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PROCESS-DEPENDENT CHARACTERISTICS OF WELDING FUME PARTICLES

KLAS G MALMQUIST¹, GERD JOHANSSON^{2,3}, MATS BOHGARD^{1,2} AND K ROLAND AKSELSSON²

1. Department of Nuclear Physics, Lund University Institute of Science and Technology, Box 118, S 221 00 Lund, SWEDEN
2. Department of Working Environment, Lund University Institute of Science and Technology, Box 118, S 221 00 Lund, SWEDEN
3. Department of Environmental Health, University of Lund, Sölvegatan 21, S 223 62 Lund, SWEDEN

INTRODUCTION

In electric-arc welding operations more or less hazardous particles are generated. Thus there is a need for actions against health effects such as changes of welding techniques and welding parameters, changes of joining technique, local exhausts, respiratory protective equipment, job rotation and robotization. It gives priority to actions involving economic as well as health factors, there is a need for reliable dose-response relations and for good exposure data. For both of these needs extensive data on process-dependent characteristics of welding fume particles are of utmost importance.

This paper describes a comprehensive investigation of the total mass emission, particle size distribution and elemental composition for 13 different welding methods at different currents and voltages. The oxidation state of chromium was also investigated where applicable. See ref. 1 for an extensive report of this work performed at the Lund Institute of Technology. The results are discussed in the light of some recent results from the literature.

EXPERIMENTAL ARRANGEMENTS

Sampling equipment

Figure 1 shows the design of the sampling arrangement. The welding takes place beneath the aluminium hood. The velocity of the air is low (<0.15 m/s) around the welding point to ensure that the welding process and the aerosol formation are not significantly affected. To obtain the size distribution the welding aerosol was sampled by a Battelle-type single orifice cascade impactor² drawing 1 litre/min. For an accurate investigation of the elemental composition of the welding aerosols, a membrane filter arrangement was used. The flow-rate was 1-3 l/min. To determine the total mass of the welding aerosol a glass fibre filter was used.

Analytical methods

In this investigation more than 3000 samples have been analysed for many elements. The multi-elemental analysis method PIXE³, Particle Induced X-ray Emission, was used for quantification of all elements heavier than phosphorous. A nuclear reaction, $^{19}\text{F}(p,\alpha)^{16}\text{O}$, was used for fluorine analysis⁴. An analytical

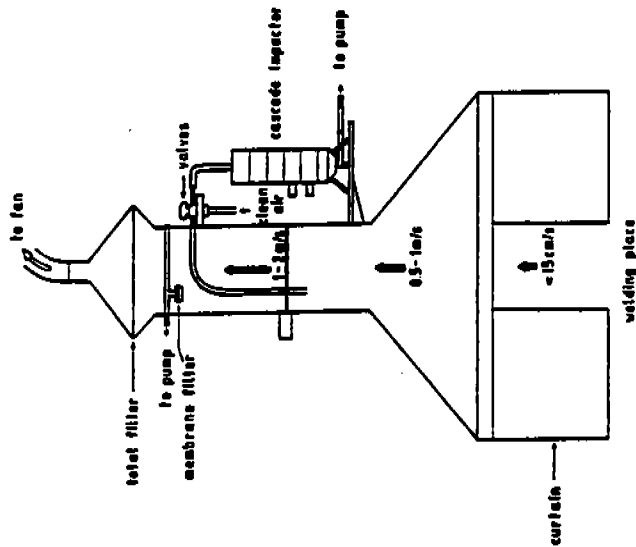


Fig. 1. Sampling equipment for the characterization of welding aerosols. The arrows indicate the air velocity in different parts of the system.

procedure was developed to quantify the masses of soluble and less soluble Cr(III) and Cr(VI) (ref. 5). This procedure includes the PIXE method, electron spectroscopy for chemical analysis (ESCA), a spectrophotometric method and transmission electron microscopy (TEM).

EXPERIMENTS

Sampling procedures

Table 1 shows the electrodes used in this investigation. For each of the electrodes the welding current was varied within the intervals recommended for each of the electrodes by the manufacturer, while the welding voltage was varied in an interval significantly larger than the recommended in order to enhance any systematic effect on the fume production.

For the direct current SHAW (Shielded Metal Arc Welding) methods reversed polarity (positive electrode) was used. The welding was performed manually by

Electrode	Type	Coating/Gas	AMS ^b -class.	Diam. (mm)	
1	OK 38.65	SHAW	Iron powder, low hydr. zirconium added	E 7028	3.25
2	OK 38.85	SHAW	Iron powder, low hydr. rutile	E 7028	5
3	OK 38.95	SHAW	Iron powder, low hydr. zirconium added	E 7028	4
4	OK 48.00	SHAW	Iron powder, low hydr.	E 7018	2,3,25,4
5	OK 61.41	SHAW ^b	rutile	E 308 L-15	3.25
6	OK 63.35	SHAW ^b	low hydrogen	E 316-15	2.5,3,25,4,5
7	OK 69.21	SHAW ^b	low hydrogen-rutile	-	3.25,4,5
8	OK 12.51	GMW	CO ₂	E 70 S-6	1.2
9	OK 16.32	GMW ^b	Ar	ER 316 I S1	1.2
10	OK 16.32	GMW ^b	Ar/CO ₂	ER 316 I S1	1.2
11	OK 18.01	GMW ^c	Ar	Er 1260	1.2
12	OK 18.13	GMW ^c	Ar	ER 5154	1.2

a) AMS-class. - American Welding Society classification

b) welding on stainless steel; c) welding on aluminum

Table 1. A list of the welding methods included in this study. The numbers are used for identification in the various figures.

a skilled welder exerting himself to maintain constant welding conditions.

For the GMW (Gas Metal Arc Welding) methods the welding gun was mounted in a fixed position perpendicular to the work piece, which was fixed onto a wagon running on rails. The speed of the wagon could be varied to simulate the normal welding speed.

For each set of welding parameters three to five measurements were carried out. The results are given as averages.

RESULTS AND DISCUSSION

Total Fume Emission

For the comparison of fume production from different welding techniques, two entities can be defined, viz. the total fume emission rate, E (g/min), and the relative fume formation index, R , which is the total mass of emitted fume normalized to the mass of the deposited consumable (excluding slag) in mg/g. In Table 2, our experimental values of E and R are summarized.

The total fume emission rate is dependent on electrode dimensions and electric power. Due to variations in these parameters, E varies in the interval 0.2 to 2 g/min for the methods in the present study (except for GTAW). As can also be seen

Electrode	Diam. (mm)	I (A)	U (V)	E (g/min)	R (mg/g)
OK 38.65	3.25	160	35	0.58	16.7 ³
OK 38.85	5	300	34	1.30	15.7
OK 38.95	4	210	32	0.93	21.7
OK 38.95 ²	4	205 ²	30 ²	0.75	19.2
OK 48.00	3.25	140	23	0.45	26.0
OK 61.41	3.25	115	33	0.38 ³	11.3 ³
OK 63.35	4	140	24	0.39	15.6 ³
OK 69.21	4	140	22	0.29	12.4
OK 12.51 CO ₂	1.2	180	30	0.23 ⁴	5.4 ⁴
OK 16.32 Ar	1.2	180	26	0.20	3.8
OK 16.32 Ar/CO ₂	1.2	180	26	0.29 ³	5.7
OK 18.01 Ar	1.2	180	22	0.49	20.5
OK 18.13 Ar	1.2	160	24	0.91	24.1

- 1) Direct current; reversed polarity (electrode as anode).
- 2) Alternating current.
- 3) Standard error of the mean: 5-10%.
- 4) Standard error of the mean: 10-15%.

Table 2. The welding situations referred to in the text as "normal" welding, implying that the welding currents were chosen to be in the middle of the intervals recommended. E and R denote the total fume emission rate and the relative fume formation index respectively. The standard errors on the mean were less than 5% if not explicitly given.

from Table 2, large variations in the relative fume formation index are found between the different methods (3-35 mg/g). It may also be inferred that, with the one exception of GMAW on aluminium, the SMAW methods generally give higher values than the GMAW methods for both E and R.

The results in Table 2 can be compared with those obtained in the systematic study presented in ref. 6. The differences are normally smaller than 10%. The discrepancies might be explained by somewhat different sampling and welding conditions as well as by variations in different brands of welding consumables of the same classification and between different conditions and ages of the covered electrodes.

Shielded Metal Arc Welding. Despite their different dimensions, coatings and core compositions, the seven SMAW methods in this study seem to have approximately the same current dependence (see fig. 2). These results are in good agreement with those of refs. 6 and 7.

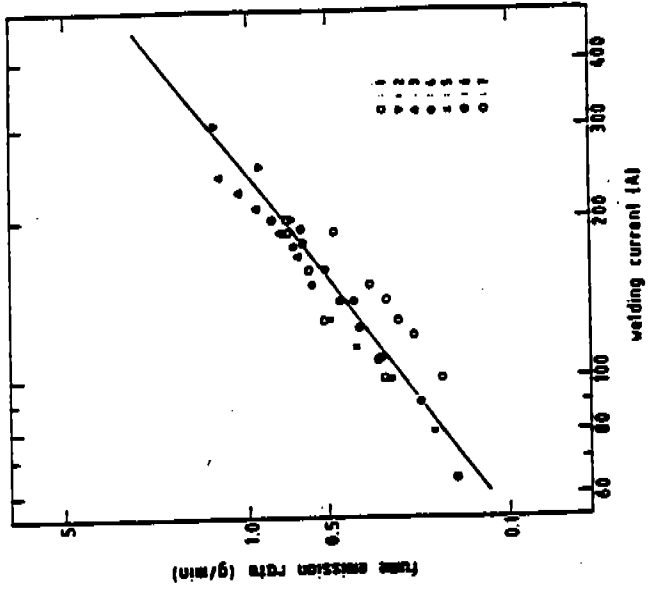


Figure 2. Total fume emission rates for all the SMAW methods in this study plotted versus welding current ($r^2 = 0.88$). The number at each symbol refers to the corresponding welding method in Table 1.

For the relative fume formation index, the influence of welding current is normally low.

In figs. 3 and 4 the total fume emission rate, E, and the relative fume formation index, R, for three SMAW methods are plotted versus welding voltage. Increases in both E and R are observed with increasing voltage. A high voltage, i.e. a long electric arc, implies an increased residence time for the transferred melted material before reaching the weld pool, thus increasing the fume formation. The covering forms a protective crater for the arc hindering oxygen penetration into the arc region. When the arc length is increased this protection may be less efficient and oxygen may interfere in the arc region. This normally promotes fume formation (ref. 8). The long arc also suffers from more severe wire explosions and bubble bursting of boiling material. The instantaneous evaporation in wire explosions and the spatter from bubble bursting have been shown by Gray et al.

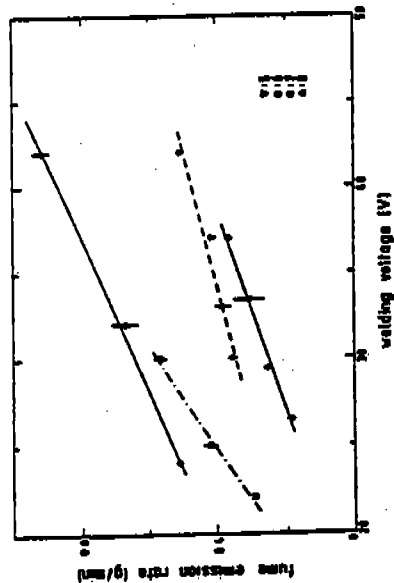


Figure 3. Total fume emission rates for three SHAW methods (stainless steel welding) and for the GMAW method with CO_2 as protective gas (mild steel welding) plotted versus welding voltage. The number at each symbol refers to the corresponding welding method in Table 1. The welding currents were 115, 160 and 140 A for methods 5, 6 and 7 respectively, and 200 A for method 9. The error bars show one standard error on the mean.

to be significant sources of fumes. In GMAW the spatter produced up to 30% of the fume and is probably also important in SHAW.

The increase in the emission rate with voltage as seen in fig. 3 is very similar to that observed in other studies (10,11). From fig. 4, it is evident that the influence of the welding voltage on the fume formation index is dependent on the type of coating on the electrode in question. Part of the explanation for this finding may be the coating dependent relation between voltage and arc length. A significant impact from coating composition on fume formation has been demonstrated by Kobayashi et al (2).

Gas Metal Arc Welding. In semi-automatic gas metal arc welding the influence of the protective gas on the electric arc and on the metal transport process makes the fume emission a complex function of the welding parameters.

With pure CO_2 the transfer of the melted metal from the electrode tip to the work piece is characterized by large globules (diameter: 2 to 3 mm). If, however, the protective gas is argon or mixtures of argon and CO_2 , different modes of transfer will occur. For low voltage and very low current the transfer will be short-circuiting and for somewhat higher current the transfer will be globular with decreasing size and increasing number of globules for increasing current. In these modes the tendency towards wire explosions and bubble bursting

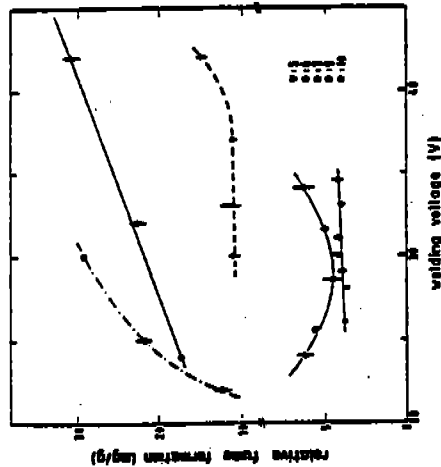


Figure 4. Relative fume formation index plotted versus welding voltage for the same SHAW methods as in figure 3 and for the GMAW method with pure argon (○) and an argon/ CO_2 mixture (■) as protective gas respectively. The number at each symbol refers to the corresponding method in Table 1. The welding current in method 9 and 10 was 180 A. The error bars show one standard error on the mean. Note the shift of scale on the ordinate axis.

is rather high with spatter yielding significant fume emission as was shown by Gray et al (9). For high voltage and high current, metal transfer becomes a spray of smaller droplets (diameters between 0.5 and 1 mm). The drop size remains essentially constant when the current is increased. The detachment of the small droplets from the electrode is due partly to the magnetic "pinch effect" and transport along the arc is due mainly to the plasma jet (3). The value of the current at which this transition occurs is proportional to the diameter of the electrode and dependent on the material and electrode extension (4).

In fig. 4 the relative fume formation index, R, is plotted versus welding voltage with pure argon and with a mixture of 80% argon and 20% CO_2 as protective gases. While for pure argon, R is almost independent of the welding voltage, there is a well-defined minimum at a specific voltage for the Ar/ CO_2 mixture. The magnitude of R is higher for all voltages when CO_2 is mixed in the gas. The oxides of several elements have higher vapour pressure than the pure elements, thus promoting fume formation in an oxidizing atmosphere (oxygen enhanced evapora-

tion). This effect has been discussed in detail in refs. 8 and 15.

The welding current for the GMAW methods in fig. 4 (1-180 ± 5 A) is above the transition level for spray transfer for this particular electrode¹⁶. The minimum of R for the Ar/CO₂ mixture coincides with the lowest voltage at which a stable spray arc can exist. Once a stable spray arc is established, R will increase with voltage in the case of Ar/CO₂ gas but remain constant for pure argon. The increased voltage corresponds to a longer electric arc with a consequently longer residence time for the droplets in the oxidizing atmosphere while being transferred to the work piece, and hence, according to what is stated above, an increased probability for fume formation. The inert argon atmosphere, which surrounds the arc, protects the droplets from oxygen during transfer.

In pure CO₂ welding the fume emission rate increases strongly with voltage, as can be seen from fig. 3. This dependence is in good agreement with the results of refs. 17 and 18, where the same or very similar welding parameters have been used. Part of this increase with voltage is due to increased oxygen penetration into the arc but since the oxidizing CO₂ is used as a protective gas the instability and high degree of spatter is probably a more important source of increased fume production. If, instead, the welding current is increased at constant voltage, the wire feeding speed increases with decreasing length of the welding arc¹⁷. Due to the decreasing time for the globules in the CO₂ atmosphere, R decreases with increasing current⁸. As an example, for method 8 (see table 1) at 30 V the relative fume formation index decreased from 10 mg/g to 5 mg/g and further to 3.5 mg/g when the welding current was increased from 150 A to 200 A and further to 300 A.

Elemental Composition

In Table 3, the elemental compositions of welding aerosols including fluorine and elements heavier than sulphur are given for the different welding processes for the same parameter values as those given in Table 2.

Basically, the elemental composition of a welding aerosol reflects the composition of the consumable electrode used but often with an altered relative abundance. In the electric-arc column the highest temperature is found at the axis near the melting tip of the electrode¹⁹. Consequently, fumes will come mainly from the melting electrode and from the surface of the droplets being transferred in the arc. This statement is supported by the findings in ref. 20.

Table 4 gives fractionation factors of the different metals in the welding aerosol relative to the welding consumable for four different welding methods. Noticeable are the high factors for manganese (2-7) while the factors of the other elements are well below unity. This is in good agreement with the results from Kobayashi et al²⁰. Since manganese has a much higher vapour pressure than, e.g. chromium and iron, it will also have a high tendency towards fume formation.

Table 3. Relative elemental compositions (expressed as per cent of the total mass of aerosol) of the welding fumes from the welding situations described in Table 2 as determined in this study. The standard errors of the mean are less than 10% if not explicitly shown.

1) See Table 1; 2) Alternating current; 3) Standard error of the mean: 10-20%
4) Standard error of the mean: >20%

Element	1	2	3	4	5	6	7	8	9	10	11	12
Na	7.1	.26 ³										
F		.33 ³										
Cl		.54 ³										
K	8.8											
Ca	2.6	.62										
Ti		.54										
Cr	.07											
Mn	5.9	4.7	3.2	3.2	3.7	3.4	3.0	5.3	4.8	12	12	.04
Fe	32	4.7	24	24	3.7	3.4	3.4	28	4.8	31	31	.14
Ni	.08	.29 ⁴			.22	.24	.43	4.5	4.8	.12 ⁴	.12 ⁴	.06
Cu		.17 ³			.01	.01	.01	.06	.09	.03	.03	
Zn	.17 ³	.29 ⁴			.01	.01	.01	.06	.09	.03	.03	
As	.06 ³	.04 ³			.03 ³	.04 ³	.04 ³	.26 ³	.17	.18	.18	.02
Rb		.23 ³			.01	.01	.01	.06	.09	.03	.03	
Zr	.54	.36 ³			.02	.01	.01	.06	.09	.03	.03	
Mo		.23 ³			.01	.01	.01	.06	.09	.03	.03	
Pb	.10 ³	.07 ³			.03	.03	.03	.06	.09	.03	.03	

	Shielded metal arc welding		Gas metal arc welding	
	Low alloy electrodes (n=4)	Stainless steel electrodes (n=3)	CO ₂ - gas Low alloy steel (n=1)	Argon - gas Stainless steel (n=2)
Cr		0.17-0.21		0.68-0.70
Mn	2.2-6.1	2.3-3.8	6.9	4.2-5.2
Fe	0.22-0.33	0.055-0.066	0.49	0.47-0.50
Ni		0.025-0.040		0.36-0.41
Mo		0.027-0.052 (n=2)		0.24-0.32

Table 4. The elemental concentrations in the fume divided by the elemental concentrations in the welding consumables. The intervals are defined by the minimum and maximum values. n = the number of methods included.

Shielded Metal Arc Welding. The voltage dependence of the relative abundances of elements in the fume is varying between different electrodes. Nevertheless, potassium and fluorine constitute one group and the core metals another group with inter-group covariations. In our results the elements of typical flux origin, e.g. fluorine and potassium, show a decrease with increasing arc voltages at low voltages. These results may seem to be contradictory to the findings by Gray et al¹⁰. However, the discrepancy might be explained by differences in welding parameters and electrodes used in the two investigations.

In a systematic study, Kobayashi et al¹² have shown how the concentrations of the elements in the covering are reflected in the fumes. Generally, a positive linear relation holds for all elements except fluorine and iron. The coefficients of regression depend on the vapour pressures of the respective elements. The concentrations of alkaline metals, such as potassium, are much higher in fumes from electrodes with a lime-type covering than in fumes from non-lime electrodes. The presence of calcium, especially CaF₂. In the covering seems to be the main source of this special characteristic.

The contribution to the fume from the elements in the metal core will depend on the arc voltage and on the flux composition in the covering. Generally, when the voltage is increased elements with low vapour pressures, e.g. iron, are enhanced relative to those with high vapour pressures, e.g. manganese (see fig. 5). For the electrodes OK 48.00 and OK 63.35, which have relatively equal flux compositions, this effect is pronounced. The main reason for this dependence is a relative increase in the unfractionated fume production due to increased severity of wire explosions followed by instantaneous non-fractionated vaporisation of the elements¹⁰.

As seen in Table 3 a change from DC to AC may cause a drastic change in the relative composition. The temperature at the electrode tip depends on the

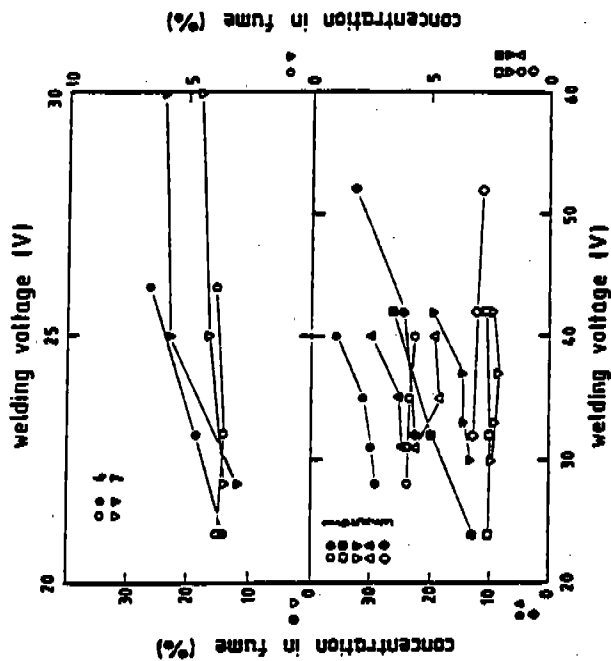


Figure 5. Iron (filled symbols), and manganese (unfilled) concentrations in the welding fume versus welding voltage for seven SMAW methods. The numbers refer to the methods given in Table 1. The ordinate axis corresponding to each symbol is indicated by the symbols close to origin of each axis respectively.

polarity and consequently the use of an alternating current is expected to change the conditions for fume production and hence the chemical composition.

Gas Metal Arc Welding. In the semi-automatic GMAW methods the composition of the welding fumes is determined by the composition of the metal wire and by the character of the protective gas.

For mild steel a CO₂ atmosphere is normally used giving globular transfer. When the welding parameters are varied, no significant variation in the elemental composition has been observed in the present study. This observation is in good agreement with the results from other studies^{8,21}.

In fig. 6, the concentrations of five elements in the fumes versus voltage for an argon GMAW method are shown. When comparing with an argon/CO₂ mixture (80/20) all elements except manganese have higher abundances with the mixture than with

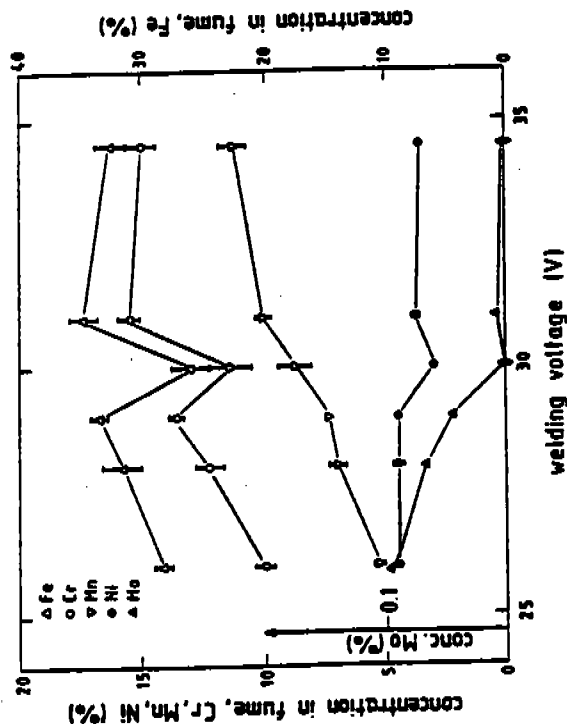


Figure 6. Relative elemental abundances from stainless steel welding with GMAW (0% 16.32, 100% argon, I = 180 A) plotted versus welding voltage. The errors indicated are one standard error on the mean.

the pure argon. For both protective gases, the general trend for chromium and manganese is an increase with voltage, while the iron concentration is essentially constant and nickel and molybdenum concentrations decrease with increasing voltage. However, in pure argon, a dip in the relative abundance is observed (at 30 V) for all elements except manganese. This minimum voltage is the lowest for which stable spray transfer can be sustained. A tentative explanation for this may be that the very stable arc, essentially free from spatter and turbulence, significantly reduces oxygen-enhanced vaporisation in the inert argon gas. When the voltage is further increased the increasing arc length makes the arc less stable again. Since CO₂ is oxidizing the same effects are not observed for argon/CO₂ as shielding gas.

In fig. 6 it can be seen that the concentration of molybdenum decreases rapidly with voltage, disappearing when the material transfer changes. Apparently the major mechanism for molybdenum to produce a fume is non-fractionated instantaneous vaporisation in connection with wire explosions which are more frequent for

globular transfer. The voltage dependence of molybdenum is in good agreement with the results obtained in a study by Gray et al.⁹

Oxidation State of Chromium

See Table 5. In aerosols from the three SMAW methods for stainless steel welding, more than 50% of the chromium was found to be soluble and hexavalent. Between 60 and 100% of the chromium in the particle surface layers was hexavalent as determined by ESCA analysis, but decreases after washing the aerosol with a buffer solution (pH 7.4). Apparently most of the hexavalent chromium on the particle surfaces leaches out during washing. TEM studies have shown that after washing, the core particles consist of smaller homogeneous particles with diameters of about 0.01 μm. The ESCA results are representative of about 80% of the volume of the particles of this size. The formation of hexavalent chromium depends on which elements have been added to the coating and it has been shown by Kimura et al.²² that it is possible to reduce the amounts of hexavalent chromium by changing the additives to the coatings and still perform technically acceptable welding.

For argon gas metal arc welding only about 2% of the total chromium is soluble and hexavalent and for both the unwashed and washed aerosol samples the concentrations of hexavalent chromium on the particle surface are below the detection limit of the ESCA method (< 15%).

Within the uncertainties of the differences in welding conditions and parameters, the results concerning the content and oxidation state of chromium in welding aerosols found here are consistent with those of other studies.²³⁻²⁵

Method number ¹	Diam. (nm)	I(A)	U(V)	Cr-tot (%)	A	B	C
5	3.25	100	35	3.4	.50	.60	.27
6	3.25	100	22	4.4	.73	1.00	<.15
7	3.25	105	21	2.9	.52	1.00	<.15
9	1.2	180	26	12	.019	<.15	<.15

1) see table 1

A) Cr(VI)-soluble/Cr total

B) Cr(VI)/Cr-total on the particle surfaces

C) Cr(VI)/Cr-total on the particle surfaces after washing

Table 5. Results from the determination of oxidation state and solubility of chromium in welding aerosols from stainless steel welding.

Particle Size Distribution

The mass median aerodynamic diameters (MMAD) were calculated for each element. For SHAW and GMAW methods the MMAD is between 0.35 and 0.6 μm . The variation with element is small. A typical value of the geometrical standard deviation of the distribution is 1.5. Thus the particles in all welding aerosols studied are respirable and have a rather high probability of being deposited in the lower parts of the respiratory tract. The results of refs. 6, 8, 18, 26-28 are essentially in agreement with those of the present study.

The particles emitted in SHAW methods contain significant concentrations of highly soluble and hygroscopic compounds derived from elements such as fluorine, potassium and sodium in the electrode coating. The high relative humidity of the human respiratory tract, RH > 99% in the subglottic region²⁹, enables the particles to rapidly absorb water, which may significantly alter the pattern of regional lung deposition.

Particle size determinations have been carried out for all methods and sets of parameters. Only negligible variations (< 10%) in the particle diameter occurred. The variation in the MMAD between elements for a certain method is also negligible.

SUMMARY

Several welding methods were characterized using a specially designed collection apparatus which has been found to be reliable and to yield accurate and representative sampling of welding aerosols. The results are compared with some recent results from the literature.

The highest fume emission in this study is found for SHAW methods and for GMAW methods on aluminium followed by GMAW methods on steel. The fume emission rate (E) is determined primarily by the welding current. Similar current dependence is found for all SHAW methods if used at normal voltage. The voltage also affects E but to a smaller extent. The relative fume formation index (R) varies drastically among the methods and is dependent on the welding parameters. For gas metal arc welding of mild steel with pure CO₂ as the protective gas, R essentially decreases with increasing current.

The composition of the shielding gas in GMAW is important for the fume production. The fume formation index is higher in the case of argon/CO₂ mixture than in the case of pure argon. The influence of the welding parameters on the fume formation is altered by mixing CO₂ into the argon. This study supports the findings of earlier works, viz. that the oxidizing potential of the gas surrounding the electric arc is of considerable importance in determining the fume production, with increased fume production when the oxidation potential of the protective gas is increased.

The fume contains the same elements as the consumable but with the relative abundances changed due to fractionation effects. This is explained by the different properties of the elements, e.g. with regard to vapour pressures of the pure elements and their compounds. For SHAW only minor variations occur when the current is changed. Welding voltage and current mode (AC/DC) have drastic effects on the elemental composition of the fumes. This is probably due to changes in electric-arc length and arc characteristics. The elemental composition of a GMAW aerosol is also dependent on the protective gas. Thus, a relative decrease in several elements is noted when the transition from globular to spray transfer takes place in the argon atmosphere.

While the chromium in the SHAW aerosols is almost entirely hexavalent (and soluble), only trivalent chromium is found in the GMAW aerosols.

The particles in the welding aerosols are below 1 μm in diameter and consequently respirable. Mass median aerodynamic diameters vary from 0.35 μm to 0.6 μm and seem to be essentially independent of the welding parameters. Hygroscopicity may be an important factor in evaluating lung deposition of aerosols from SHAW methods.

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EXPOSURE MONITORING AND CHEMICAL ANALYSIS
OF WELDING FUME

E. TIHONSEH, Chemconsult, Oldvejen 7, Røgsrup, DK 4050 Skibby.
R. M. STERN, Danish Welding Institute, Park Alle 345, DK 2600
Glostrup.
B. PEDERSEN, Danish Institute of Occupational Health,
Bøunegårdsvej 73, DK 2900 Hellerup.

INTRODUCTION

Standardized and quality assured sampling and analysis procedures for welding fumes are essential in efforts to demonstrate causality between occupational exposures and possible health effects. Three important but frequently overlooked sources of significant errors are: LOSS OF PARTICLES during collection and storage, LOSS OF PARTICLES during digestion and storage, CHANGES IN ANALYSIS of refractory matrices.

In the case of metal inert gas (MIG) and electrode (MMA) welding of stainless steel (SS), it has been shown that over 90% of the Cr content of MMA/SS fume of 5-8% is in the form of stable water soluble Cr(VI). MIG/SS fume may contain 11-13% Cr, of which only 50-75% is detected by standard aqueous digestion procedures. Complete digestion with perchloric acid can lead to significant loss due to formation of volatile CrO₂Cl₂ (1). The water soluble Cr(VI) content, thought to be 0.1-0.5% decays towards zero in the solid MIG/SS fume after collection on membrane filters independent of filter type (2). When collected in an impinger filled with water short arc MIG/SS fume appears to contain of the order of 3% stable water soluble Cr(VI) (3). This ample evidence that monitoring and analysis dependent effects can lead to severe underreporting of exposures to toxic species such as Cr(VI) suggest the need for establishing standardized and appropriate protocols for use with welding fumes, as reported below.

MATERIALS AND METHODS.

MIG/SS Welding fumes are produced in downhand welding on stainless plate with the aid of a robot (ESAB 3RS17 1.2mm wire, 20 l/min Ar or Ar.250, 30 cm bead, 10 cm/min). The fumes are collected via a 20 cm diameter 1.5 m column on Whatman 41 paper filters, and/or in an impinger (0.2-0.5 mm orifices, 1-1.2 l/min, 50 ml liquid volume (deionized water) having parallel filter cassette for absolute determination of fume densities: fume concentrations are typical 200 mg/m³ with filter placed in top of column. Aliquots are removed convenient at intervals for analysis.

Chemical Analysis is performed either on total fume scraped from the membrane filters or collected in the impinger, or on water soluble species (30 min. at 20°C under agitation) and precipitate separately, using atomic absorption (AAS). In some cases the filter is carried along with the sample to determine filter-matrix effects if any. Cr(VI) is determined using the standard diphenylcarbazide technique (DPC). Fume digestion is performed using a series of methods to enable a determination of procedures dependence if any as

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