

THE GENERATION AND CHARACTERIZATION OF WELDING FUMES FOR TOXICOLOGICAL INVESTIGATIONS

P. J. HEWITT, R. HICKS and H. F. LAM

University of Bradford

Abstract—Methods for the controlled generation and characterization of fumes from flux coated rod and metal inert gas welding processes are given. The design of equipment for the exposure of experimental animals to atmospheres containing known uniform concentrations of fume materials for more than 5 h is described. Physical characteristics of particulates in the fume which are related to inhalation toxicology, such as surface topography, solubility, and particle size have been established.

INTRODUCTION

TOXICOLOGICAL studies, particularly involving inhalation, form a necessary part of investigations of the possible hazard to the health of workers occupationally exposed to welding fume. Preliminary studies of the inhalation and fate of welding fume particulate materials in experimental animals have been described previously (HEWITT and HICKS, 1973). These are related to short term intermittent exposure of rats, and no significant toxic effects were detected. In order to perform more extensive investigations, modifications to the fume generation and animal exposure equipment were necessary.

The first requirement was to produce, for periods of several hours, uniform fume concentrations that had known chemical and physical characteristics, using two different types of welding process—manual metal arc with flux coated electrodes, and semi-automatic metal inert gas (MIG). The fume could then be used to expose laboratory animals in a specially designed chamber.

EQUIPMENT AND METHODS

Welding fume generation

Manual metal arc welding using flux coated electrodes. Electrodes with a rutile based flux coating (Mirrospeed 4mm*) were arced on to a mild steel workpiece using normal manual techniques to produce a good weld. The fumes generated by the welding arc were drawn off at a fixed distance from the arc by means of an exhaust pump. The average time to complete a weld run was 3 min and an interval of $\frac{1}{2}$ min between each weld run was necessary to replace the electrode. Using a team of welders it was possible to generate fume for several hours.

Automatic metal inert gas welding. An MRCS 200B* welding power source and a Lynx 11 E* wire feed unit were used (Fig. 1). The arc was struck by feeding stainless

* BOC Ltd., England.

steel wire through a welding torch Type LT4* on to a circular mild steel workpiece, mounted and revolving on a Berco multispeed turntable*. Welding was performed using Bostrand 61* (Type AISI 316) stainless steel wire, 0.6 or 0.8 mm diameter under Argoshield 5 gas* (approximate composition: 5% CO₂, 1% O₂, 94% Ar). The operational conditions were established experimentally with voltage range, inductance conditions and speed of the wire feed as the main variables. The precise arc voltage was automatically controlled according to the chosen wire feed rate.

The welding head was fitted with a cowl linked to an exhaust pump so that fumes could be drawn off continuously for use in experiments.

Exposure chamber

The design factors considered to be important in animal exposure chambers have been discussed by HINNERS *et al.*, 1966. These include provision of adequate oxygen for respiration, tolerable temperature for the animals and facilities for exposure of large numbers of animals at the same time to a uniform and monitored test atmosphere. Provision for urine and faecal collection should also be provided. The chamber was built with these criteria in mind and on information made available by D. G. Clark, I.C.I. Central Toxicology Laboratories (Personal communication, 1975).

The exposure chamber (Fig. 2) consisted of a rectangular perspex box with attachments for ten animal holders on each side. Animals were held individually in cylindrical containers fitted at one end with a stainless steel nose cone. A sliding barrier restrained each animal in the container in a position with its nose protruding from the cone through a hole in the exposure chamber. The body of the animal was thus shielded from contact with the exposure atmosphere to prevent contamination

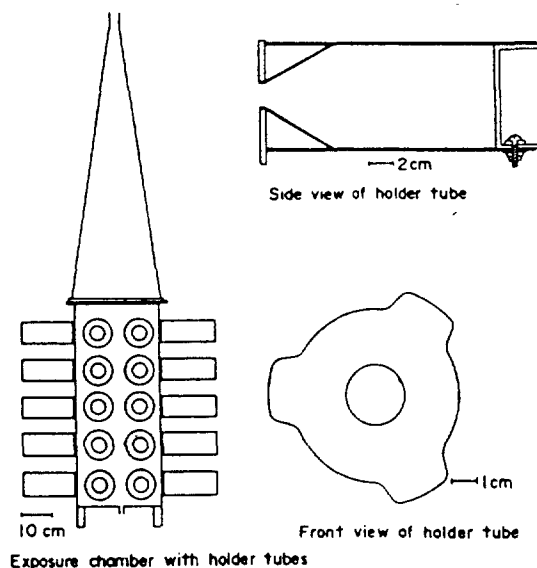


FIG. 2. Animal exposure chamber.

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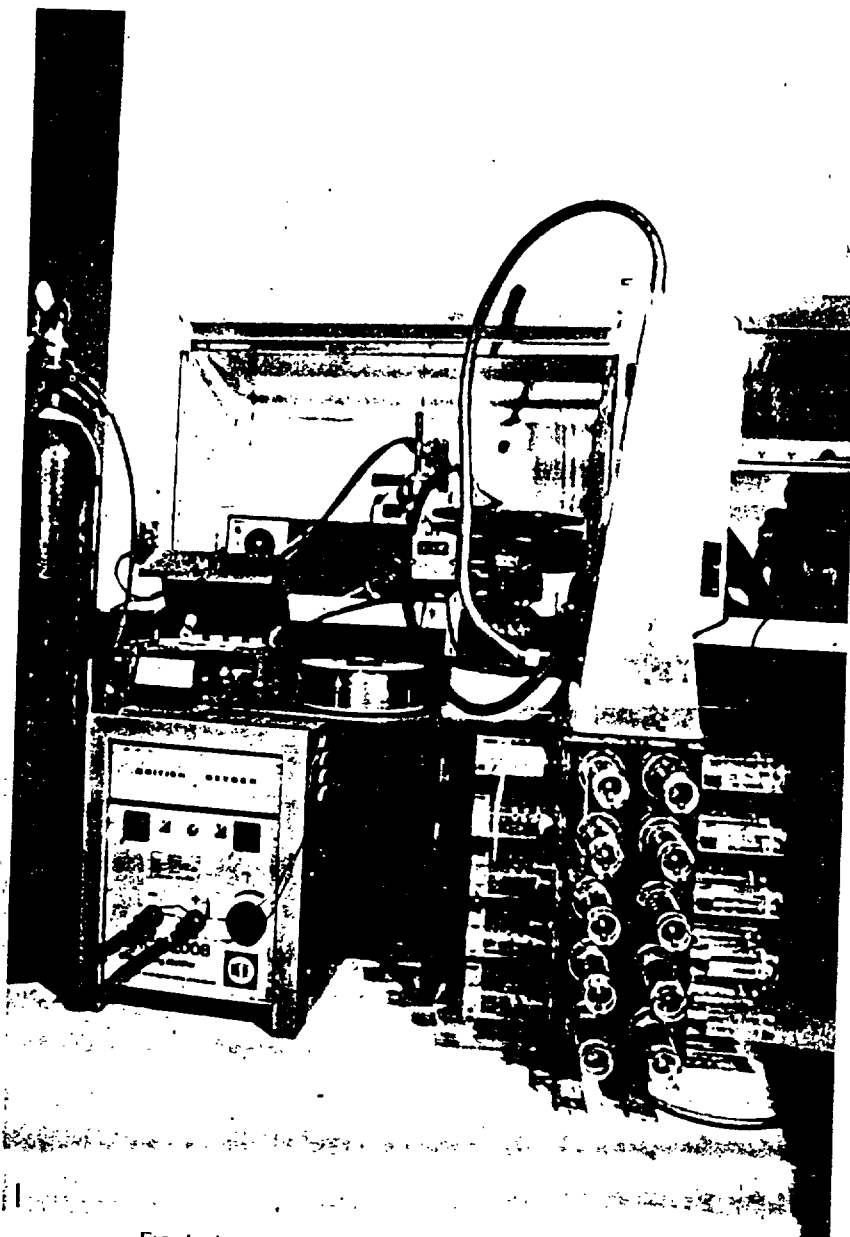


FIG. 1. Automatic metal inert gas welding fume generation.

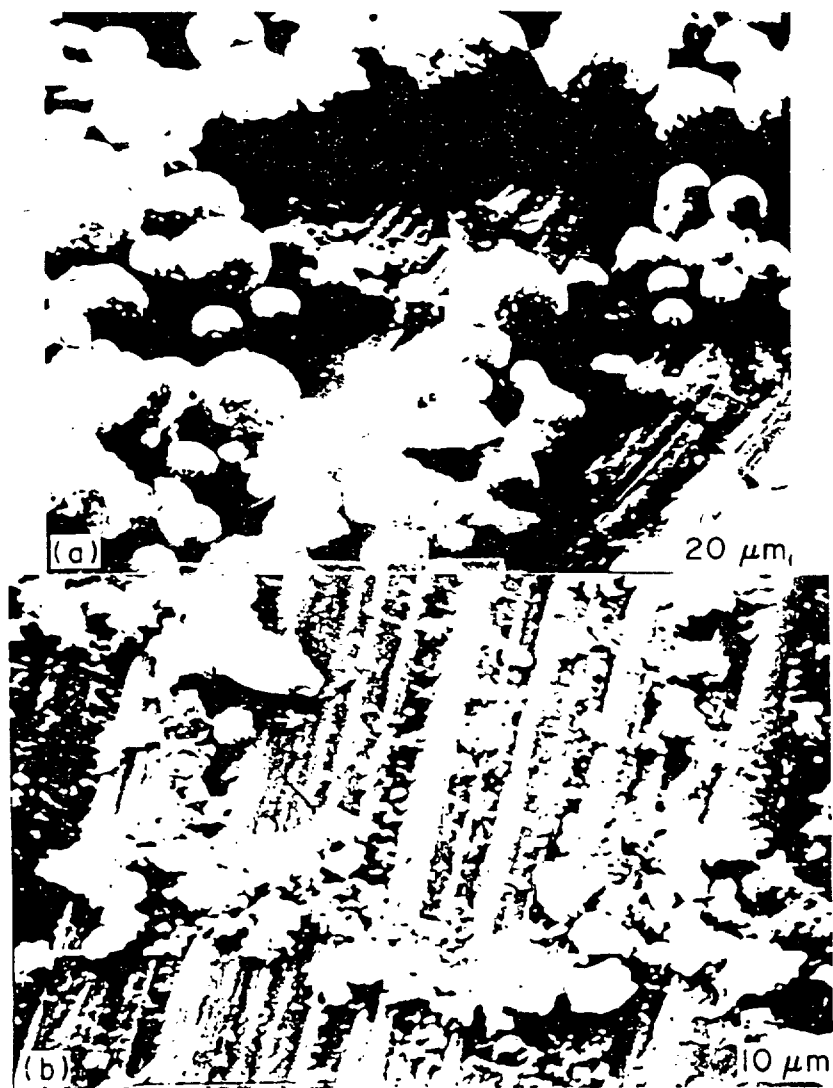


FIG. 3. Stereoscan of fume particles. (a) Flux coated; (b) MIG.

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of its coat. Fume flows down into the chamber via an aluminium diffuser in the shape of a tall pyramid, the walls of which are at 7° to the vertical (Fig. 1). This provides good dispersal of fume into the inhalation space and facilitates uniform flow of fume into the chamber as recommended by D. G. Clark (personal communication, 1975). The aluminium diffuser also allows substantial cooling of the hot gases extracted from the welding apparatus so that in the chamber the animals are not exposed to an unacceptably high temperature.

The atmosphere in the chamber during the passage of material from the arc was periodically sampled to determine its particulate composition and monitored for humidity and temperature. Particulate samples were obtained using Casella* personal air samplers fitted with membrane filters and operating at 2 l./min; the samplers were introduced into the chamber through a side entry in positions corresponding to the breathing zone of the animals under exposure.

Particle size analysis

Particulate material was collected on filters for examination by optical microscopy, by deposition on aluminium stubs for scanning electron microscopy and on formvar coated copper grids for transmission electron microscopy. For optical microscopy samples were mounted dispersed in Canada balsam and xylol. Particles were classified and counted according to the method given in BS 3406: Part 4 (1963) using a graticule of the type specified in BS 3625 (1973). Of the methods used, only transmission electron microscopy was found to have sufficient resolution to count the submicron range of particle sizes encountered. Optical and scanning electron microscopy were useful to examine the surface structures of the particles and their aggregates. Specific surface area measurements were made using a method based on the BET technique (ALLEN, 1968).

Solubility of fume particulate in cell culture medium

Thirty milligram portions of the particulate samples were shaken in 20 ml diluted cell culture medium† at 37°C continuously for 40 days. Periodically, samples of supernatant fluid were centrifuged and analysed to determine the concentration of elements leached from the particles.

EXPERIMENTAL RESULTS

The efficiency of generation and the uniformity of fume in the exposure chamber under different operating conditions were measured by weighing samples of particulate material collected using the personal sampler at selected positions within the chamber. For fume generated by the MIG welding process, different torch-workpiece approach angles and distances were used and the distance of the torch from the workpiece centre in relation to the speed of rotation of the workpiece was varied to find the optimum conditions (Table 1). On the basis of these results the configuration chosen was a torch approach angle of 75–85°, at a height of 1–2 cm and at a position 11–16 cm from the centre of the turntable rotating at 1 rev/min. This gave good fume

* C. F. Casella and Co. Ltd, Britannia Walk, London N1 7ND.

† Wellcome TC medium 199 10 × concentrate (TC 22) 100 ml, sterile 4.4% sodium bicarbonate solution 50 ml, water 850 ml.

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TABLE 1. OPERATING PARAMETERS FOR PRODUCTION OF MIG FUMES

Variable	Range tested*	Optimum fumes produced at
Torch workpiece approach angle, °	62-85	75-85
Torch distance, cm	6-19	13
Torch height, cm	1-3	1-1.5
Turntable speed, rev/min	0.5-1.3	1

* Except where a parameter was changed for test purposes, conditions used were: wire type, usually Bostrand 61, 0.6 mm diameter; wire speed, 15.5 m/min; distance of torch position from centre of workpiece, 12 cm; height of torch above workpiece, 1.5 cm; turntable speed, 0.75 rev/min.

production, a quiet arc with smooth transfer of metal into the weld and a minimum of spatter. Fume particulate concentrations and temperatures were recorded during a period of continuous operation at the upper and lower ports of the chamber; these two positions were selected so that fume entering the chamber and fume near the exhaust could be simultaneously sampled in order to check the uniformity. The relative humidity in the chamber was also recorded. Results are shown in Table 2.

The system for exposure to fume from manual arc flux coated electrode fume was tested by successive arcing of eight welding rods over a period of 24 min. Fume particulate concentrations in relation to temperature and humidity were as shown in Table 3. For both MIG and rod processes, fume generation was variable during the first 10 min exposure, but it became more uniform with continued operation. The maximum temperature did not exceed 25°C, while relative humidity did not fall below 50% in either mode of welding.

Examination of the physical characteristics of collected particles revealed marked differences between those generated by MIG and manual arc welding. Differences in surface characteristics are illustrated in Fig. 3. Flux coated electrode particles presented a smooth glassy and regular appearance in marked contrast to the irregular shape and porous surface of MIG particles. Examination by transmission electron microscopy confirmed the generally spherical nature of both types of particles, especially in the smaller size range. It was also observed that the very small MIG welding particles

TABLE 2. EXPOSURE CHAMBER CONDITIONS DURING MIG FUME GENERATION

Time (min)	Fume conc. (mg/litre)		Temperature (°C)		Relative humidity
	Upper	Lower	Upper	Lower	
	port	port	port	port	(%)
0	—	—	21.0	21.0	57
2	1.5	1.4	22.0	21.5	55
5	1.9	1.8	23.0	22.0	54
10	2.2	2.4	23.5	22.5	53
15	2.3	2.5	24.0	23.0	52
20	2.5	2.6	24.5	23.5	52
25	2.5	2.5	25.0	24.0	50
30	2.4	2.5	25.0	24.0	50

TABLE 3. EXPOSURE CHAMBER CONDITIONS DURING CONSECUTIVE ARCING OF FLUX COATED ELECTRODES

Rod no.	Fume conc. (mg/litre)		Temperature (°C)		Relative humidity (%)
	Upper port	Lower port	Upper port	Lower port	
0	—	—	21.0	21.0	55.0
1	2.3	1.9	22.0	22.0	54.0
2	2.4	2.2	22.5	22.0	54.0
3	2.4	2.5	23.0	22.5	53.5
4	2.4	2.7	24.0	23.0	53.5
5	2.5	2.6	24.0	23.0	53.0
6	2.6	2.7	24.0	23.5	52.0
7	2.7	2.8	24.5	24.0	51.0
8	2.6	2.8	25.0	24.5	51.0

tended to aggregate into larger, apparently quite coherent masses. These features were consistent with the specific surface area of MIG particulates which was much larger ($30 \text{ m}^2/\text{g}$) than that of flux coated electrode particles ($13 \text{ m}^2/\text{g}$). Substantial differences between the two forms were also obvious when examined by optical microscopy. However, neither the optical microscope nor the scanning electron microscope available could resolve the smaller particles and it was necessary to use transmission electron microscopy. Flux coated electrode fume had a count median diameter determined by transmission electron microscopy of $0.125 \mu\text{m}$ ($\sigma_g = 1.84$) and the MIG particulate count median diameter was $0.064 \mu\text{m}$ ($\sigma_g = 2.34$) (Fig. 4).

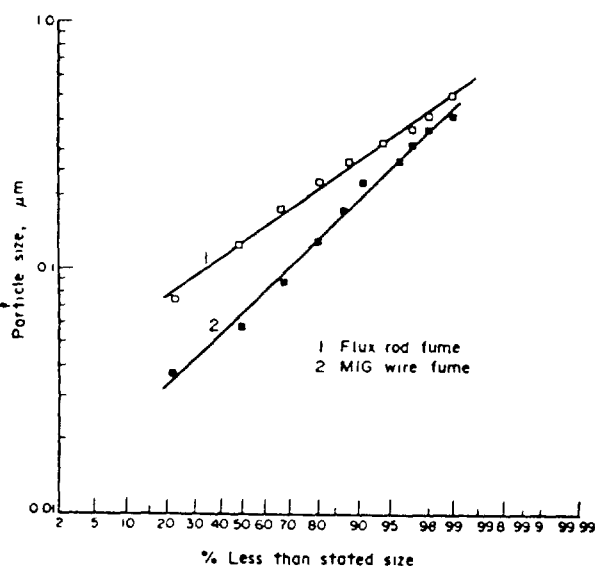


FIG. 4. Particle size distribution by transmission electron microscan for particulate from flux coated and MIG particulate.

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Curves showing the progressive dissolution of some elements from welding fume particles are shown in Fig. 5. Again, marked differences between the characteristics of the two types of fume were seen. In flux coated electrode particles the loss of iron was highest (7%) over 40 days with less dissolution of chromium and cobalt. From MIG fume particles, the loss of chromium and cobalt was higher and the loss of iron was low. There was no overall significant difference in total loss.

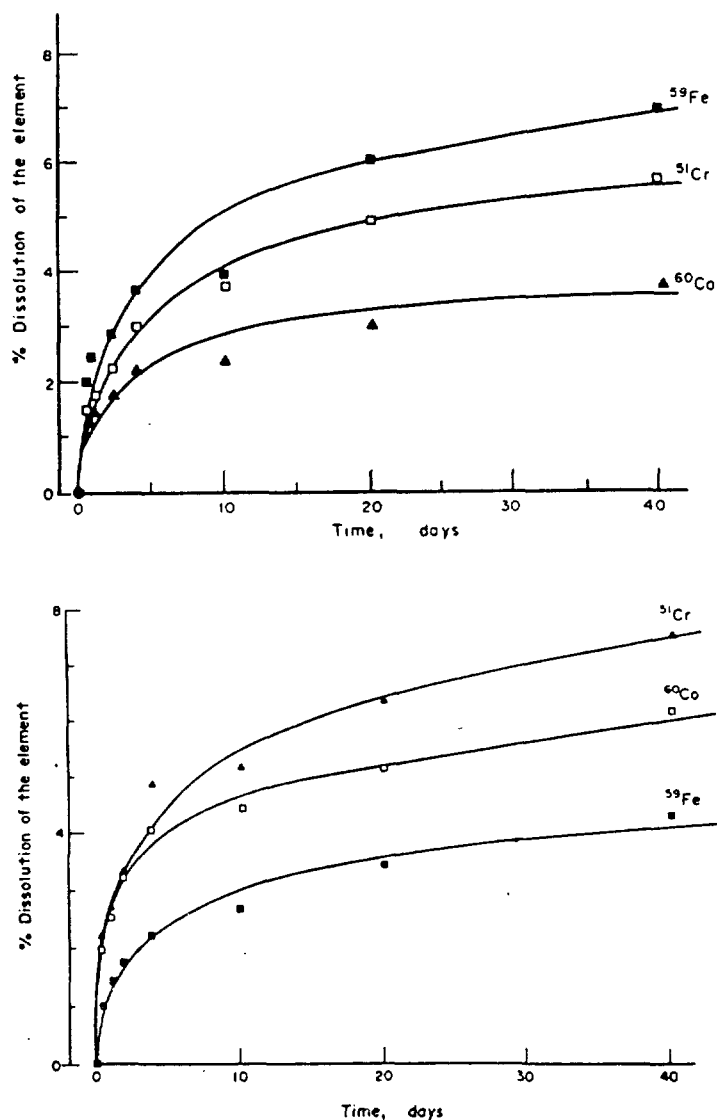


FIG. 5. Dissolution of weld fume particulates in cell culture medium (Wellcome TC medium 199 single strength). a. Flux coated; b. MIG.

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CONCLUSION

The methods described allow continuous exposure of laboratory animals to a reasonably uniform fume concentration from either manual flux coated or automatic metal inert gas welding. It is clearly technically easier to provide uniformity of concentration from an automatic process but even with the manual process the results are satisfactory, bearing in mind that the techniques used for generation must be compatible with normal workshop welding practice. Only in this way can the results obtained in laboratory experiments be related to the occupational exposure conditions of welders. It is relevant to note that the best mechanical welds were in fact associated with maximum fume generation. The chemical and physical characteristics of welding fumes are extremely complex, and are sensitive to changes in their method of generation. This highlights the necessity for careful investigation of parameters and the precise definition of those chosen for experimental exposure of animals. Where practicable both chemical constitution and physical characteristics of the fume during the exposures should be monitored. Methods of multi-element analysis of welding fume have been reported previously (HEWITT, 1972) and the methods of particle size analysis and surface characterization by electron microscopy described in this paper have been satisfactorily used by the authors in a variety of welding fume environments.

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