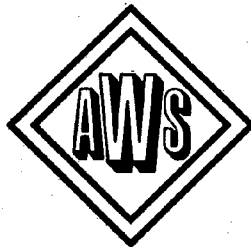


FUMES AND GASES

In the Welding Environment



AMERICAN WELDING SOCIETY

Fumes and Gases in the Welding Environment

*A Research Report on Fumes and Gases
Generated During Welding Operations*

Research performed at Battelle-Columbus Laboratories
under contract with the American Welding Society and
supported by industry contributions

Under the direction of the AWS RESEARCH COMMITTEE ON
SAFETY AND HEALTH

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Preface

The environment presented by welding, cutting, and similar operations is a concern to industry. Management seeks to provide a safe and healthy working environment for welders, and the Occupational Safety and Health Act of 1970 has added the force of law to this desire. Although fumes and gases associated with welding and cutting are the most obvious potential hazards, other factors—radiation, heat, and noise—must also be considered.

Prior research for industry and for the American Welding Society has scarcely scratched the surface of this problem. Some work conducted has raised more questions than it has answered. Typical of these questions are the following:

- (1) Can fumes and gases be characterized on the basis of electrode classification?
- (2) Can simplified procedures be developed to evaluate the hazards presented by airborne contaminants?
- (3) What are typical noise levels associated with welding and cutting operations?
- (4) How can ozone and nitrogen dioxides be detected accurately in the presence of dense fumes?
- (5) Are fume concentrations affected in a predictable manner by the welding variables?
- (6) Can the health and safety of workers be protected without affecting productivity?

Reliable data are clearly needed to demonstrate that welding operations are safe when carried out properly and do not constitute an unusual occupational hazard.

To help industry, AWS proposed a continuing investigation at Battelle Memorial Institute-Columbus Laboratories to study the various environments to which welders are exposed, to quantify them, to demonstrate means to cope with them in a safe manner, and to correlate laboratory and shop generated data.

The processes to be studied were arc welding, oxyfuel gas welding and cutting, brazing, and thermal spraying.

The investigation required funding at a rate of \$150,000 per year for two years. Support was obtained from industry subscriptions, and progress reports were distributed to the sponsoring companies.

This report summarizes work completed to September 1978, except for studies of the noises and radiations generated in arc welding and cutting. A research report on the measurement of welding and cutting noise has been published separately as "Arc Welding and Cutting Noise" (Ref. 1)*. Two reports on radiation have been issued by the U.S. Army Environmental Hygiene Agency in cooperation with the American Welding Society and Battelle-Columbus Laboratories (Refs. 2 and 3) and a brief summary has been published in the "Welding Journal" (Ref. 4).

All measurements shown in the tables and text of this report are given in the system (U.S. customary or S.I.) in which they were made, followed by an approximate S.I. conversion in parentheses if the measurement was in U.S. units. No conversions are considered necessary for scientific measurements made directly in metric units.

*References are grouped together following the appendix.

Supporting Organizations

Airco Welding Products	J. I. Case Company
A. O. Smith Corporation	Lincoln Electric Company
Arcair Company	Miller Electric Company
Arcos Corporation	Motor Vehicle Manufacturers Association
Armco Steel Corporation	National Constructors Association
AWS Detroit Section	National Institute for Occupational Safety and Health (NIOSH)
Babcock and Wilcox Company	Sandvik, Incorporated
Cabot Corporation (Stellite Division)	Steel Plate Fabricators Association, Incorporated
Caterpillar Tractor Company	Stoody Company
Champion Commercial Industries, Incorporated	Sun Shipbuilding and Dry Dock Company
Chemetron Corporation	Teledyne McKay
Combustion Engineering, Incorporated	The Trane Company
Dover Corporation (Bernard Division)	Union Carbide Corporation, Linde Division
Eastman Kodak Company	United States Steel
E. I. Dupont de Nemours	Victor Equipment Company
General Electric Company	WABCO Construction and Mining Group (American Standard, Incorporated)
The Heil Company	Westinghouse Electric Corporation
Hobart Brothers Company	
Huntington Alloys, Incorporated	
International Harvester Company	

Contributing Organizations

Alabama Oxygen Company	Industrial Welding Supplies, Incorporated (Alabama)
AWS Central Texas Section	Iweco, Incorporated
AWS Cleveland Section	Lake Welding Supply Company
AWS Houston Section	Lex Company, Incorporated
AWS Los Angeles Section	McKenzie Repair, Incorporated
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AWS Philadelphia Section	Prest-O-Sales and Service, Incorporated
AWS Pittsburgh Section	Rodgers Welding Supply Company
Bel Welding Supply Company, Incorporated	Suburban Welders Supply, Incorporated
Coastal Welding Supply	United Association

In addition to the supporting and contributing organizations listed above, 119 other organizations contributed amounts up to \$500 each to the program. All contributions are gratefully acknowledged.

Fumes and Gases in the Welding Environment

*A Research Report on Fumes and Gases
Generated During Welding Operations*

Abstract

The environment surrounding many welding processes contains *fumes* (particulate matter) that may be harmful (toxic) or relatively harmless and *gases* that may have pulmonary or non-pulmonary effects. This report summarizes five experimental studies and several literature surveys (conducted by Battelle Memorial Institute-Columbus Laboratories for the American Welding Society) to evaluate the extent to which ventilation may control the exposure of the welder to these fumes and gases and to investigate the nature of the various fumes and gases generated in arc welding, in brazing with silver-based filler metals, in thermal spraying, and in oxyfuel gas cutting.

Comprehensive fume control requires exhaust flow rates adequate to reduce room contamination below critical levels, or cross-draft ventilation (or air-ventilated helmets) to remove fumes from the welder's breathing zone, or sometimes both.

Tables in this report show what fumes and gases are generated by fourteen types of covered electrodes for shielded metal arc welding, seven electrodes for flux cored arc welding, eleven gas metal arc solid electrodes, two BAg-class brazing filler metals, seven spraying and surfacing metals, and three thicknesses of carbon steel plate severed by oxyacetylene and oxymethane cutting under various operating conditions.

These data can be used in part to determine blower capacity and exhaust flow rates needed for ventilation.

Introduction

The American Welding Society has sponsored a two-year program, entitled "Improving the Welding Environment," conducted by Battelle's Columbus Laboratories. This book is a report of that research and consolidates the content of five topical reports on the program.

Overview of Fume Constituents

Fumes are particles formed by electrode (and base metal) constituents that are vaporized and subsequently condensed in the welding area. Because of their small size, fume particles may remain suspended in the aerosol form for long periods. Since the particles have mass and size and are affected by air movement, electrical fields, gravity, diffusional forces, and other external forces, they tend to agglomerate into clumps that gradually settle on the floor and other surfaces. While suspended, however, they are inhaled by all persons in the vicinity.

In addition to fume particles, there are also gases formed that have toxic effects. These include ozone, oxides of nitrogen, and carbon monoxide.

The presence of fumes and gases in the welding environment is a matter of concern to those responsible for the well-being of welding personnel. Some constitute a potential hazard to the health of the welder while others are merely a nuisance. Potential problems can be anticipated by estimating the concentrations of fume and gas

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constituents in the welding area and comparing these data to established exposure standards.

There are three basic ways to protect the welder from the fumes and gases generated in his or her vicinity:

- (1) Isolate the welder from the fumes through the use of respirators and air supplied helmets.
- (2) Remove the fumes from the welder's immediate environment by ventilation and exhaust ducts.
- (3) Reduce the quantity of fumes at the source through changes in the welding process or the conditions of welding.

In the broad view, both the welder and those in the vicinity of the welding area must be protected from these fumes since no one should be exposed to accumulating concentrations of fumes and gases that are hazardous to safety and health. Accordingly, ventilation devices (method 2) are expected to become increasingly relied upon. Method 1 ignores the local environment, although it may be necessary to use it on particular tasks while keeping other personnel out of the contaminated area. Method 3 requires knowledge of the fume generating characteristics of all available processes and procedures and, in the long range, the development of fume-free processes.

The cost of operating fume control devices (method 2) will be an important factor as energy costs rise. Determining the most effective method of controlling fumes and gases generated during various welding processes will require iterative calculations of cost trade-offs that are a function of the concentration and characteristics. The level of control required will have a major effect on the cost, but in many cases more than one of the possible methods of control may need to be used in order to minimize costs.

Survey of Part I, Ventilation Studies

A major objective in studying the various welding processes was to generate data needed to design systems that will control the flow of fumes and gases. In order to meet this objective, it was necessary first to characterize the flow fields associated with fumes and gases generated by these welding processes. Then, theoretical and experimental studies were conducted to obtain the data used to define design curves for the performance of various local ventilation devices. Two series of experimental studies were conducted: local ventilation experiments were performed to define the effect that various ventilation conditions have on the welder's exposure to welding fumes, and local exhaust experiments were conducted to define the effect of various local exhaust devices on the welder's exposure to welding fumes and on the reduction in environmental contamination resulting from the collection of the fumes.

Certain welding processes were studied to provide basic information on the fume generation characteristics of commonly used arc welding electrodes as a function of welding process, electrode classification, and selected

operating variables. This task emphasizes a comprehensive laboratory investigation of arc welding fumes to determine the rate at which they were produced with selected welding conditions in order to relate the fume generation rate to various electrode characteristics. More limited studies were also conducted to detect gases in the welding area, determine fume composition, and characterize fume particles in terms of size, crystalline structure, etc. Such data will be useful to industry in planning industrial hygiene programs and determining ventilation requirements.

The technical literature of the past two decades was reviewed for references to research conducted that sampled fumes and gases in the welding area, determined individual fume and gas constituents, and calculated concentrations of these constituents for comparison with recognized allowable limits. Many of these references were included in the AWS publication, *The Welding Environment* (Ref. 5). These investigations generally had limited objectives because they were undertaken to study the fumes associated with a particular welding application, to evaluate a specific electrode, to assess the performance of a ventilation system, or for some other definite purpose. The usefulness of some of this work is questionable today because supporting data on welding procedures, sampling methods, and analytical techniques are often incomplete or totally lacking. Nonetheless, these studies are important because the results form the basis for much of today's knowledge.

The design of fume control systems was not examined during this study. The American Welding Society has identified 84 welding processes by letter designations for diverse welding applications. It is not practical (from cost and time viewpoints) to study all possible combinations of factors and develop design data specifically for each combination. The approach taken in this study was limited to experimental and theoretical efforts to generate the information needed to design systems that will control the flow of fumes and gases generated during specific welding processes.

The experiments to define the effectiveness of the exhaust devices were conducted using a simulator gas instead of the arc welding fumes and gases. The simulator gas plumes duplicated the thermal and fluid mechanic characteristics of plumes from welding operations and enabled the experiments to be conducted continuously over a long period of time under reproducible conditions. Two subsets of experiments were conducted to ensure that the pertinent thermal and fluid mechanic characteristics of the simulator plume were identical to those of the weld plume. These consisted of tests to characterize the weld plumes for various welding processes and tests to establish the simulator operating conditions required to duplicate the actual welding plumes.

Theoretical analyses were conducted to define the overall room concentration level of welding fumes and gases in terms of the ventilation and weld fume generation rates.

Survey of Part II, Arc Welding Fumes and Gases

The key task in the AWS research program, "Fumes and Gases in the Welding Environment," was an investigation of the fumes and gases associated with conventional arc welding operations. This part of the program underscored the importance of these airborne contaminants and the need to develop a comprehensive understanding of factors governing their occurrence and behavior in and around welding areas. Fumes and gases are produced during all arc welding operations. Their potential effect on the well-being of welding personnel is highly dependent upon their amount and composition. More fumes, for example, are produced when carbon steels are welded with the shielded metal arc process than when austenitic stainless steels are welded in the same manner. On the basis of fume generation rate alone, the carbon steel welding operation appears to be potentially most harmful. Such may not be the case, however, because the fumes associated with the welding of 300-series stainless steels contain nickel and chromium compounds with threshold limit values (TLV's® [Ref. 6]) much lower than that of iron oxide, the principal constituent in the fumes produced during the welding of carbon steels.

In other words, the concentrations of the nickel and chromium compounds associated with the welding of stainless steel may exceed allowable limits even though the fume generation rate is low. In evaluating problems associated with the welding environment, the following must be taken into account:

- (1) Welding process
- (2) Welding consumables
- (3) Welding conditions
- (4) Base metal
- (5) Characteristics of the welding area (size, height, air movement, etc.).

In addition, some knowledge concerning the relative hazards of specific fume and gas constituents is needed.

A limited number of welding processes was selected to represent the family of welding processes because of their common use and their wide range of fume generation rates. The selected processes included shielded metal arc welding (SMAW), flux cored arc welding (FCAW), gas metal arc welding (GMAW), and gas tungsten arc welding (GTAW) operations. Commercially-available electrodes were used in this study at manufacturer-specified arc voltage and current conditions.

A comprehensive matrix of tests was selected and followed to ensure versatility in the application of the results. Relationships were established between fume generation rate and various electrode characteristics (melting rate, metal deposition rate, etc.) to obtain data that could be used effectively by welding engineers, industrial hygienists, ventilation specialists, and others concerned with the health and safety aspects of arc welding. Research was also conducted to investigate the fume

generation characteristics of selected electrodes as a function of various process variables such as current, voltage, and arc length.

During the course of this investigation, limited research on fume particle characterization, fume analysis, and gas detection during welding was included. No determination of the oxidation state of chromium in the fumes was attempted, however. Although fume characterization was an objective of the original program, budget limitations (especially in view of the expense of sophisticated analytical research) precluded a thorough analytical program, even though the need is recognized. A NIOSH criterion document issued in 1975 and the recent indictment of hexavalent chromium by OSHA identify certain compounds of chromium of value +6 as being carcinogenic (cancer-causing). It remains for some future program to determine the oxidation state of chromium in fumes from welding stainless steel. The concentrations of Cr given in this report must be identified as total Cr. Possibly two-thirds of the total Cr may be hexavalent, of which 95 percent may be water-soluble and, therefore, noncarcinogenic; the remaining 5 percent of that two-thirds would be presumed to be insoluble and carcinogenic.

Analytical research coupled with fume and gas studies could improve our ability to reduce the quantity of fumes and gases generated at the source by varying the process conditions. A limited amount of such research was included in this program. The results are sufficiently useful to indicate the value of further study.

Survey of Part III, Brazing Fumes and Gases

Another purpose of the American Welding Society research program was to examine the fumes generated during brazing. The broad objective of this task was to show experimentally the relationship of the fumes given off to the brazing filler metal used.

A literature search on brazing references was conducted to learn the extent and usefulness of the bibliographic data available. Study of this literature revealed the adequacies and deficiencies of the available information.

The experimental research program was developed without benefit or knowledge of any published prior experience by other investigators. Its magnitude and scope were restrained by the availability of funds assignable for brazing fume studies.

The investigation was limited to the BAg-class filler metals which are predominantly silver but contain copper, zinc, and cadmium. It was directed toward determining the fume generation characteristics of two filler metals having widely different cadmium contents: Ag-15Cu-16Zn-24Cd (BAg-1) and Ag-22Cu-20Zn-7Cd-1Sn. These filler metals have similar melting characteristics and are used extensively in industry for torch brazing.

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The research plan was designed to minimize the variables caused by changes in flame shape, character, and position that occur during torch brazing. Therefore, procedures similar to those used during welding fume studies were suggested. Total fume samples collected in the AWS-Battelle welding fume collection chamber were used to find the influence of brazing variables on the fume generation rates and quantities. The fume samples were analyzed by atomic absorption methods to determine how brazing variables affect fume compositions. Unfortunately, it became increasingly evident, as the program progressed, that the procedures chosen did not provide the precision required for accurate measurement of brazing filler metal fumes.

In the brazing studies, the small quantities of fume produced and its apparent extremely small particle size presented problems in filter choice, chamber design, sample weight-analysis balance, and sampling environments. To minimize these problems, a fume collection chamber having the least volume possible, containing an atmosphere that is inert or readily controllable, and which can be made part of a closed system is advised. Filters or fume collection media must be capable of collecting very fine particles ($<1\mu\text{m}$) and should be small enough to avoid masking of actual fume weights by large blank filter weights. Continuous sampling through an atomic absorption type of analytical system appears worthy of consideration instead of filter sampling systems.

Attention to the details of actual filler metal melting and fluxing practices is also required. Melt sizes, quantities of flux used, exposed melt surface areas, and heating and cooling rates need attention. Melt size, particularly with respect to exposed areas, may alter fume generation rates because of flux cover variation. Crucibles should be a metal that is wet by the filler metal to avoid flux collection around the melt. This implies combined weight determination that includes the crucible. Weighing exercises should include checks of flux losses in addition to filler metal losses. Ideally, all tests should begin in a cool chamber and heating furnace to minimize differences in heating and cooling rates. The closed chamber already suggested should eliminate any influence of humidity in the test area.

Analytical procedures for fume analysis should be validated for the tests being conducted. An early phase of any analytical work should be directed toward determining the chemical character of the fume (metal, oxides, soluble, insoluble, etc.). Early analytical work should include complete analyses. Subsequent analyses requirements may be relaxed when the whole story is known.

Survey of Part IV, Thermal Spraying Fumes and Gases

As another part of the program, Battelle investigated the fumes and gases produced by thermal spraying opera-

tions and the manner in which the nature of the spraying process and the type of metal being sprayed affect their characteristics and the rate at which they are generated.

Thermal spraying processes are used by industry to repair or build up worn parts and to produce coatings that resist oxidation, corrosion, wear, erosion, abrasion, or impact. In practice, finely divided metallic or non-metallic particles in the molten or semimolten state are sprayed on a suitable substrate to produce a dense, adherent deposit or coating. Thermal spraying encompasses three distinct processes that are differentiated mainly by the manner in which the particles are produced and heated: (a) gas combustion spraying, (b) electric arc spraying, and (c) plasma arc spraying. These processes are characterized by relatively low deposition efficiencies, moderate-to-high fume levels, and moderate-to-high noise levels.

In the area of thermal spraying, research efforts were directed toward a study of the fumes associated with the most commonly used processes: gas combustion spraying and electric arc spraying. In each instance, the metal being sprayed was in the form of wire. The metals included in the investigation were mutually agreed upon by the AWS Research Committee and Battelle.

Fume collection studies for thermal spraying were limited to those conducted at recommended spraying conditions. No work was done on detonation spraying, which is also included among the thermal spraying processes; it is a proprietary process and little is known about its characteristics.

Survey of Part V, Fumes and Gases from Oxygen Cutting

Finally, the fumes associated with oxygen cutting operations were investigated. These fumes occur as the result of the chemical reaction between iron and high purity oxygen and the process through which molten oxides and unoxidized metal are removed from the kerf by the cutting jet. Fume quantities are dependent upon the cutting process variables, base metal thickness, base metal composition, surface contaminants, and other factors. Fume compositions are governed by the composition of the metals being cut and any coating that may be on the surface of the metal.

To study the fumes associated with oxygen cutting operations, total fume samples were collected to accumulate data for use in determining fume generation rates and quantities relating fume generation rates to important process variables.

Research was directed toward a study of the fumes produced during oxyacetylene and oxynatural gas (methane) cutting of carbon steel plate in thicknesses of 1/2, 1, and 2 in. (12.7, 25.4, and 50.8 mm) at conditions recommended by the cutting torch manufacturer. Also included were studies of the effect of selected process variables on fume formation rates.

Although the potential problems presented by oxygen cutting fumes have long been noted, there are few references to this subject in the technical literature on safety and health. There is little information on the rate at which fumes are produced during oxygen cutting operations. The data obtained in the course of this investigation only partially fill this void.

Additional research would be needed to more fully characterize cutting fumes. Such research should include studies to determine the distribution of fume particles by size and examination of fume deposits with the scanning electron microscope.

In this study, concentrations of major elements could not be determined accurately because of difficulty in interpreting the spectrographic record and because of the lack of suitable standards. As a result, concentrations of such elements are expressed in a range of weight percentages instead of discrete weight percentages. If more accurate compositional data are needed, optical emission spectroscopy should be supplemented by other analytical techniques such as atomic absorption analyses or wet chemistry methods.

No study of arc cutting was made, although that was an original aim of the research program. Suitable equipment was not available at Battelle, and alternative loca-

tions at which tests could run could not be identified by the Committee.

Organization of This Report

Each of the five sections of the body of this report is organized in the following format:

- Introduction
- Scope
- Limitations
- Background (Part II only)
- Program
- Equipment, Materials, Procedure
- Description of Work (Organized under Section A, Section B, etc.)
- Discussion
- Summary

Appendixes have been included at the end of the report which present the tabular data for Parts II, III, IV, and V in sequence.

The references cited in the Preface, Introduction, and Parts I, II, III, and V have been grouped together following the appendixes.

An index completes this compilation.