrical function is related to initiation and stabilisation of the arc, while the physical action concerns the viscosity and the surface tension of the slag, which control the transfer of metal droplets, the effective shielding of the weld pool and its wettability. The metallurgical role involves chemical exchanges between the weld pool and the slag, i.e. refining of the weld metal.

The covering contains a certain amount of calcium carbonate ($CaCO_3$) which dissociates in the arc at about 900° C, to form CaO and CO_2, the latter ensuring protection of the arc zone.

The following section gives a short description of the most frequently used covered-electrodes:

Rutile (titania covering) electrodes : Slag formation is the main shielding mechanism in rutile based electrodes, which are easy to handle, ensure low spatters and produce welds with smooth surfaces. A typical composition of this type of covering is : TiO_2 : 42% ; CaF_2 : 4% ; $CaCO_3$ or / and $MgCO_3$: 20% ; Mica : 10% ; Fe-Cr : 10% ; Fe-Mn : 4% ; Feldspar : 4% ; Slipping agents (kaolin, talc, bentonite) ; binding agents (sodium and /or potassium or lithium silicates)

Basic (limestone covering) electrodes: Limestone is a main constituent of basic covered electrodes due its favourable arc – stabilising and metallurgical characteristics. It also evolves carbon dioxide, which provides a gas shield. However, a major disadvantage of limestone is its high melting point. This is counteracted by additions of fluorspar (CaF_2), which helps to lower the slag melting point. A typical composition of this type of covering is: TiO_2 : 4% ; CaF_2 : 35% ; $CaCO_3$ or / and $MgCO_3$: 30% ; Mica : 6% ; Fe-Cr : 8% ; Fe-Mn : 2%; Slipping agents (kaolin, talc, bentonite) ; binding agents (sodium and / or potassium or lithium silicates).

Slipping agents are used to aid the extrusion and alkaline silicates which are used to aid the binding of covering fluxes are also the prime source of alkali ions in the plasma arc and can lead to the formation of Cr VI compounds. On the other hand, the alkali ions in the arc plasma are an essential aid to the arc formation and its stability.

The common work piece thickness range is : 1.0 to 2.5 mm for a single run process and 3.0 to 12.0 mm for a multi pass technique.

2.6 Submerged Arc Welding: SAW

In the SAW process the welding heat is generated by the passage of a heavy electric current between one or several continuous wires and the workpiece under a powdered flux which forms a protective molten slag covering .

This molten blanket covering is very effective in shielding the arc and the molten weld metal from the atmosphere and consequently is an essential aid to prevent the release of welding fumes.

The process is suitable for butt and fillet welding in the flat position and horizontal – vertical fillet welding. For welding stainless steels a “lime / fluoride” type flux is most widely used, its typical composition being :

25% M CaO + MgO M 40% ; SiO_2 M 15% ; 20% M CaF_2 M 35%.

Two forms exist, produced either by melting or bonding. Fused fluxes are produced by heating to temperatures of the order to 1600 – 1700° C, and are converted to powder form either by atomisation on leaving the furnace, or by crushing and screening the solidified bulk material. Bonded fluxes are produced from raw materials of appropriate grain size, bonded together with an alkali silicate binder. The mixture is dried then mechanically treated to obtain the desired final particle size. Only part of the flux is fused during welding and the unfused material is picked up, usually by a suction hose and returned to a hopper for further use. The fused flux solidifies behind the welding zone and on cooling contracts and can be readily detached.

The SAW process is generally used for joining heavy work pieces in the thickness range 10 – 80 mm, after the root run has been completed, using another welding process.

3. Welding Fume Formation

In the electric arc, the temperature is very high (of the order of 6.000 – 8.000° C for the GTAW, GMAW, FCAW and SAW processes, and up to 10.000 – 20.000° C for the PAW process) and well above the boiling point of the base and filler materials (2680°C for Cr, 2860°C for Fe and 2915°C for Ni).

With the exception (in most cases) of GTAW and PAW processes, the melted metal is transferred in the form of droplets from the filler material (GMAW, FCAW, SMAW and SAW processes) to the molten pool or weld pool. A small fraction of the filler metal is vaporised – condensed (oxidised) or vaporised (oxidised) – condensed, creating small particles with an individual diameter ranging from 0.05 to 0.2 µm.

Fume particles formed during welding, whatever the filler metal, can be split in three categories:

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- Spherical particles, which are agglomerated in the form of clusters with a linear size of the order of 4 µm and a maximum of 10 µm.
- Particles, which are agglomerated in the form of chains with a linear size of the order of 4 µm and a maximum of 10µm.
- Spherical particles, which are agglomerated in the form of globules (spherical agglomerates) with a diameter up to 100 µm.

This typical situation is summarised in table 1.

Table 1: Size and morphology of welding fumes that can be formed during the welding of stainless steel

Category	Morphology	Size (µm)
1	Cluster	Average: 4 Maximum: 10
2	Chain	Average: 4 Maximum: 10
3	Globule (Spherical agglomerate)	Up to 100 µm

Different investigations have shown that the main source of welding fumes is the consumables and whatever the process involved, less than 5% of the fume comes from the weld pool.

According to the welding process the fume formation rate (FFR) can range from zero to a maximum of the order of 0.50 g / min. as it is shown in table 2.

Table 2: Fume formation rate related to welding processes

Process	Shielding Gas	Fume Formation Rate (FFR)	
		g / min	g / kg. deposit
GTAW PAW	Ar or 95% Ar + 5% H_2	0.005 max	(*)
GMAW	98% Ar + 2% O_2	0.10 / 0.50	3.0 / 6.0
FCAW	No (Self-Shielded)	0.40 / 0.60	2.0 / 3.0
SMAW	No	0.15 / 0.30	3.5 / 8.0
SAW	No (granulated flux blanket)	0.005 max	0.08 max

(*) In most cases no filler metal is used

Particularly with the GMAW process, there is a close dependence between the fume formation rate (FFR) and the two main welding parameters, i.e. the couple formed by the voltage and the welding current, which have a strong influence on the metal transfer.

With GMAW, the mechanism of metal transfer is therefore of a great importance. Three principal modes are distinguished:

- The **short-circuiting** or **dip transfer mode**, in which the metal melts to form large droplets. This mode is associated with a low FFR which is of the order of 0.10 g / min.
- The **globula**r or **gravity transfer mode**. As in the previous case, melting occurs in the form of large droplets, which break away when their mass is sufficient to overcome surface tension forces. This mode is associated with a high FFR which can reach 0.60 g / min.
- The **spray transfer mode** involves current densities above a certain transition level, of the order of 200 A / mm^2. The electrode melts to give a stream of fine droplets. This mode is associated with a moderate FFR ranging from 0.10 to 0.40 g / min.

The effect of transfer mode on fume formation rate is summarised in table 3.

Table 3: Effect of transfer mode on fume formation rate (FFR) in GMAW

Transfer Mode	FFR – (g / min)
Short circuiting or Dip transfer	0.10 → 0.40
Globular or gravity transfer	0.50 (maximum)
Spray transfer	0.10 → 0.40

Some investigators (1) – (2) – (3) have tried to identify the relative significance of welding parameters, i.e. welding current and voltage on the FFR. In fact, this distinction is difficult to make because for each welding current, there is an associated voltage, which is selected to give the best welding condition in order to minimise the formation of spatter. For this reason, it is better to associate the FFR to the transfer mode which takes into account both voltage and welding current (4).

A few studies devoted to the SMAW (covered electrode) process have considered fume formation. The two most comprehensive surveys were carried out by Kobayashi et al. (5) and Voitkevich (6). From those, it has been demonstrated that the droplet surface during the transfer in the arc plasma zone (high temperature zone) is the main source of metal vapour, which can be oxidised and condensed. Welding current density (A / mm^2) is a very important factor affecting fume formation rate. Increasing current density, increases droplet temperature and could increase vaporisation. On the other hand, covering of the electrode provides slag, which contributes to fume formation through chemical reactions, which can decrease FFR. The electrode covering, also provides shielding gases through decomposition of carbonates, increasing protection against the air immediately surrounding the welding zone.

Submerged arc welding (SAW) uses a bed of granulated flux, which will be fused to shield the arc and molten weld metal from the atmosphere. As the arc is not exposed to the air, there is a negligible emission of fume through the blanket covering.

4. Composition and Particle Structure of Welding Fumes

In order to take into account the valence state and the solubility of chromium in stainless steel welding fumes, it is necessary to classify chromium as shown in table 4.

Table 4: Classification of chromium states in stainless steel welding fumes (7)

Total Chromium			
Soluble Cr		**Insoluble Cr**	
Soluble Cr VI	Soluble Cr III	Insoluble Cr VI	Insoluble Cr III

To determine (by wet chemical analysis) Cr VI, because of the possible oxidation of Cr III into Cr VI or the possible reduction of Cr VI into Cr III, it was recommended to use an adequate dissolution medium such as a water solution containing 3% of sodium carbonate (Na_2CO_3) and 2% of sodium hydroxide (NaOH) – (4).

At present the wet chemical analysis making possible chrome speciation is mainly based on the following methods:

- Atomic – Absorption – Spectroscopy (AAS)
- Spectroscopy with Induction – Coupled – Plasma (ICP)

and for solid phase methods:

- X-ray Absorption Near Edge Spectroscopy (XANES)
- X-ray Absorption Fine Structure (XAFS)
- Laser Ablation Mass Spectroscopy (LA – MS) and
- Secondary Ion Mass Spectroscopy (SIMS)

Combining results of these various methods (6), (8), (9) and according to the arc welding process involved, the chemical composition of welding fumes is given in table 5.

From the examination of the welding fume composition (table 5), it is obvious that there is no relationship between the chemical composition of the fume and the chemical composition of the base metal and / or the filler metal.

For stainless steel welding fumes complex metal oxides and sodium and potassium species were identified (table 6) in SMAW. According to Eagar et al (10) in GMAW performed with a ER 308 filler metal (ER 308 is a 20% Cr and 10% Ni containing filler metal) under a shielded gas mixture of 98% Ar and 2% O_2, the theoretical metal vapour can contain approximately 20% Cr, 6% Cr O, 0.5% Cr O_2, and a negligible amount of Cr VI. It was concluded that chromium and / or its oxides must subsequently oxidise.

Spinel type structures were found in all particle fumes which are basically different of both base material and / or filler metal which have metal structures i.e. **face-centered cubic structure** (fcc) for the austenitic grades and a **body-centered cubic** (bcc) structure for the ferritic ones.

Table 5: Fume Composition related to welding processes

Process	Shielding Gas	Fume Composition, Wt (%)										
		Fe	Mn	Si	Ca	K	Na	F	Mg	Ni	Cr VI	Cr Total
S.M.A.W.	No	5 – 20	1 – 12	0.2 – 13	0.2 – 10	1 – 25	1 – 15	0.1 – 20	--	0.1 – 6	0.5 – 6	1 – 12
G.M.A.W.	98% Ar / 2% O_2	30 – 40	1 – 12	1 – 4	--	--	--	--	--	2 – 8	0.2 – 1	8 – 13
F.C.A.W.	75% Ar / 25% CO_2	10 – 20	4 – 8	2 – 8	0.1 – 5	1 – 3	5 – 12	3 – 6	--	1 – 3	0.3 – 2	8 – 13
	No(Self-shielded)	13	6	4	1	18	5	21	0.01 – 3.0	3	4	9
G.T.A.W. **P.A.W.**	Ar or 95% Ar / 5% H_2	30 – 60	20 – 60	--	--	--	--	--	--	1.5 – 6	< 0.1	5 – 12
S.A.W.	No (Granulated flux blanket)	--	--	--	--	--	--	--	--	< 1.0	< 0.1	2

Table 6: Phase Composition of Chromium in St ainless Steel Welding Fumes (after 6)

Element	Phases	
	SMAW	**GMAW**
Cr III	$Cr_2 O_3$ $Fe Cr_2 O_4$ $K_2 Na Cr F_6$	$Cr_2 O_3$ (Fe, Mn, Ni) $(Fe, Cr, Mn)_2 O_4$
Cr VI	$K_2 Cr O_4$ $Na_2 Cr O_4$ $NaK_3 (Cr O_4)_2$	

5. Health Effects of Welding Fumes

5.1 Occupational Exposure Regulations

Welding is an important activity, in part because approximately 2% of the working population in industrialised countries is engaged in welding operations. Although there are various processes, it has been estimated that GTAW, PAW, GMAW, FCAW, SMAW and SAW in combination account for 90% of stainless steel welding. In arc welding processes, about 95% of the fume comes from the consumable, mainly from the filler metal .

Fumes from stainless steel welding may contain hexavalent chromium compounds (Cr VI) and exposure to these fumes is subject to national regulations as it is reported in table 7.

It should be noted that national regulations permit the calculation of a limit for the total welding fume, which is of the order of 5 mg / m^3, while individual limits are specified for specific species such as chromium VI compounds as shown in table 7. Providing there is good ventilation usually called "fume extraction", the levels of fume generated when welding stainless steel are normally below the occupational exposure limits (OELs).

Table 7: Existing OELS for Cr III and Cr VI compounds within EU Member States and the USA

Country	Cr VI		CR III	
	Cr VI Compound	**Exposure limit (µ g / m³ as Cr)**	**Cr III Compound**	**Exposure limit (µ g / m³ as Cr)**
Austria	Cr VI compounds (soluble)	TWA = 100		
Belgium	Cr VI compounds	TWA = 50	Cr III compounds	TWA = 500
Denmark	Chromic Acid and Chromates	TWA = 50	Soluble Cr III salts	TWA = 500
Finland	Cr VI compounds	TWA = 50	Cr III compounds	TWA = 500
France	Cr VI compounds	TWA (VME) = 50 STEL = 100	Cr Metal	TWA (VME) = 500
Germany	Cr VI compounds	TWA (TRK) = 50 (as CrO_3) In welding fumes (SMAW) TWA (TRK) = 100 (as CrO_3)		
Sweden	Chromates and chromic acid	TWA = 20 STEL = 60	Inorganic compounds	TWA = 500
U.K.	Cr VI compounds	TWA (MEL) = 50	Cr III compounds	TWA = 500
USA / ACGIH	Cr VI compounds (water soluble)	TWA (TLV) = 50	Cr III compounds	TWA (TLV) = 500
	Cr VI compounds (insoluble)	TWA (TLV) = 10		
USA / OSHA	Cr VI compounds	CL = 100	Cr III compounds	TWA (PEL) = 500

5.2 Epidemiological Investigations

In the largest epidemiological study carried out by the International Agency for research on Cancer (IARC) –(11) in nine European countries on 11092 mild steel and stainless steel welders, a distinction was made between four categories of welders according to the potential exposure to hexavalent chromium (table 8).

Table 8: Categories of Welders and their Potential Exposure to Hexavalent Chromium According to IARC

Study Group	Exposures to Cr VI
Mild Steel Welders Predominantly stainless steel welders Ever stainless steel welders Shipyard welders	No Yes Yes No

Table 9 contains standardised mortality ratios (SMR) on which comparisons can be made between the different categories of welders.

Table 9: Standardised Mortality Ratios (SMR) for the European Cohort of Welders in relation to Cancer (Simonato et al. ref. 11)'

	Arc Welders		**Ever stainless steel welders**		**Predominantly stainless steel**		**Mild steel welders**		**Shipyards welders**	
	SMR	**Cases of lung cancer**	**SMR**	**Cases of lung cancer**	**SMR**	**Cases of lung Cancer**	**SMR**	**Cases of lung cancer**	**SMR**	**Cases of lung cancer**
≥ 20 years since first exposure Total	--	--	152	22	174	13	198	25	107	25
≥ 10 years of employment (*)	--	--	157	13	176	11	173	15	96	10
TOTAL	134	116	128	39	123	20	179	40	126	36
Exposure to chromium VI compounds (and nickel compounds) is not encountered in shipyard and mild steel welding.										

The conclusion of this most outstanding epidemiological study drawn by Simonato et al is: "The excess mortality from lung cancer is present among shipyard welders, mild steel welders and stainless steel welders, but it does not appear to be related to duration of employment or cumulative exposure to total fumes, total Cr, Cr VI or Ni".

The only conclusion, which can be drawn from these figures, is that the mild steel welders in this cohort were at higher risk of lung cancer than the stainless steel welders were. The SMR for lung cancer among welders as whole, when all the relevant studies are considered together, is of the order of 140. The cause of this excess is attributed by most experts first to asbestos and then to smoking. It should be remembered that there were five mesotheliomas observed in the Europe cohort. These two biases are also addressed in the Simonato study.

This study is ranked as the best in quality and is probably the one with the least potential for exposure of subjects to asbestos.

In a recent follow up study (1989 – 1995), among arc welders exposed to chromium and nickel containing fumes, Becker (12) concluded that the increase in mortality is predominantly due to a large excess in mortality from mesothelioma, which is known to be caused chiefly by asbestos exposure, and there is no indication of an elevated cancer risk specifically associated with exposure to welding fumes containing chromium and nickel.

Meta-analysis is a technique for combining the results of different epidemiological studies to arrive at a single estimate of risk. In a meta-analysis carried out in 1995, Moulin (13) concluded that despite the exposure of stainless steel welders to chromium and nickel compounds, the results do not provide clear evidence to suggest that stainless steel welders are at higher risk of lung cancer than mild steel welders.

6. Conclusion

Based on the speciation concept, this paper provides information on the different forms of chromium compounds in fumes generated during arc welding of stainless steels.

With most arc welding processes (GMAW, FCAW, SMAW and SAW) a small fraction of the filler metal is vaporised condensate (oxidised) or vaporised (oxidised) – condensed creating a fume consisting of small particles containing chromium, which is mainly in the trivalent form (Cr III). Hexavalent chromium (Cr VI) is only present in small proportions. The fume from SMAW (covered electrode) and FCAW processes contain the highest proportion of Cr VI compounds but with these two processes it is possible to employ very efficient fume extraction systems. GTAW, GMAW and SAW processes do not generate signification amounts of hexavalent chromium.

With the GMAW process, the fume formation rate (FFR) is closely dependant on the transfer mode. Selecting the right welding parameters and / or employing pulsed GMAW is a way to reduce the FFR.

From the examination of both chemical composition and the structure of the welding fume particles, it is obvious that there is no relationship between the fume characteristics and those of the base material and / or the filler metal. The chemical composition and the structure of fume particles reflect reactions between the filler metal and its arc environment (covering for SMAW, flux core for FCAW, shielding gas for GMAW, etc...). Given the respirable nature of the welding fume and the presence in it of hexavalent chromium compounds suspected to be carcinogenic, attention has been drawn to assessing the possible risk of lung cancer in welders. Taking into account the most relevant epidemiological and meta-analysis studies, it can be concluded that despite the exposure of stainless steel welders, welding fumes containing chromium compounds, the results show that stainless steel welders appear to be at no higher risk of contracting lung cancer than mild steel welders.

Abbreviations and Foot notes

- ACGIH : American Conference of Governmental Industrial Hygienists
- bcc : Body-Centered Cubic structure
- CL : Ceiling Limit (concentration that should not be exceeded during any part of the working exposure)
- FCAW : Flux Cored Arc Welding
- fcc : Face-Centered Cubic structure
- FFR : Fume Formation Rate
- GMAW : Gas Metal Arc Welding
- GTAW : Gas Tungsten Arc Welding
- IARC : International Agency for Research on Cancer
- MEL : Maximum Exposure Limit
- OEL : Occupational Exposure Limit
- OSHA : Occupational Safety and Health Administration
- PAW : Plasma Arc Welding
- PEL : Permissible Exposure Limit
- SAW : Submerged Arc Welding
- SMR : Standardised Mortality Ratio
- STEL : Short Term Exposure Limit (Recommended for substances that have acute effects but the toxic effects are primarily chronic)

- TRK : Technische Richtkonzentrationen (Technical Exposure Limit defined as the concentration of substances in the air at the workplace, which can be reached according to the state of technology. TRK, therefore is the lowest level to be reached)

- TWA : Time Weighted Average (Average concentration time-weighted over an 8 hour work day)

- VME : Valeur moyenne d'exposition

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