

Survey of air contaminants from welding

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Introduction

In 1973 the Swedish National Board of Occupational Safety and Health resolved to launch an investigation into the problems associated with welding and related operations in the work environment. Work on the project began with a survey designed to chart the extent and scale of welding operations in the work life of Sweden. A

number of partial reports have been published concerning the occurrence and effects of air contaminants in various operations. The present report is a collation of the technical findings related to hygiene and a brief summary of the medical results that have been processed to date.

Scope of welding in Sweden

A survey carried out in 1974 among all Swedish firms which, according to data centrally collected at the Swedish Central Bureau of Statistics, were consumers of welding materials (5) revealed (according to a previously unpublished collation) that the breakdown of welding methods and materials in relation to numbers of welders was as shown in fig 1. The total number of persons engaged in fusion welding was just under 32,000.

If the proportion of work time involved in welding operations is included, a more accurate picture of the exposure situation is possible. In all, 3,550 welders were occupied in the manual metal-arc welding of stainless steel, 2,000 of whom spent at the most 10 % of their time on such work. Only 198 were occupied in it full-time. Another 1,261 welders were engaged in the tungsten inert-gas (TIG) welding of stainless steel, and 298 of these workers spent the whole of their worktime on such work. Altogether 923 welders were engaged in the metal inert-gas (MIG) welding of stainless steel, but only 64 in all of Sweden were engaged full-time in such work. Of 643 welders engaged in the TIG

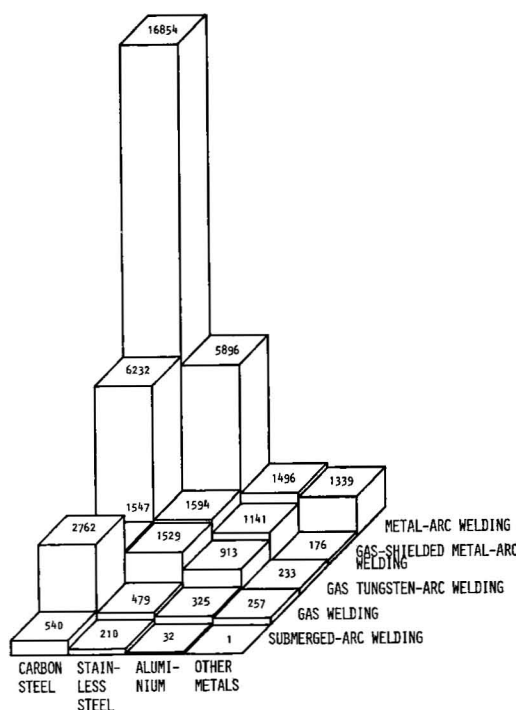


Fig 1. Number of welders in Sweden in 1974 broken down by type of material and method. The same welder may be included under several different methods and materials. The total number of persons engaged in fusion welding was just under 32,000. [Collation of data according to Hallne & Erlandsson (5)]

welding of aluminum, 79 worked at it full-time, while only 47 of the 593 welders

engaged in the MIG welding of aluminum worked at it full-time (6).

Purpose of exposure studies

Studies of welding air contaminants have been carried out in many contexts over a long period of years. Investigations of this kind were performed with a number of coated electrodes as far back as the early 1940s (17). At that time the composition of the dust associated with the welding of galvanized steel was also studied (17). Reviews of older inquiries were compiled by Lindström (11) in 1972, Bland (3) in 1973, and Ulfvarson (18) in 1974. Studies bearing upon the welding of aluminum and stainless steel have been reviewed by Ulfvarson et al (19, 20).

There are several reasons for considering exposure studies afresh. Welding methods and the materials involved are changing, the methods are being applied differently in different countries, the technique of eliminating hazards is being improved, and the methods of analysis have been greatly improved since the first studies were carried out.

In the course of the present project exposure studies have been carried out since 1974 for a number of firms and welders (table 1). The purpose of the studies was to measure the concentrations of the most important gaseous and particulate contaminants at representative workplaces, mainly in the manufacturing industry. It was also the intention to study the concentration observations, as far as possible, in relation to welding parameters such as base metal, welding method, welding current, welding electrode, arc-time factor, and the use of local exhaust ventilation and to ascertain the degree to which some easily monitored conditions find expression in the exposure circumstances. Any relationships that might be revealed between the operating conditions and exposure may prove valuable with respect to elimination measures.

In the course of the project a relatively large number of test sites where the same

Table 1. Investigation of welding air contaminants. Number of firms and employees studied and the dates of the visits.

Type of welding	Number of firms studied	Number of test sites/welders studied	Dates of study	Literature reference
Gas-shielded arc welding of aluminum	29	102	Dec 1974 — Oct 1975	Ulfvarson et al (20)
Metal-arc welding of stainless steel	18	86	Nov 1974 — July 1975	Ulfvarson et al (19)
Gas-shielded arc welding of stainless steel	14	41		
Rail welding	21	153		
	(permanent-way departments of the Swedish State Railways)		Aug 1975 — Dec 1975	Ulfvarson et al (22)
Welding of nonalloy and low-alloy steel	15	90	Jan 1976 — June 1976	Ulfvarson et al (21)
		Total 472		

welding method and materials were used were studied. Collating these studies should therefore give a correct idea as to what concentrations can be expected as a general rule in corresponding welding operations. Since the studies were carried out, the welding firms have adopted elimination measures, mainly local exhaust ventilation and ozone-reducing protective gases. Otherwise welding is carried on in

the same way as it was at the time the studies were performed. Since local exhaust ventilation was only occasionally used at the time of the studies, the result is a large body of material providing a point of departure for elimination measures. The same applies to the use of special protective gases for the removal of ozone in gas-shielded arc welding.

Selection of workplaces and procedure for workplace visits

The workplaces visited during the study were selected on the premise that the welder in question was to spend the bulk of his worktime performing a given operation on specific material. Otherwise the selection can be regarded as having been made virtually at random. Insofar the gas-shielded arc welding of aluminum and the metal-arc welding of stainless steel are concerned, the majority of the welders engaged in these operations full-time were studied.

The ground was prepared for the workplace visits by informing all the affected

persons at the firms in question. The visits were timed so as to coincide with the performance of the operations. As far as could be judged, the operations were performed in the normal manner on the measurement occasions. The measurements at any one test site were taken during one workday. On occasion, measurements at one and the same workplace were spread over several workdays, but they were concerned with different test sites. At many workplaces other welding or soldering operations were being carried out at the same time.

Materials, methods and production parameters subject to study

In the gas-shielded arc welding of aluminum the protective gas was 99.9 % argon. The base metal varied. Sometimes it was pure aluminum (99—99.5 %), and sometimes aluminum alloys with magnesium, silicon, iron, chromium, manganese, copper, and zinc in stated contents varying from a few tenths of 1 % up to 10 %. The composition of the electrodes used in the MIG welding and the fillers used in the TIG welding corresponded to that of the metals being welded.

In the present communication the term

“stainless steel” is considered to cover a group of steels with a higher resistance to chemical surface attack than ordinary carbon steels, low-alloy structural steels, and tool steels. A point which stainless steels have in common is their high chromium content. Their chromium contents have been specified to be between 12 and at least 22 %, and nickel contents between a few tenths of 1 % and at least 19 %. In addition to these elements there can be up to 2 % manganese, up to 2.7 % molybdenum, and, in some cases, around 1 %

silicon, as well as, eg, niobium and titanium. Nickel and titanium alloys were being used in a few of the cases studied.

The steels were welded with coated electrodes or, in the case of gas-shielded arc welding, electrodes and fillers with weld-metal analyses that were close to those of the respective base metals. For TIG welding the protective gas was 99.9 % argon, while for MIG welding it was usually argon containing 2 % carbon dioxide, in a few cases argon containing 5 % oxygen.

The low-alloy and nonalloy steels studied contained up to a few percent manganese, in some cases a few tenths of 1 % chromium, up to 0.6 % silicon, and in a few cases up to 0.4 % copper and up to perhaps a tenth of 1 % niobium. These materials were welded with coated electrodes or, in the cases of gas-shielded arc welding, electrodes with up to 1.5 % manganese and up to 0.8 % silicon. In gas-shielded metal-arc (MAG) welding the protective gas was carbon dioxide or a mixture of 20 % carbon dioxide and 80 % argon, in MIG welding it was argon and 2 % carbon dioxide, and in TIG welding it was 99.9 % argon.

In a few cases the steel stock was shop-primed with paints containing iron oxide and zinc tetraoxochromate as pigments, together with polyvinyl butyral and phenol

resin as binders in film thicknesses stated to be a few hundredths of a millimeter (20–30 μm) in the manufacturers' instructions for use.

A special application of metal-arc welding is the welding of rails to form railroad track. The most common methods are mold welding and overlay welding. For the past 20 a welding has been used on a large scale for joining rails. The joining method that was studied was mold welding. The web and head of the rail are joined with copper formers which make up a welding mold. The gap is filled by depositing about 18 electrodes in rapid succession. A mold-welding electrode is used, except for the finishing of the top surface of the rail head, which is done with an overlaying electrode.

Worn or damaged rails are repaired by overlay welding. After being ground off clean, the rail is heated in a gas flame, and beads about 30-mm wide are then applied side by side on the rail head in the lengthwise direction of the rail. The welding is followed by rough and fine grinding.

The rails rest on ties, also called sleepers, which are usually made of creosote-impregnated wood. The wood often catches fire during the welding operation, and combustion products are formed.

Measurement methods and principles for reporting the results

In all the studies, notes were made as to the base metal, electrode or filler material, welding current, type of current, and presence of spot suction. In some cases the work position was noted. In the later studies the arc-time factor was measured, or the number of electrodes consumed during the study period was recorded. Dust samples, and in some cases benz(a)pyrene samples as well, were collected inside the face guard (exposure measurement) and also at stationary test sites in the workroom in order to determine background concentrations.

There are two types of face guard, the welding screen or shield and the welding helmet, both of which come in a wide range of brands and patterns. It was the aim of the present investigation to see that the exposure conditions were as normal as possible at the time of measurement. Accordingly, a selection of shields and helmets was prepared that corresponded to most of the types met with in practice. These shields and helmets were fitted with two metal hoods made to suit the dimensions of filter holders for filters with a diameter of 37 mm. The metal hoods were po-

sitioned at mouth height next to the right and left cheeks and angled so that expired air would not impinge directly upon them. The sampling hoses were connected through a hole in the metal hood. A minor sampling error arose from the fact that a welder who wears a helmet raises the visor when he is not welding, and a welder who uses a welding shield lays it aside when he is not welding. The dust that is trapped in the filter when no welding is going on corresponds to the background concentrations of the work premises, to which the welder is exposed as long as he is in the room.

The samples were collected on a filter according to a standard procedure (25). The usual practice was to take two filters per test site and calculate the time-weighted average. In the exposure measurements the total sampling time for the filter samples taken at a test site varied from 1 h up to 8 h. The samples were taken under normal work conditions throughout a workday. The sampling at stationary sites, of which there were from one to four per workplace, went on all day and usually employed four filters per test site. After the sampling the filters were weighed, and from the total content of dust per filter the concentration in air, expressed in milligrams per cubic meter, was calculated. The filters were analyzed by the X-ray fluorescence method (PIXE) at the Department of Nuclear Physics of the Lund Institute of Technology with respect to elements beginning with ^{19}K (9). The detectability was 0.0001 mg/m^3 , and the margin of analytic inaccuracy $\pm 10\%$.

In the analysis for benz(a)pyrene the samples were treated and separated by vacuum sublimation and thin-layer chromatography, after which the quantitative determination of benz(a)pyrene was carried out by fluorescence (15).

In relevant cases, hexavalent chromium was determined on the filters by leaching with a sodium-acetate buffer, rinsing and leaching again to ensure that all soluble chromium had passed into the eluate, and analyzing the buffer solution together with the rinsing water with the diphenyl-carbazide method (4). The total chromium on these filters was determined by dissolving the residue on the filter in aqua regis

(nitric acid and hydrochloric acid) at 70°C , adding this solution to the eluate as has already been mentioned, then analyzing it for chromium by atomic absorption.

Where relevant, the fluorine content on the filters was determined by digesting the filters in sulfuric acid, driving the fluorine off as hydrogen fluoride, and collecting it in sodium hydroxide. The fluorine concentration was measured after buffering with an ionselective electrode.

For the samples for analysis with respect to oxides of nitrogen, nitrogen dioxide and carbon monoxide, air was collected for about 15 min in sacks. About 30 l of air was pumped during 15 min by an accumulator-powered man-carried pump through latex hoses into a sack $60 \times 60 \text{ cm}$ in size with laminated walls consisting, from the inside outwards, of $12 \mu\text{m}$ of polyester, $12 \mu\text{m}$ of aluminium foil and $70 \mu\text{m}$ of polythene. The gases were determined with detector tubes of the Dräger type from samples taken straight from the sack. In trials with this equipment, the concentrations of the gases mentioned did not change over a 40-min period.

Determinations carried out on calibrating gas mixtures showed that the imprecision of detector tubes for oxides of nitrogen (total oxides of nitrogen, no CH294, and nitrogen dioxide, no CH300) was about $\pm 15\%$ and that the inaccuracy (the systematic error) was $\leq 10\%$ (14). The sensitivity was 0.5 ppm over five strokes of the pump. With the same method as for oxides of nitrogen, the imprecision of the detector tubes for carbon monoxide (no CH256) was found to be about $\pm 15\%$. There was a tendency to overestimate the concentration by 10–20% (13). The sensitivity was 5 ppm over ten strokes of the pump.

Samples for ozone testing were taken over 15-min periods inside the face guard at mouth level. The concentration was determined with two brands of direct-reading ozone analyzers, based on the principle of chemiluminescence upon the reaction of ozone with ethylene. The instruments are practically specific for ozone (12): sensitivity at least 0.001 ppm, accuracy (depending on how well calibration has been carried out) within plus or minus 20%. Most of the readings were taken with an instrument of the Analytical In-

strument Development brand, a Portable Ozone Analyser model 560. The instrument was calibrated with an ozone calibrator of the same brand, model 565. Readings were also taken with the Bendix Ozone Analyser model 8002, with calibrator. The sampled air was filtered through a Teflon filter located at the far end of the sampling hose. A wet-chemical potassium-iodide method (24) was used as a reference method for the calibrators.

The sampling for oxides of nitrogen, ozone and carbon monoxide was not representative for the whole workday in that it was confined to periods in which welding was going on.

In connection with the welding of painted steel, organic substances were collected in carbon tubes carried on the welder's shoulder, with a sampling time of between 15 min and 2.5 h. The carbon tubes consisted of a glass ampul with two carbon beds, a front test section of 100 mg of carbon and a following check-up section of 50 mg. The sampling volume was below 5 l. In a few cases, too, air was collected directly by means of a motor-powered gastight glass syringe, a "Lundiaspruta." The sampling volume was 30 ml. In the analysis, which was carried out by the Swedish Institute for Water and Air Pollution Research, the sampling and check-up sections of the carbon tubes were dissolved one after the other in 3 ml of carbon disulfide and shaken for 30 min. One microliter of the solution was injected into a

gas-chromatographic unit with a flame-ionization detector. The test chromatograms were compared with chromatograms obtained from reference solutions. The desorption efficiency was taken overall to be 75 %. In direct sampling the yield was assumed to be 100 %. The detection limit was considered to be about 0.03 mg per cubic meter of air with carbon-tube sampling and 0.1 mg/m³ with direct sampling. It is suspected that aldehydes break down when collected on carbon tubes, but it is assumed that they can be detected by direct sampling (10).

The arc time, the time during which the arc is passing, was measured with a stopwatch or, as a general rule, with a specially developed electronic arc-time gauge. The arc-time gauge is a no-contact time gauge with a transducer activated by the magnetic field of the welding current, which is detected by a pick-up clip applied around the cable leading to the welding gun. The time gauge has three counters, each with its own digital display unit. Counter 1 registers total time, ie, the time during which the time gauge has been switched on. Counter 2 accumulates time during which current is flowing through the welding cable, ie, arc time. Counter 3 also accumulates arc time, but during a preselected and set period, eg, a 15-min period during which gas measurements are carried out. The arc-time factor is calculated as the quotient of arc time divided by total time. In the following presentation it is also stated as percentage.

Principles of result reporting

The concentrations that were found have been grouped in various ways so as to shed light on the exposure associated with different welding situations and on the influences exerted by the production parameters on this exposure.

There has been some deletion of test sites in relation to the total number of measurements carried out. This deletion is due to deficiencies in the characteriza-

tion of situations at test sites, eg, that several types of welding were going on at the same time or that the arc-time factor was not recorded. When the recorded quantities of a substance were below the detection limit, a concentration corresponding to the detection limit was assumed to apply to the test site in question.

The air-contaminant concentrations measured in connection with the welding

operations showed a well-nigh logarithmic normal distribution (19, 20, 21, 22). It has also emerged that the arc-time factors had a logarithmic normal distribution if their average was not too close to 0 or 1 (22). The readings can therefore be processed and presented on this assumption. The parameters are the geometric mean (the antilogarithm of the mean of the logarithms of the concentration) and the geometric standard deviation (the antilogarithm of the standard deviation in the logarithms of the concentrations). The geometric standard deviation functions analogously with the standard deviation, with the difference that it is used multiplicatively instead of additively. In most distributions of air-contaminant concentrations found in welding, the geometric standard deviation varies between 2 and 3. The results are graphically presented as histograms or as cumulative frequency polygons on normal distribution paper with a logarithmic concentration axis. In the latter case the highest value cannot be represented, since it corresponds to 100 %, which on normal distribution paper is a point at infinity. Another method of presentation, especially advantageous for comparisons among different welding processes and materials, is the bar diagram with a linear concentration axis, on which the geometric mean and the 75 and 90 percentiles are indicated.

It was noted earlier that arc-time factors have a powerful bearing on exposure (21, 22). It is also important to take account of the arc-time factors in comparisons between various types of welding when the arc-time factors diverge significantly. The concentrations of air contaminants during the time the arc is alight cannot be measured directly. As already noted, sampling for particles went on throughout most of the workday or shift, while sampling for gases lasted about 15 min.

A measure of the exposure from welding when the arc is alight is obtained if the measured concentrations of the air contaminants in the breathing zone, C_{az} , after the deduction of the room concentration, C_f , is divided by the arc-time factor, f_b (a number between 0 and 1), at the test site in question. To avoid confusion with the

directly measured concentrations, the corrected concentration will be referred to from now on as the immission index (ie, an index of the immission of the air contaminants due to the welding operation, which is not to be confused with emission factors defined in various ways):

$$I = (C_{az} - C_f)/f_b.$$

When the arc is alight, the welder is exposed to approximately $I + C_f$ mg/m³. When the arc is out, he is exposed to only C_f mg/m³. In welding out of doors it is assumed that $C_f = 0$.

Probably the foremost source of error in I was that it was not possible to measure the background concentrations with full dependability. For obvious reasons such concentrations must be measured some distance from the welder, and they vary from point to point in the room. According to the rules for calculating occasional errors in taking indirect readings (Swedish Draft Standard SS 014150), the relative standard error in the immission index is:

$$s_I/I = [(s_{C_{az}}^2 + s_{C_f}^2)/(C_{az} - C_f)^2 + (s_{f_b}/f_b)^2]^{1/2}$$

The standard error in C_{az} , $s_{C_{az}}$, was estimated at 5 % of C_{az} , that in C_f at 0.05 mg/m³ (from the variations between two determinations at different times at the same stationary test sites at ten workplaces) and that in f_b at 0.005. If it is assumed that C_f is 2 mg/m³, that C_{az} is 5 mg/m³, and that f_b is 0.05, the relative standard error in the immission index becomes 21 %. If f_b is instead put at 0.2, the relative standard error in the immission index becomes 20 %. For $C_f = 2$ mg/m³ and $C_{az} = 10$ mg/m³, the corresponding values work out to 13 and 9 %, respectively. The difference between the concentration in the breathing zone and the background concentration is the most important in regard to the relative standard error in the immission index — the greater the difference, the more accurate the calculated immission index.

The main reasons for using immission indices is that they give a better idea of the exposure than can be obtained merely by studying direct readings and that they make for better comparability between different welding processes and production parameters. The presumption that one and

the same arc-time factor, other conditions being unchanged, will always give the same exposure does not always hold true. In a spell of arc welding with the same arc-time factor, to take two extreme cases, the welder may allow the arc to go on passing until one electrode has been consumed and then pause in his work or he may repeatedly strike and extinguish the arc at frequent intervals. These two modes of working will show differences in the evolution of air contaminants, owing, among other things, to the emission from hot surfaces. Exposure may also differ in the two cases because of different ways of using the face guard.

It has been found that a collection of immission indices, despite the sources of

error, generally gives a lower standard deviation than a corresponding set of primary concentration readings. If the immission indices for different situations are compared, it is possible to draw conclusions that would not otherwise be accessible. However, the directly measured concentrations are always made the primary item in reporting. Only in the refined analysis of the data is the immission index calculated. In principle, immission indices can be used for all air contaminants, but they have only been worked out for dusts and dust components. In these cases, given the way in which the measurements are carried out, the greatest differences are obtained between the directly measured concentrations and the immission indices.

Collation and discussion of the results

In the following account, only a general reference is made to the diagrams and figures, which are discussed in more detail in the literature references.

When welding is carried out indoors without spot suction or other elimination measures, the air contaminants that are formed spread freely through the premises. The general level in the work site varies with roughly the same geometric standard deviation as the breathing-zone concentrations applying to the welders in the respective premises, as illustrated in fig 2, which is valid for the MIG and TIG welding of aluminum and aluminum alloys.

In fig 3 and 4 the elemental composition of the dust in the breathing zone, in the case of certain methods and materials, is compared with the composition of the dust at stationary test sites on the same premises. It emerges that the composition of the dust in the breathing zone and the dust in the room air were heavily interdependent. The composition of the dust in the breathing zone was close to that of the dust on the premises, but it was modified by the emission from the particular welding operation being performed. Thus in metal-arc welding the proportion of the coating components potassium, calcium,

and titanium was greater than in MAG welding (fig 3). The dust in the room air contained more iron than the dust in the breathing zone when aluminum was welded, since the breathing zone had higher concentrations of aluminum (fig 4).

As shown by fig 3 and 4, the composition of welding dust from similar operations varied within fairly narrow limits. This phenomenon is also shown by the relationship between the contents of chromium and total dust in the welding of stainless steel (fig 5) and the relationship between the contents of chromium and manganese and total dust in overlaying work on rails (fig 6). As a consequence, gravimetric dust measurements may be substituted for the determination of certain elements when the relationship is known.

Total dust contents

The total dust concentrations in the breathing zone during the welding operations under study can be seen from fig 7. There were great differences between the geometric means for the various methods. Still greater were the differences between the 90 percentiles. The geometric standard

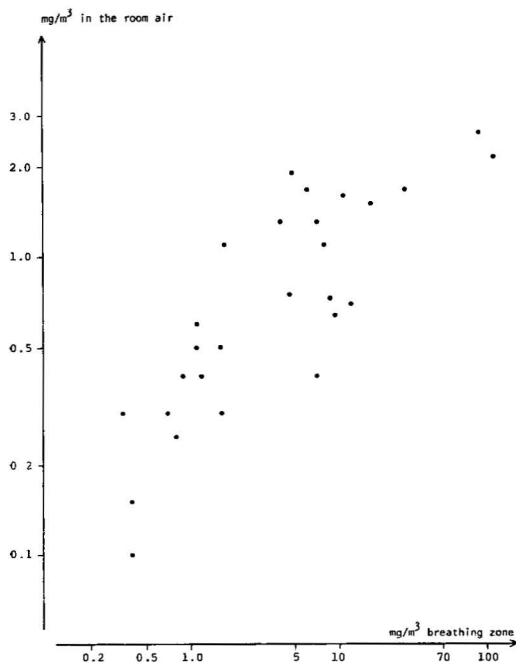


Fig 2. Relationship between the daily average of the total dust content in the breathing zone of welders and the total dust content in their work environment (20). The contents stated for the breathing zone are mean values from several test sites on the same premises. The correlation coefficient is + 0.70. This diagram is valid for gas-shielded arc welding of aluminum and aluminum alloys. Similar conditions were obtained for the indoor welding of other metals. Note that the breathing-zone concentrations run about ten times higher than the concentrations on the premises.

deviations, on the other hand, were roughly equal (19, 20, 21, 22).

If attention is confined to the mean values (which are the geometric means in all cases) at all the workplaces studied, with and without local exhaust ventilation, the highest contents, about 10 mg/m³ as a daily average, occurred for MIG welding on aluminum and ordinary metal-arc welding on steel, and the lowest contents, 1–2 mg/m³, appeared for TIG welding on aluminum and stainless steel. About 5 mg/m³ as a daily average was the figure that emerged for metal-arc welding on stainless steel and MAG welding on steel. Practically all the dust was respirable, and the bulk of the particles was below 1 μm (8, 22).

The arc-time factor varied greatly for the various types of production. A good

example is the difference in arc-time factor for the overlaying and mold welding of rails, for which the geometric mean was 5.4 % for the former and 12.2 % for the latter (fig 8). For the metal-arc welding of nonalloy steel in workshops, the geometric mean of the arc-time factor was 22 %, while for gas-shielded arc welding on the same material it was 18 % (21).

The exposure during the actual welding while the arc was passing, the immission index, was thus considerably greater than the average concentrations during a workday. This situation is illustrated in fig 9, 10, and 11. Fig 9 and 10 are histograms covering daily averages in overlay and mold welding, while fig 11 shows the distribution of immission indices for both types of welding, now treated as one since they showed no difference in immission index. As fig 11 shows, total dust contents in the breathing zone rose in some cases to several hundred milligrams per cubic

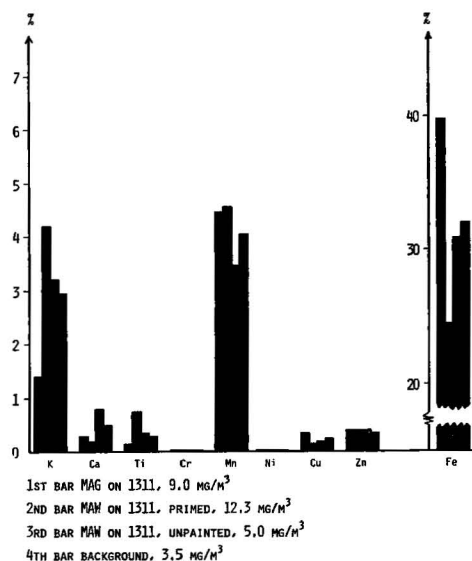


Fig 3. Elemental compositions of the dust in the breathing zone of certain welders and in the background of the work site sampled at the same time. In all, there were 12 welders in the shop. Welding was carried on behind screens. The gas-shielded metal-arc (MAG) method was used in one case, and the metal-arc (MAW) method in two cases. In all cases the base metal was nonalloy carbon steel (SIS 1311). The background contents were measured at the same time in the middle of the welding shop. The total dust contents are stated in the text in the diagram. [Collation of primary data pertaining to Ulfvarson et al (21)]

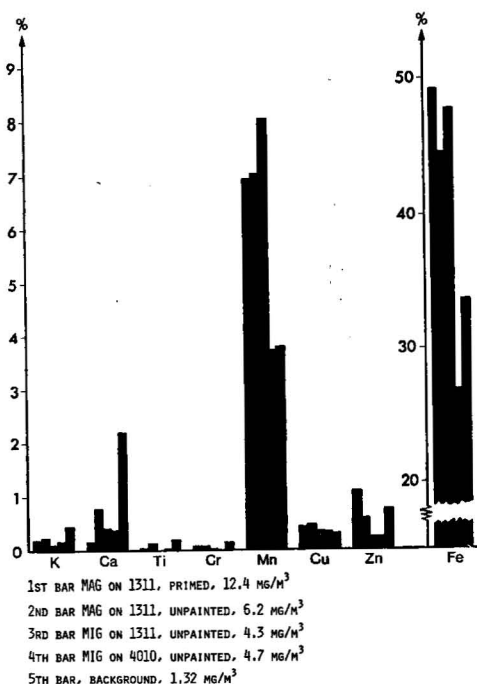


Fig 4. Elemental composition of the dust in the breathing zone of certain welders and in the background of the work site, sampled at the same time. In all, there were 115 welders in the shop. Welding was performed by the gas-shielded metal-arc method (MIG or MAG) on low-alloy carbon steel (SIS 1311) in three cases and on aluminum (SIS 4010) in one case. The background contents were measured at the same time in the middle of the shop. [Collation of primary data pertaining to Ulfvarson et al (20, 21)]

meter when the arc was passing (22). The immission indices for the total dust contents are also discussed in connection with the study of painted steel.

It thus emerges that the differences among different welding methods or applications of welding methods as regards total dust exposure during a full workday that appear to exist according to fig 7 may in some cases have been almost entirely due to differences in the arc-time factor. During shop welding on nonalloy steel with the metal-arc or MAG processes without local exhaust ventilation the immission index was 34 mg/m³. This value was very close to the immission index found in the mold welding and overlaying of rails (41 mg/m³). Since the arc-time factor was not consistently measured in the studies of welding on aluminum and stainless steel, it was not possible to extend the corresponding comparisons to these materials. It is reasonable to assume that, irrespective of any differences in the arc-time factor, there were large differences in emission, at least between TIG and MAG welding. In TIG welding only the base metal melts, while in MAG welding the metal of the electrode melts as well. From the difference between these two methods in the welding of aluminum, it seems that the bulk of the dust comes from the electrode when a consumable electrode is being used.

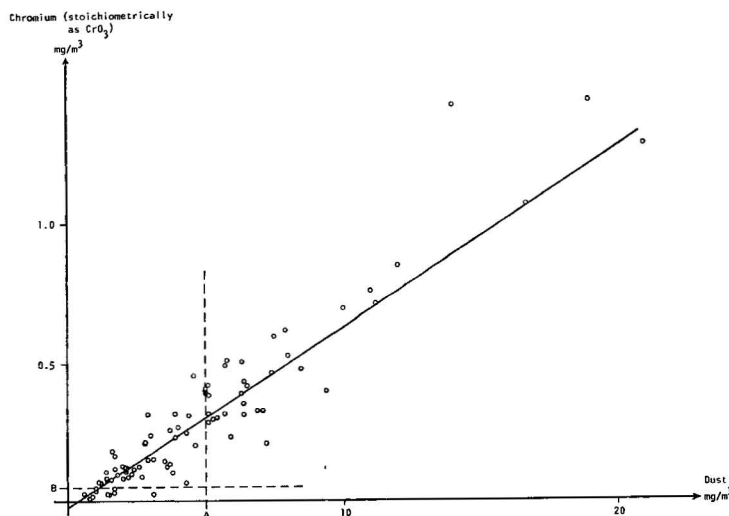


Fig 5. Relationship between the contents of chromium (as chromium trioxide) (Y mg/m³) and total dust (X mg/m³) in the breathing zone with metal-arc welding, 86 pairs of readings (20). Regression line: $Y = -0.0268 + 0.0655 X$. [A = time-weighted average limit value for fine inert dust (1); B = time-weighted average limit value for chromium (as chromium trioxide) (1)]

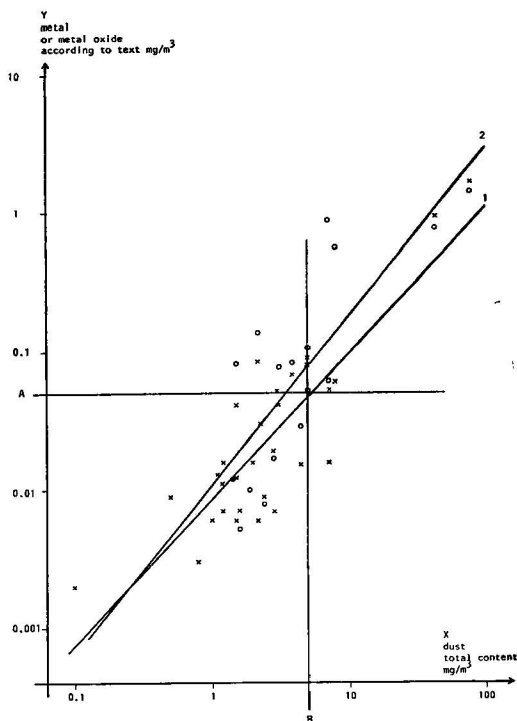


Fig 6. Relationship between the contents of chromium (as chromium trioxide) ($Y \text{ mg/m}^3$) or manganese ($Y \text{ mg/m}^3$) and total dust ($X \text{ mg/m}^3$) in the breathing zone during overlay welding (22) — 32 and 18 pairs of readings, respectively. Logarithmic scales. [A = time-weighted average limit value for chromium (as chromium trioxide); B = time-weighted average limit value for fine inert dust (1)]
 Curve 1 (x) is valid for chromium with the regression line $\log Y = -2.07 + 1.05 \log X$
 Curve 2 (o) is valid for manganese with the regression line $\log Y = -1.95 + 1.23 \log X$

In the study of the gas-shielded arc welding of aluminum and the welding of stainless steel, it could not be shown that the size of the welding current affects the dust content in the breathing zone, nor the contents of ozone or nitrogen oxides (19, 20). The type of current, however, did affect the metal-arc welding of stainless steel. Alternating current gave a lower dust concentration than direct current (19). In the gas-shielded arc welding of nonalloy steel without local exhaust ventilation there was a significant relationship between high amperage and high dust content in the breathing zone (21).

A relationship between amperage in arc welding and the dust content in the breath-

ing zone is to be expected and has been demonstrated by Stern (16) and by a working party set up within the Welding Research Commission of the Royal Swedish Academy of Engineering Sciences (7). The fact that the relationship could not be detected in several field studies may be due to the great variations that occur both in the observed and in the unobserved production parameters.

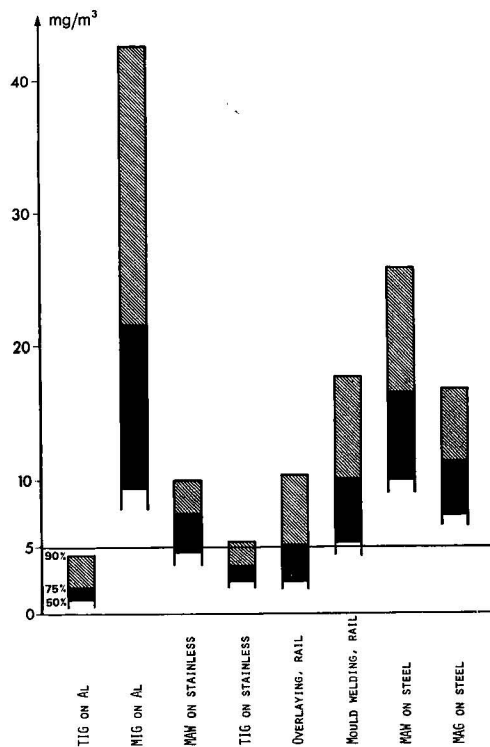


Fig 7. Daily averages of dust concentrations in welders' breathing zones (inside face guard) in workplaces without local exhaust ventilation. The lower boundary of each bar indicates the geometric mean (half of the welders were exposed below this value). The boundary line between the black and the hatched zones indicates the 75 percentile (three-quarters of the welders were exposed below this value), and the uppermost boundary indicates the 90 percentile (ninety-ninths of the welders were exposed below this value). The line at 5 mg/m^3 indicates the level limit value for iron oxide fumes, converted to ferric oxide (2). The compilation is based on material reported in Ulfvarson et al (19, 20, 21, 22). All bars are valid for workplaces without local exhaust ventilation. (TIG = tungsten inert-gas welding, Al = aluminum, MIG = metal inert-gas welding, MAW = metal-arc welding, MAG = gas-shielded metal-arc welding with active gas)

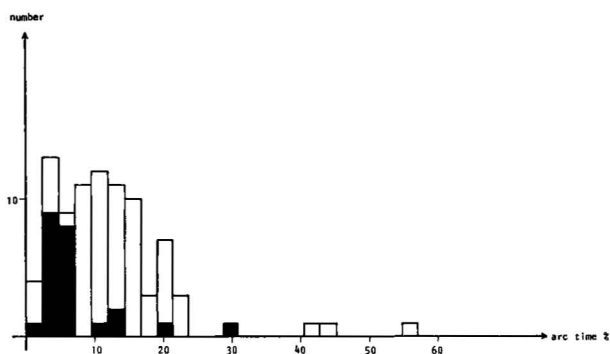


Fig 8. The arc-time factor as a percentage in mold welding and overlay welding (22). [Solid bars = overlaying (23 test sites), geometric mean 5.4 %; open bars = mold welding (64 test sites), geometric mean 12 %]

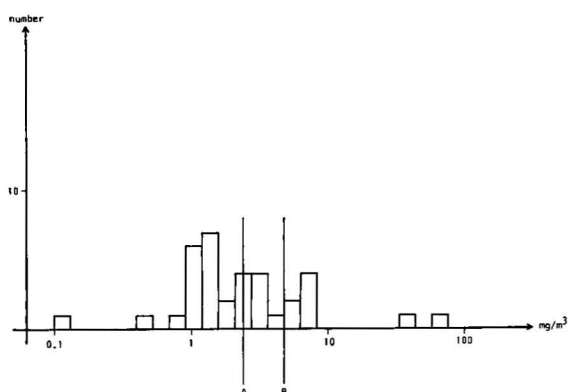


Fig 9. Histogram covering total dust content in the breathing zone during overlay welding at 35 test sites (22). [A, geometric mean = 2.4 mg/m³; B = time-weighted average limit value for fine inert dust (1)]

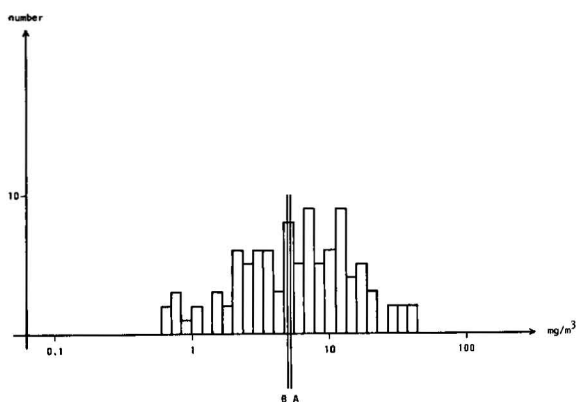


Fig 10. Histogram covering total dust content in the breathing zone during mold-welding at 95 test sites (22). [A, geometric mean = 5.3 mg/m³; B = time-weighted average limit value for fine inert dust (1)]

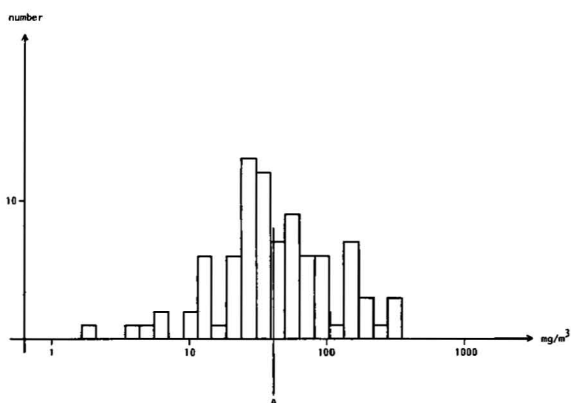


Fig 11. Dust content during arc passage (22). Histogram covering immission indices (see the text) in the breathing zone during overlay welding and mold welding at a total of 88 test sites. (A, geometric mean = 41 mg/m³)

Effect of work position on dust exposure

During measurements in the course of shop welding on nonalloy steel (21), the main work position was recorded. The various observed positions were classified as: (i) standing erect, (ii) standing bent over work, (iii) sitting, and (iv) varying work positions. The geometric mean of the dust content in the breathing zone was 6.3 mg/m^3 at 17 test sites with an erect work position, 6.6 mg/m^3 at 51 test sites at which the welder stood bent over his work, 6.0 mg/m^3 at 9 test sites at which the welder sat during his work, and 8.4 mg/m^3 at 8 test sites where varying work positions were adopted. An isolated reading, obtained when a welder was working inside a tank, was 7.3 mg/m^3 . A variance analysis of the total dust contents in the breathing zones of welders working in the different positions revealed no influence due to work position ($p = 0.79$).

In regard to the significance of the arc-time factors for exposure during a work-

day, an inquiry was also made to ascertain whether these factors varied from one work position to another. The geometric mean of the arc-time factor was found to be 21 % for work in the erect position, 17 % when the welder was standing bent over his work, 20 % with the welder seated, and 24 % for varying work positions. No significant difference was obtained ($p = 0.5$).

In line with the finding that there was no significant difference in arc-time factor between different work positions, it was also found that work position made no difference to the immission index.

Contents of individual elements or substances

The elemental composition of the dust has been illustrated in fig 3 and 4 by some of the previously presented examples. Elements lighter than potassium could not be determined with the multielement method that was used. Fluorine, however,

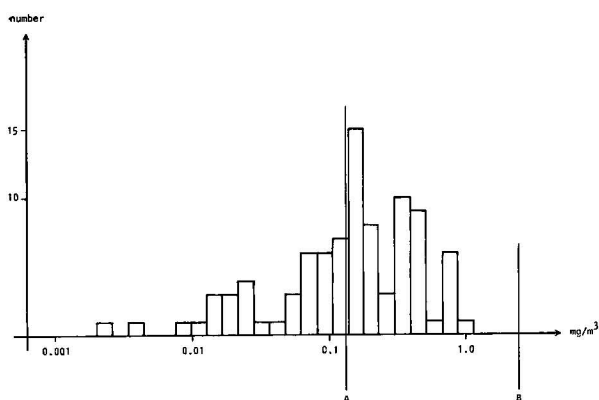


Fig 12. Histogram covering manganese content in the breathing zone during mold welding at 92 test sites (22). The mold welding was carried out with an electrode containing 1.3 % manganese. [A, geometric mean = 0.13 mg/m^3 ; B = time-weighted average limit value for manganese (1)]

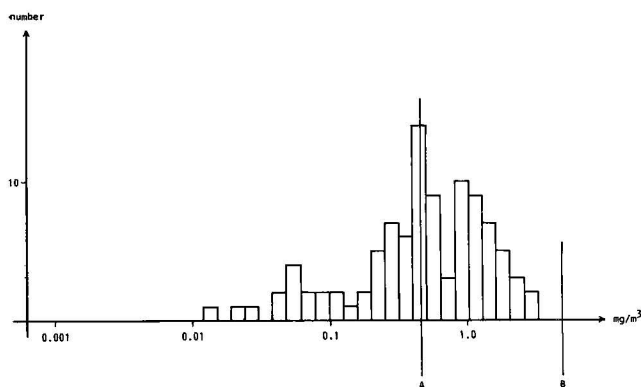


Fig 13. Histogram covering potassium content in the breathing zone during mold welding at 98 test sites (22). [A, geometric mean = 0.44 mg/m^3 ; B = time-weighted average limit value for fine inert dust (1)]

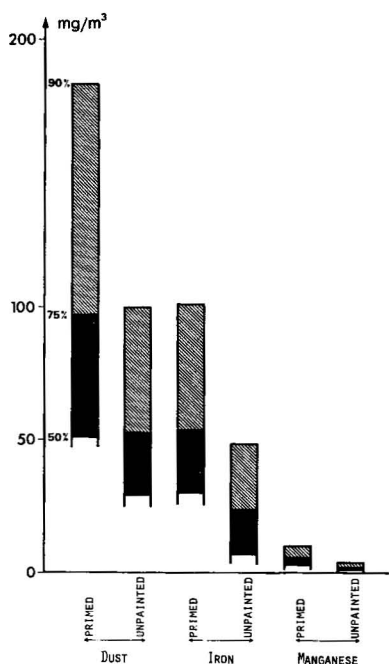


Fig 14. Contaminant contents during passage of arc. Distribution of the immission index for metal-arc and gas-shielded arc shop welding, taken together, on nonalloy steel. For the interpretation of the bars see the legend of fig 7. All readings were taken at test sites without local exhaust ventilation. In order, in milligrams per cubic meter, geometric mean, 75 percentile and 90 percentile: 51, 97, 170 for dust, primed steel; 28, 55, 100 for dust, unpainted steel; 30, 57, 100 for iron, primed steel; 14, 27, 48 for iron, unpainted steel; 3.1, 5.8, 10 for manganese, primed steel; and 1.3, 2.3, 4.0 for manganese, unpainted steel. [Collation of data from Ulfvarson et al (22)]

was determined by a special method in a number of cases. The compounds in which the elements occur can only be a matter of guesswork. The significance of elemental composition for exposure to various elements will be considered in the following discussion.

In the welding of nonalloy steel the main constituent in the dust, as might be expected, was iron. It was followed in approximate declining order by manganese (electrode component), potassium, calcium, titanium (coating components in metal-arc welding), copper, and zinc (21). The presence of a large number of other elements may have been demonstrated, but they are of no significance as regards hygiene.

Fig 12 and 13 illustrate the distribution of the manganese and potassium exposure, respectively, during the metal-arc welding of steel, the mold welding of railroad rails. As already mentioned, the arc-time factor was on the low side in this type of welding, as compared with shop welding.

Immission indices for some elements occurring in the gas-shielded arc welding and metal-arc welding of painted and unpainted steel in workshops are illustrated in fig 14 and 15. These figures also shed light on the conditions that arise in the welding of painted steel. The paint coat was a thin film (20–30 μm) of red shop primer with zinc tetraoxychromate and

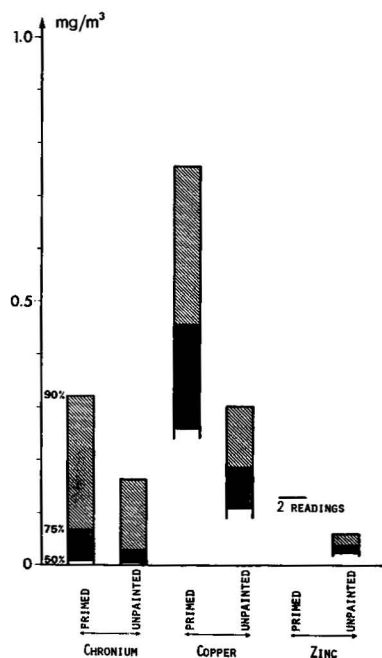


Fig 15. Contaminant contents during passage of arc. Distribution of the immission index for metal-arc and gas-shielded arc shop welding, taken together, on nonalloy steel. For the interpretation of the bars see the legend of fig 7. All readings were taken at test sites without local exhaust ventilation. In order, in milligrams per cubic meter, geometric mean, 75 percentile and 90 percentile: 0.012, 0.032, 0.16 for chromium, primed steel; 0.0051, 0.032, 0.16 for chromium, unpainted steel; 0.26, 0.46, 0.76 for copper, gas-shielded arc welding on primed steel; 0.11, 0.19, 0.30 for copper, gas-shielded arc welding on unpainted steel; 0.43, 1.24, 3.21 for zinc, gas-shielded arc welding on primed steel; and 0.11, 0.23, 0.45 for zinc, gas-shielded arc welding on unpainted steel. [Collation of data from Ulfvarson et al (22)]

iron oxide as the pigments. It appears reasonable to expect that iron, zinc, and chromium would attain higher contents when painted rather than unpainted steel is being welded.

When the effect of differences in the arc-time factor has been eliminated by the calculation of immission indices, one can see that it is not only these elements that show higher contents when the steel being welded is painted instead of unpainted but that the same applies to the elements manganese and copper as well, even though they are not present in the shop primer. The explanation is that painted steel is commonly welded with thicker electrodes and heavier currents than unpainted steel, and they therefore give rise to a higher total dust content and, of course, to higher contents of the components present in the breathing zone. It is therefore not possible to tell how great a proportion of the dust contents encountered in the welding of painted steel is attributable to the coat of paint. Unfortunately, no notes were kept as to the nature of the weldments. It is at least possible that shop-primed base metals differed in their dimensions from untreated stock and went into products of quite different kinds. This may be the reason why welding was carried out in a way that resulted in higher total dust contents. The observation shows how difficult it can be to single out the influence of a given factor in field measurements. The problem analysis that was performed has also shown that, even if shop-priming were to be discontinued, the problem of the more copious dusting that occurs in the welding of objects that used to be painted would not be solved.

During metal-arc welding with basic electrodes, the concentrations of fluorine (in the form of fluorides) found in the welder's breathing zone had a median of 0.51 mg/m^3 (fig 16). At the workplace studied, the base metal was stainless steel. According to the literature pertaining to this matter, fluorine occurs as fluorides, as has been discussed by Ulfvarson et al (19).

Benz(a)pyrene was recorded in rail welding, but not in the other welding operations. The geometric mean was low, 18 ng/m^3 (fig 17). In this context polycyclic

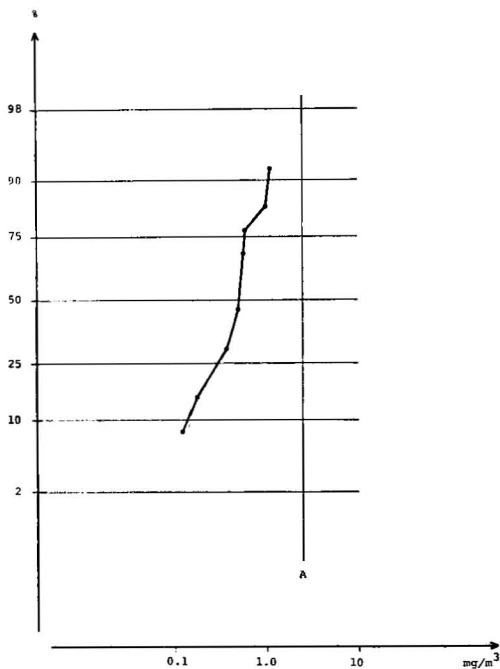


Fig 16. Fluoride concentrations (19). Cumulative distribution polygon on normal distribution paper for contents of fluorides (as fluorine) (logarithmic abscissa) at 13 test sites where metal-arc welding was performed with basic electrodes on stainless steel. Note that the highest value cannot be represented. Contents correspond to time-weighted average for a full work shift. [A = time-weighted average limit value for fluorides (as fluorine) (1)]

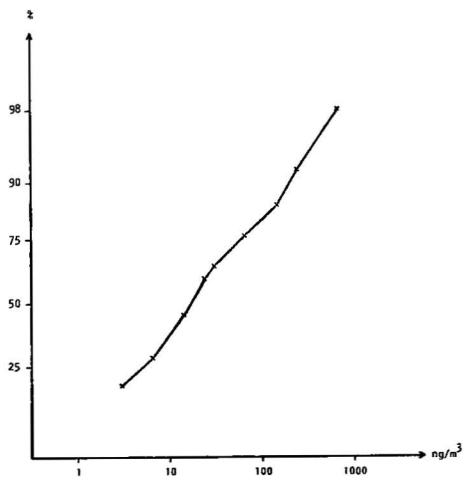


Fig 17. Benz(a)pyrene concentrations (22). Cumulative distribution polygon on normal distribution paper for benz(a)pyrene contents in the breathing zone (logarithmic x-axis) in overlay welding and mold welding at a total of 131 test sites. Note that the highest value cannot be represented.

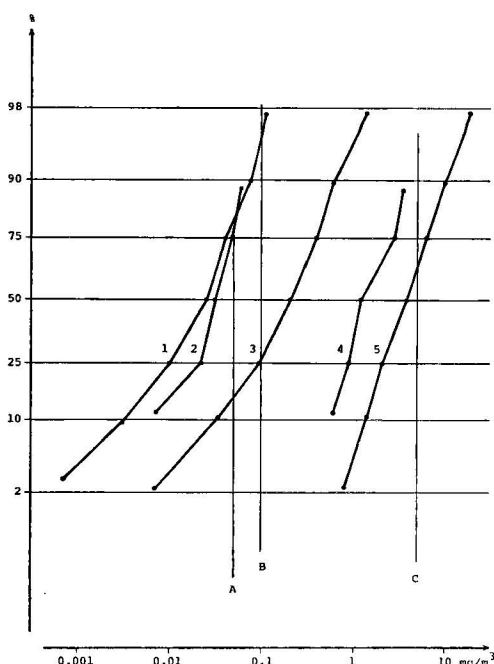


Fig 18. Contaminants from the welding of stainless steel (19). Cumulative distribution polygon on normal distribution paper for concentrations of particulate air pollutants (logarithmic abscissa) from the metal-arc welding of stainless steel. Note that the highest value cannot be represented. Concentrations correspond to the time-weighted average for a full work shift. [A = time-weighted average limit value for chromium (as chromium trioxide) (1), B = the American Conference of Governmental Hygienists' time-weighted average limit value for nickel, C = time-weighted average limit value for fine inert dust (1)]

Curve 1: Nickel in the breathing zone (inside face guard) at 71 test sites without local exhaust ventilation.

Curve 2: Chromium (as chromium trioxide), average values for background concentrations in shops where the exposure readings were taken at 17 firms.

Curve 3: Chromium (as chromium trioxide) in the breathing zone (inside face guard) at 86 test sites with or without local exhaust ventilation.

Curve 4: Total dust, average values for background concentrations in shops where the exposure readings were taken at 17 firms.

Curve 5: Total dust in the breathing zone (inside face guard) at 86 test sites with or without local exhaust ventilation.

hydrocarbons may be derived from sources other than the metal-arc welding as such. In the first place there is preheating and postheating by torch; in the second place the tie and other organic material in the vicinity may catch fire during the operation.

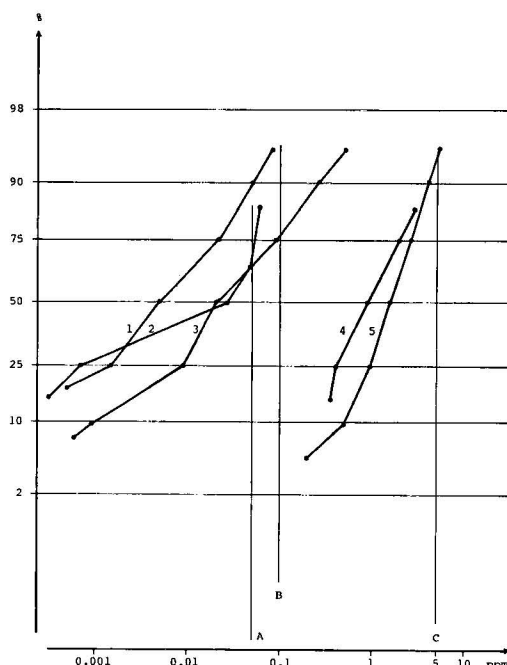


Fig 19. Contaminants from the welding of stainless steel (19). Cumulative distribution polygon on normal distribution paper for concentrations of particulate air pollutants (logarithmic abscissa) from the gas-shielded arc welding of stainless steel and some other alloys. Note that the highest value cannot be represented. Concentrations correspond to the time-weighted average for a full work shift. Local exhaust ventilation was used in some cases. [A = time-weighted average limit value for chromium (as chromium trioxide) (1), B = the American Conference of Governmental Industrial Hygienists' time-weighted average limit value for nickel, C = time-weighted average limit value for fine inert dust (1)]

Curve 1: Nickel in the breathing zone (inside face guard) at 39 test sites.

Curve 2: Chromium (as chromium trioxide), average values of background concentrations in shops where the exposure readings were taken at 13 firms.

Curve 3: Chromium (as chromium trioxide) in the breathing zone (inside face guard) at 41 test sites.

Curve 4: Total dust, average values for background concentrations in shops where the exposure readings were taken at 13 firms.

Curve 5: Total dust in the breathing zone (inside face guard) at 41 test sites.

In the welding of stainless steel by the metal-arc process with coated electrodes, almost all the chromium present was in the form of soluble hexavalent chromium, and the contents in the breathing zone were, in most cases, above the limit value for this group of elements, 0.02 mg/m³ (as

chromium) (fig 18). In the gas-shielded arc welding of stainless steel the valency was difficult to determine, but only a small part of the chromium in the dust was soluble. The contents were, moreover, considerably lower (fig 19). Nickel was commonly present in contents below the limit value for nickel compounds (0.1 mg/m^3) in the welding of stainless steel (fig 18 & 19).

The fumes produced in the aluminum welding consisted mainly of aluminum oxide, although it was not revealed by the X-ray fluorescence method. With the TIG and MIG welding of aluminum and its alloys, other elements, primarily iron, chromium and copper, have been detected in relatively small concentrations, both in the breathing zone and in the room air as a whole; in some cases a number of other metals have also been detected (20).

Biological monitoring

Blood samples were taken from welders who had worked with stainless steel and with aluminum and from referents. The samples were analyzed by mass spectrometry, and a total of 17 trace elements, of which one was chromium, was registered. The data were put through a discriminant analysis, from which it emerged that there was no difference between the groups either as regards the average levels of the elements in the blood or as regards the structure of the correlations between the elements. It can be assumed from this finding that the blood concentrations of the analyzed elements in individual persons do not afford any information concerning their exposure to welding contaminants (23). Therefore the use of multielement determination in blood samples from welders seems to be ruled out as a method for monitoring exposure to welding fumes.

Gaseous contaminants

The highest ozone concentrations were obtained in the MIG welding of aluminum. The average (geometric mean) of the readings was close to 0.1 ppm , which is the time-weighted average limit value (fig 20). More than 10 % of the readings were above a calculated ceiling of 0.3 ppm . The MIG

welding of stainless steel also gave readings close to 0.1 ppm , but it was studied only on a small scale. The TIG welding of aluminum and stainless steel gave lower concentrations, and the same applies to the MIG and MAG welding of steel.

The aggregate for oxides of nitrogen varied somewhat among the different methods (fig 21). The highest mean of all the readings was obtained for the TIG welding of aluminum, about 1 ppm (immediately outside the face guard). The ceiling for nitrogen dioxide was 5 ppm , and, since it can be assumed that this gas accounts for one-half of the levels obtained in the measurements, the concentration should be well below the ceiling level.

Carbon monoxide was found only sporadically and in low concentrations with all types of arc welding except MAG on steel,

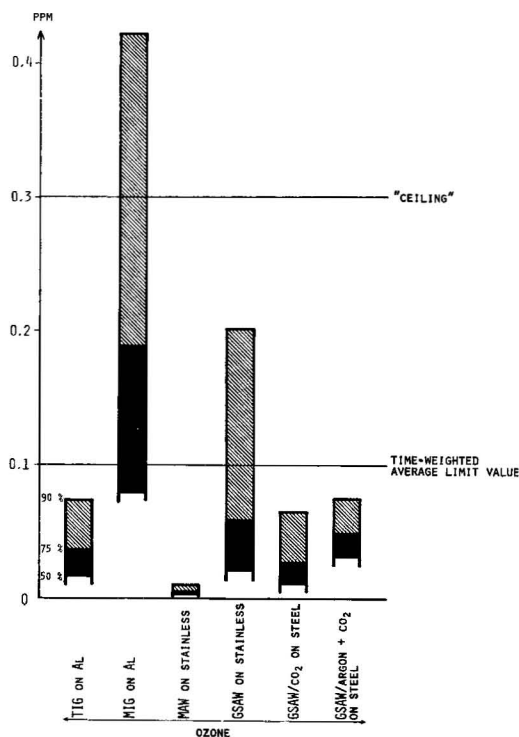


Fig 20. Distributions of ozone concentrations in the breathing zone (inside face guard) for welders working with various materials and processes. For the interpretation of the bars see the legend of fig 7. (TIG = tungsten inert-gas welding, Al = aluminum, MIG = metal inert-gas welding, MAW = metal-arc welding, GSAW = gas-shielded arc welding, CO₂ = carbon dioxide) [Collation of data from Ulfvarson et al (19, 20, 21, 22)]

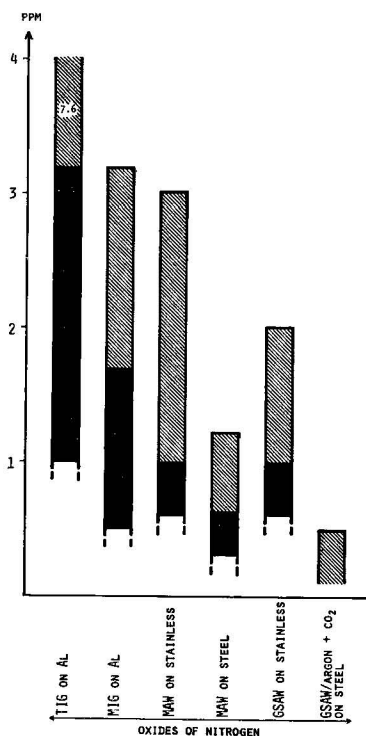


Fig 21. Distributions of concentrations of oxides of nitrogen [sum of mainly nitrous oxide and nitrogen dioxide, roughly half of each gas according to readings taken by Ulfvarson et al (19)] at head height but outside the face guard for welders working with various materials and methods. For the interpretation of the bars see the legend of fig 7. (TIG = tungsten inert-gas welding, Al = aluminum, MIG = metal inert-gas welding, MAW = metal-arc welding, GSAW = gas-shielded arc welding, CO₂ = carbon dioxide) [Collation of data from Ulfvarson et al (19, 20, 21, 22)]

particularly where the protective gas was pure carbon dioxide. Most of the concentrations recorded were still low, even with MAG, but 50 ppm or more was found in some 10 % of the cases, with peak readings at 150 ppm (21).

Organic substances, such as volatile alcohols, ketones and hydrocarbons, were recorded in low concentrations in the welding of primed steel. The aggregate concentrations of organic substances were less than 1 mg/m³ on the average. It is probable that the odor of these substances would be detectable in some cases and that they might cause some measure of irritation of the eyes and the respiratory passages (21).

Comparisons with occupational health standards

All the investigations were carried out while the occupational health standards adopted in 1974 (1) were in force. Since the beginning of 1979 some revised standards have been in force as regards substances of importance in welding. There are grounds for comparing concentration findings with both the old and the new standards. At the time the measurements were carried out, the levels that one could expect under workplace conditions were based on the old standards. However, the readings should also be compared with the new standards. The readings give a representative picture of the conditions so long as the welding operations remain unchanged. In those cases in which local exhaust ventilation has come into use on a greater scale since the investigations were carried out, the original state of affairs, without local exhaust ventilation, is unchanged so long as the welding process as such has not changed.

If the exposure situation is considered for welders in comparison with occupational health standards (table 2), it emerges that, except in TIG welding, the dust exposure is in general substantially higher than the standard (fig 7). This situation often applies to the daily average and in a particularly high degree to the time the arc is alight (cf fig 11 & 14) and irrespective of whether the comparison is made with the standard for total dust or the standard for the fine fraction of the dust, which was official in Sweden up to 1978. The exposure to iron, too, is usually higher than the standard, on the average over the workday.

In the welding of stainless steel the daily average for exposure to chromium is almost always higher than the standard, on the assumption that all the chromium is hexavalent (fig 18 & 19). If the chromium in gas-shielded arc welding is not hexavalent, a question which is still open, the standard is exceeded only occasionally (fig 19).

When the arc is alight, fairly high concentrations may arise in the case of other metals, chiefly manganese, but also copper (fig 14 & 15). The rules governing the application of the standard to occasional in-

fractions in the case of particulate air contaminants are unclear.

Among other air contaminants it is usually only ozone, with certain kinds of gas-shielded arc welding, which gives concentrations in the breathing zone that exceed the standard. Conditions become particularly troublesome in the MIG welding of aluminum, though high ozone concentrations may also occur during the gas-shielded arc welding of stainless steel (fig 20).

Effect of local exhaust ventilation

In the course of the field studies some instances of local exhaust ventilation appeared in the very earliest cases concerned with the welding of aluminum and stainless steel. Since then the use of local exhaust ventilation has become increasingly common at workplaces. It may be supposed that the ventilation has also become more efficient and is used in a more efficient manner. It is possible, by purely statistical means, to arrive at an idea of how effective local exhaust ventilation has been in practical service at the test sites that were studied. In the following comparisons mean values are used from test sites where local exhaust ventilation was used and other test sites where it was not used. This procedure gives a true and fair picture of the efficiency of local exhaust ventilation only if it can be assumed that local exhaust ventilation, by and large, was adopted on a random pattern and was not, for example, confined to particularly troublesome operations. The arc-time factor was studied at workplaces in shops where nonalloy steel was welded with and without local exhaust ventilation, and no significant differences were found (21). As part of the same study, unpublished findings show that the wire diameter and the amperage were not significantly greater in operations with local exhaust ventilation. Unpublished findings from the studies of welding on aluminum and stainless steel show no correlation at all between amperage and the use of local exhaust ventilation.

There is a pointer indicating that local exhaust ventilation was used when the arc-time factor was large, when the wire

diameters were large and when the welding current was heavy in the study on the shop welding of nonalloy steel. When it comes to high amperage and the use of local exhaust ventilation, the correlation was close to being significant. Local exhaust ventilation was used in 18 cases versus the expected 14 when the current was at least 175 A and in 7 cases versus an expected 11 when the current was less than 175 A at a total of 89 test sites ($\chi^2(1) = 3.53$, $p = 0.06$).

Table 2. Occupational health standards for substances measured during welding. Time-weighted average limit values are given unless otherwise stated.

Substance	Limit value 1974—1978	Limit value from 1 January 1979
Benz(a)pyrene	—	0.01
Dust, total (mg/m ³)	—	10
Dust, inert, mineral, fine fraction (mg/m ³)	5	—
Fluorides (as F) (mg/m ³)	2.5	—
Fluorides and hydrogen fluoride, total (as F) (mg/m ³)	—	2
Iron oxide, fumes (mg/m ³)	5	—
Iron oxide, fumes (as Fe) (mg/m ³)	—	3.5 ^a
Carbon monoxide (ppm)	40	40
Copper, fumes (mg/m ³)	—	0.2
Chromic acid and chromates (as CrO ₃) (mg/m ³)	0.05	—
Chromic acid and chromates (as Cr) (mg/m ³)	—	0.02 ^b
Chromium and inorganic compounds other than chromic acid and chromates	—	0.5
Nitrogen dioxide (ppm)	5	2
Nitrogen dioxide, ceiling (ppm)	—	5
Nitrous oxide (ppm)	—	25
Manganese and inorganic compounds (as Mn) (mg/m ³)	2.5	2.5
Manganese and inorganic compounds (as Mn), ceiling (mg/m ³)	5	5
Nickel compounds (oxide, carbonate and soluble salts) (as Ni) (mg/m ³)	— ^c	0.1
Ozone (ppm)	0.1	0.1
Zinc oxide, fumes (mg/m ³)	5	—
Zinc oxide (mg/m ³)	—	5

^a No change; stoichiometric conversion only.

^b Calculated as CrO₃, the change is from 0.05 to 0.04 mg/m³.

^c The limit value that was set originally (0.01 mg/m³) was cancelled by the National Board of Occupational Safety and Health in *Bulletin* 1975: 5.

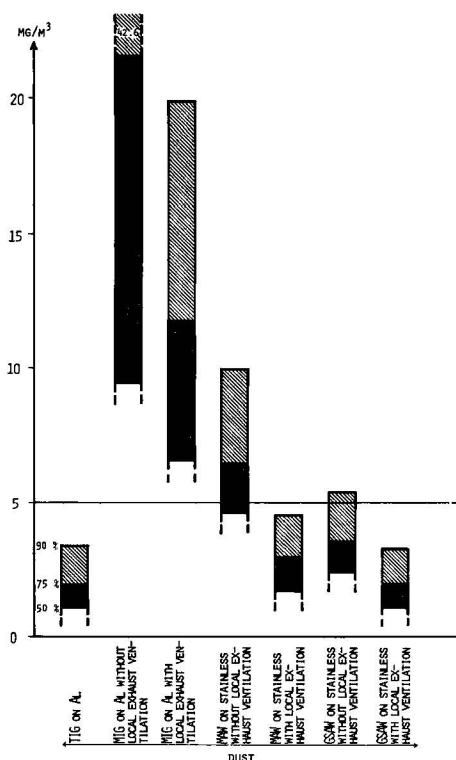


Fig 22. The effect of local exhaust ventilation. Distributions of total dust content in the breathing zone (inside face guard) during metal-arc or gas-shielded arc welding on aluminium (Al) and stainless steel with and without local exhaust ventilation. For the interpretation of the bars see the legend of fig 7. The solid line at 5 mg/m³ marks the limit value for iron oxide, in the form of fumes, converted to ferric oxide (2) and corresponds to the older limit value for dust, inert, mineral, fine fraction (1). The diagram is based on a collation of results published in Ulfvarson et al (19, 20). (TIG = tungsten inert-gas welding, MIG = metal inert gas welding, MAW = metal arc welding, GSAW = gas-shielded arc welding)

Despite this tendency in one of the studies, it is probably true to say that in the majority of the cases studied local exhaust ventilation was adopted without regard to whether the operation had been generating particularly large amounts of dust. Probably, therefore, it is safe to assume that statistical comparisons between average dust contents can tell something about the effectiveness of local exhaust ventilation. There is reason to believe that the effectiveness differs between gas-shielded arc welding and metal-arc welding. The use of unduly strong local exhaust ventilation in

gas-shielded arc welding is liable to disturb the shielding-gas envelope.

In the MIG welding of aluminum the daily average value for dust in the breathing zone was 10 mg/m³ without local exhaust ventilation and a shade less than 7 mg/m³ in the rather rare cases where local exhaust ventilation was available (fig 22). This difference is too small to be statistically certain.

In the welding of stainless steel by the gas-shielded arc process the difference was also uncertain, from 2 mg/m³ without local exhaust ventilation to 1 mg/m³ in some cases with such ventilation (fig 22).

In later studies on the MAG welding of steel, local exhaust ventilation was available in a third of the cases. In this context local exhaust ventilation had a definite

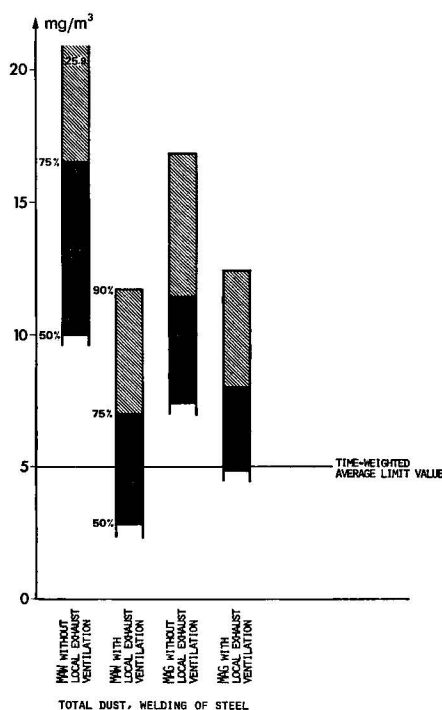


Fig 23. Effect of local exhaust ventilation. Distribution of total dust concentrations in the breathing zone (inside face guard) during metal-arc and gas-shielded arc welding on nonalloy steel in workshops with and without local exhaust ventilation (21). For the interpretation of the bars see the legend of fig 7. The significance of the solid line at 5 mg/m³ marks the limit value for iron oxide, in the form of fumes, converted to ferric oxide (2) and corresponds to the older limit value for dust, inert, mineral, fine fraction (1). (MAW = metal-arc welding, MAG = gas-shielded metal-arc welding)

effect, reducing the average dust contents to 65 % of what they were without local exhaust ventilation (fig 23).

In the metal-arc welding of stainless steel the dust contents without local exhaust ventilation averaged rather more than 4 mg/m³, while with local exhaust ventilation they averaged just under 2 mg/m³ (fig 22). The difference is statistically certain. In this instance, the chromium contents are of particular interest. Without local exhaust ventilation the chromium content, as chromium trioxide (CrO₃), averaged rather more than 0.2 mg/m³ (as CrO₃), which was far in excess of the limit value (0.03 mg/m³ as CrO₃) (2). With local exhaust ventilation the average was 0.06 mg/m³ (fig 24). Thus, even though local exhaust ventilation had a statistically certain effect, it was not sufficient to bring the geometric mean down below the limit value.

In later studies of metal-arc welding of steel local exhaust ventilation was used in about one-fifth of the test sites and had a definite effect, reducing the average dust contents to 42 % of what they were without local exhaust ventilation (fig 23). Consequently almost all the test sites had a lower dust content than 5 mg/m³, which is the limit value for iron oxide fumes as ferric oxide (Fe₂O₃) (2). Local exhaust ventilation appears to be more effective in metal-arc welding than in gas-shielded arc welding. As regards the effect of local exhaust ventilation on the gases recorded, it was established that the oxides of nitrogen are markedly reduced in metal-arc welding (19). Local exhaust ventilation did not have any measurable effect on ozone exposure (19). Ozone in significant concentrations is formed only during gas-shielded arc welding, where it is difficult to position the local exhaust ventilation nozzle effectively.

Jansson (8), in 1978, determined the degree of collection for 15 different types of local exhaust ventilation nozzles in laboratory trials with fixed workplaces. The tests were carried out in a room with controlled ventilation and consisted of particle counts during welding with and without a local exhaust ventilation nozzle. The tests showed that, when used to the best possible advantage in metal-arc weld-

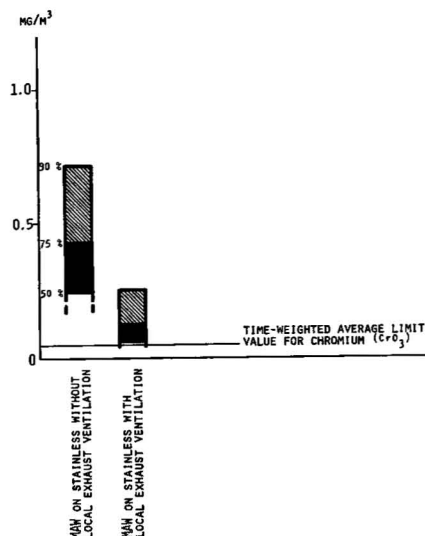


Fig 24. Effect of local exhaust ventilation. Distributions of concentrations of chromium, as chromium trioxide (CrO₃), in the breathing zone (inside face guard) during metal-arc welding (MAW) on stainless steel with and without local exhaust ventilation. The time-weighted average limit value for chromium, 0.02 mg/m³ (2), has been converted to CrO₃. For the interpretation of the bars, see the legend of fig 7. [Collation of data from Ulfvarson et al (19)]

ing, the exhaust nozzles collect 97–99 % of the particles in the important size range from 0.1 to 1.4 μm. The degree of collection was somewhat lower in gas-shielded arc welding, 70–90 %. When the nozzles are used as intended, the differences in collection degree among various local exhaust ventilation arrangements are small, especially in metal-arc welding. In these tests, no account was taken of ergonomic considerations and mobility.

The findings as regards the difference between metal-arc welding and gas-shielded arc welding in the field tests were confirmed by the laboratory study. Furthermore, a comparison between the laboratory results and the field measurements suggests that, in practice, the exhaust nozzles are not used in the best possible way, which, it must be said, was an expected finding. Tests were also carried out in the laboratory on filters for welding dust. The separation performance was 86–99.9 % for particles in the size bracket from 0.1 to 0.18 μm, and it is better still as the particles get larger (8).

Summary

During the period 1974 to 1976 a total of almost 500 welding stations were investigated at some 70 industrial undertakings and at 21 track sections of the Swedish State Railways. These sites exhibited several different processes and materials and a variety of production conditions. Concentrations of air contaminants were measured in the breathing zone of the welders and at the work site. In this report, results from several earlier publications are summarized and compared over the whole investigation.

The composition of the dust in the breathing zone of the welders and the dust in the room air were heavily interdependent. The composition of welding dust from similar operations varied within fairly narrow limits. This finding is shown *inter alia* by the relationship between the contents of chromium and total dust in the welding of stainless steel. As a consequence gravimetric dust measurements may be substituted for the determination of certain elements when the relationship is known.

Due to the extent of the investigation the concentration ranges found for air contaminants in various processes may be considered representative. The highest mean values of dust concentrations were found with MIG welding on aluminum and metal-arc welding on steel, about 10 mg/m³ during a workday. The lowest mean values were found with TIG welding on aluminum and stainless steel, about 1–2 mg/m³ during a workday. About 5 mg/m³, as a daily average, is the figure that emerged for metal-arc welding on stainless steel and MAG welding on steel. The exposure during the actual welding while the arc is passing, defined as the immission index, was considerably greater, several hundred milligrams per cubic meter. The differences that appear to exist among the welding methods may, in some cases, be almost entirely due to differences

in the arc-time factor. In the study of the gas-shielded arc welding of aluminum and the welding of stainless steel, it could not be shown that the size of the welding current affects the dust content in the breathing zone, nor the contents of ozone or nitrogen oxides. Alternating current gave a lower dust concentration than direct current. In the gas-shielded arc welding of nonalloy steel there was a significant relationship between high amperage and high dust content in the breathing zone. The fact that the relationship could not be detected in several field studies may be due to the great variations that occur in both observed and unobserved production parameters.

No influence was revealed of work position on the total dust contents in the breathing zones of the welders.

Welding performed on steel painted with a shop primer gave rise to a higher total dust content than welding on unpainted steel. The dust not only contained higher amounts of the elements typical for the pigments of the paint, but also of elements such as manganese and copper found in the base metal or the electrodes. This phenomenon has been interpreted to show that welding on painted steel objects was carried out in a way that resulted in higher total dust contents, irrespective of the presence of the paint.

The use of multielement determination in blood samples from welders seems to be ruled out for the monitoring of exposure to welding fumes.

The highest ozone concentrations were obtained in the MIG welding of aluminum. The average of the readings was close to 0.1 ppm. The TIG welding of aluminum and stainless steel gave lower concentrations, and the same applies to the MIG and MAG welding of steel. The highest mean of all readings of oxides of nitrogen was obtained in the TIG welding of aluminum, about 1 ppm immediately outside the face

guard. Carbon monoxide was found only sporadically and in low concentrations with all types of arc welding except MAG on steel, particularly where the protective gas was pure carbon dioxide. Most of the concentrations recorded were still low, even with MAG, but 50 ppm or more was found in some 10 % of the cases. Aggregate concentrations of organic substances were less than 1 mg/m³, on the average, in welding on primed steel.

Statistical comparisons were made between average dust contents in the breathing zone of welders using and not using local exhaust ventilation. The effect of local exhaust ventilation on the dust content was not so good in the gas-shielded arc processes. The best result was found in

a study of the MAG welding of steel in which the local exhaust ventilation had a definite effect, reducing the average dust contents to 65 % of what they were without local exhaust ventilation. In a study of the metal-arc welding of steel, local exhaust ventilation reduced the average dust contents to 42 % of what they were without local exhaust ventilation. It was established that the oxides of nitrogen are markedly reduced in metal-arc welding. Local exhaust ventilation did not have any measurable effect on ozone exposure. A comparison between the field measurements and laboratory results with local exhaust ventilation suggested that, in practice, the exhaust nozzles are not used in the best possible way.

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