CDC Workplace Safety and Health

NIOSH HEALTH HAZARD EVALUATION REPORT

HETA 2006-0156-3031
Harley-Davidson Motor Company
York, Pennsylvania

December 2006

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DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

NIOSH

Preface

The Respiratory Disease Hazard Evaluations and Technical Assistance Program (RDHETAP) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSH) Act of 1970, 29 U.S.C. 669(a)(6), or Section 501(a)(11) of the Federal Mine Safety and Health Act of 1977, 30 U.S.C. 951(a)(11), which authorizes the Secretary of Health and Human Services, following a written request from any employers or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

RDHETAP also provides, upon request, technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

Acknowledgments and Availability of Report

This report was prepared by Richard Kanwal, MD, MPH, of the RDHETAP, Division of Respiratory Disease Studies (DRDS). Field assistance was provided by Stephen Martin (DRDS) and Joseph Eshelman (occupational medicine resident physician at West Virginia University on rotation at DRDS). Desktop publishing was performed by Amber Harton.

Copies of this report have been sent to employee and management representatives at the Harley-Davidson Motor Company in York, PA, and the OSHA Regional Office. This report is not copyrighted and may be freely reproduced. The report may be viewed and printed from the following internet address: http://www.cdc.gov/niosh/hhe. Copies may be purchased from the National Technical Information Service (NTIS) at 5825 Port Royal Road, Springfield, Virginia 22161.

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Highlights of the NIOSH Health Hazard Evaluation of Harley-Davidson Motor Company
York, Pennsylvania

Workers requested a NIOSH evaluation due to concerns about the adequacy of Building 4's ventilation systems for controlling welding-related exposures. Workers were also concerned about recent fires that had occurred in a fume collection unit.

What NIOSH Did

- Met with management and union representatives, including several staff with health and safety responsibilities.
- Reviewed air sampling and ventilation system assessment data provided by the company.
- Observed welding operations in Building 4.

What NIOSH Found

- Some company air sampling results for iron oxide exceeded NIOSH recommended limits; results for all metals were below OSHA regulatory limits.
- One worker reported "cramping up" in his/her hands and feet and a decreased sense of smell. No other workers interviewed reported symptoms or health problems to NIOSH staff.
- Some welding fume accumulated in the worker's breathing zone while the rest of the visible welding fume was captured by the local exhaust ventilation hood.
- The ventilation assessment performed by an outside contractor for the company identified repairs and improvements that should be implemented.

What Managers Can Do

- Implement planned interventions to improve ventilation and to decrease the likelihood of future fires in fume collection units.
- Educate employees on welding-related health risks before they begin work as welders.
- Continue yearly monitoring of welding-related exposures; reduce exposures to the lowest concentrations technically feasible.

What Employees Can Do

- Be aware of and utilize ventilation and work practices to minimize exposure to welding fume.
- Inform your supervisor if the ventilation to your area does not appear to adequately prevent exposure to welding fume.

What To Do For More Information:
We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513-841-4252 and ask for
HETA Report # 2006-0156-3031

Health Hazard Evaluation Report 2006-0156-3031
Harley-Davidson Motor Company, York, Pennsylvania

December 2006

Richard Kanwal, MD, MPH

SUMMARY

In February 2006, workers at the Harley-Davidson Motor Company plant in York, Pennsylvania, requested a NIOSH health hazard evaluation (HHE) regarding welding-related exposures in Building 4 (frame shop). The workers were concerned that the ventilation system was not adequately controlling exposures to welding fume. They reported that recent company air sampling indicated that their exposures were too high. They were not aware of any workers with respiratory problems; one of two workers interviewed reported a history of "cramping up" in his/her hands and feet and a decreased sense of smell. The workers also reported that part of the fume collection system had caught on fire in January and February 2006, requiring part of the ventilation system to be shut off for maintenance and repair. Workers reported that during one of these events, several welders were allowed to keep welding for several minutes after the local exhaust ventilation to their work area had been shut off. A NIOSH team visited the plant on May 3, 2006, to perform a walkthrough of Building 4 and to obtain additional information on exposures, controls, and worker health concerns. The company reported that it follows the 2006 American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV®) for manganese (Mn) of 0.2 mg/m^3 as its exposure limit. Of the 17 Mn exposure measurements made by the company in January and February 2006, three exceeded the TLV®; the highest Mn exposure was 0.32 mg/m^3. The company reported that it follows the ACGIH TLV® of 5 mg/m^3 for welding fume. (As of 2004, ACGIH no longer has a TLV® for welding fume.) Of the 15 welding fume exposure measurements made by the company in January and February 2006 (99% iron oxide according to management), 12 were below 5 mg/m^3. The results for the other three measurements were 5.1 mg/m^3, 5.8 mg/m^3, and 7.9 mg/m^3. The OSHA PEL for iron oxide is 10 mg/m^3 TWA. The ACGIH TLV® and NIOSH REL for iron oxide are 5 mg/m^3 TWA. Currently OSHA does not have a specific PEL for welding fume. NIOSH recommends that exposures to welding fume contaminants be reduced to the lowest concentrations technically feasible. During the site visit, no workers requested to speak privately with NIOSH staff regarding health or exposure concerns. The company reported that the most likely cause of the recent fires in the one of the fume collection units was that burning debris entered through a local exhaust duct, or a welding spark ignited particulate buildup in the ducts, ultimately leading to a fire in a filter in one of the modules of one fume collection unit. After the February 2006 fire, the exhaust ventilation ducts and hoods were cleaned out. An outside consultant hired by the company to perform a survey of the fume collection units and ventilation systems recommended several repairs and improvements. One of the consultant's recommendations was to install pressure gauges for each filter module in the fume collection units in order to detect excessive particulate accumulation on filters that could increase the likelihood of fire. The consultant also identified several local exhaust ventilation locations where air flow was insufficient. The company reported that it planned to rebalance the ventilation systems, install an additional fume collection unit and additional local exhaust ventilation hoods, and install pressure gauges for each fume collection unit filter module by the end of 2006. Management should repeat air sampling for welding-related exposures after all ventilation interventions have been completed. Work areas with exposures that are above (or only slightly below) applicable exposure limits should be reassessed to identify possible ways to further decrease exposures.

Because of the potential for decreased lung function, lung cancer, and neurologic disease (from chronic manganese exposure), company management should aim to reduce welding-related exposures to the lowest concentrations technically feasible. While only one worker in Building 4 reported any symptoms, decreased lung function and neurologic disease can have a gradual onset and may not be recognized early on. These diseases are often not reversible or treatable. Therefore, it is important to limit exposures that could lead to these conditions. It is also important that welders understand the potential health risks of welding-related exposures and how they can decrease their exposure through optimal use of controls and work practices.

Keywords: NAICS Code 336991 [Motorcycle, Bicycle & Parts Manufacturing], exhaust systems, welding, fumes

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INTRODUCTION

In February 2006, workers at the Harley-Davidson Motor Company plant in York, Pennsylvania, requested a NIOSH health hazard evaluation regarding welding-related exposures in Building 4 (frame shop). The workers were concerned that the ventilation system was not adequately controlling exposures to welding fume. They reported that recent company air sampling indicated that their exposures were too high. They were not aware of any workers with respiratory problems; one of two workers interviewed reported a history of "cramping up" in his/her hands and feet and a decreased sense of smell. The workers also reported that part of the fume collection system had caught on fire in January and February 2006, requiring part of the ventilation system to be shut off for maintenance and repair. Workers reported that during one of these events, several welders were allowed to keep welding for several minutes after the local exhaust ventilation to their work area had been shut off. We contacted the safety and health manager at the plant to request company air sampling data as well as additional information on the workforce, ventilation, and the nature of the welding activities in Building 4. He provided a written summary of this information and also provided material safety data sheets (MSDS) for the metal and electrode wire utilized in the welding process. He noted that the company was in the process of having Building 4's local exhaust ventilation hoods and ducts cleaned and had arranged for an outside consultant to perform a survey of the ventilation system in preparation for implementation of additional local exhaust and general dilution ventilation. A NIOSH team visited the plant on May 3, 2006 to perform a walkthrough of Building 4 and to obtain additional information on exposures, controls, and worker health concerns.

BACKGROUND

The Harley-Davidson plant in York, Pennsylvania is a large motorcycle manufacturing facility consisting of multiple buildings. Metal frames for Touring Line motorcycles are assembled in Building 4. This building is approximately 125 feet wide and 600 feet long. The roof height varies from 30 to 50 feet. The floor is poured concrete and the roof and sides are metal clad. The inside of the building consists primarily of one large open space. There are several roof-top exhaust fans. Motorcycle frames are assembled utilizing gas metal arc welding (GMAW; also known as metal inert gas, or MIG, welding) on mild steel tubing and subparts. The carbon steel electrode wire used contains less than 2% manganese and less than 0.5% copper by weight according to information in the MSDS.

Building 4 has 114 welders over three work shifts. Thirty-one workers are assigned to robotic weld cells and 83 are assigned to manual weld lines. There are 11 robotic weld cells: enclosed booths with local exhaust ventilation hoods located immediately above the booth. There are three manual weld lines: a nine-station line and two five-station lines. Each manual weld station is isolated with thick plastic sheeting. Most manual weld stations have local exhaust ventilation hoods, and all stations have adjustable chilled air outlets and adjustable fans. Different welds are performed at different manual weld stations and workers rotate through the different stations over the course of the week. Some manual welding (approximately 5% in a month's time) is performed via a process called "the manipulators", where all frame subparts are welded by one worker.

Welding fume exhausted by the local exhaust ventilation hoods is filtered by two Torit® fume collection units (located outside the building). Filtered air is returned to the building. The fume collection units consist of several rows of tube-shaped compartments; each compartment contains a filter. A sensor monitors the difference in air pressure across the filters as an indicator of particulate load. The units perform mechanical self-cleaning of the filters when the pressure difference across the filters indicates a high particulate load.

Company management reported that it performs yearly exposure monitoring for welding fume and metals. Personal breathing zone samples are obtained under the welders' hoods. Sampling results are averaged over 420 minutes. The company reported that the average air concentration for manganese (Mn) from May 2004 through February 2006 (34 air samples) in Building 4 was 0.140 milligrams per cubic meter of air (mg/m^3). The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for Mn is 5.0 mg/m^3 as a ceiling limit (i.e., not to be exceeded at any time). The NIOSH recommended exposure limit (REL) for Mn is 1.0 mg/m^3 as an 8- to 10-hour time-weighted average (TWA) and 3.0 mg/m^3 as a short-term exposure limit (STEL). The company reported that it follows the 2006 American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV®) for Mn of 0.2 mg/m^3 TWA as its exposure limit. Of the 17 Mn exposure measurements made by the company in January and February 2006, three exceeded the TLV; the highest Mn exposure was 0.32 mg/m^3.

Company management reported that the average air concentration for welding fume from May 2004 through February 2006 in Building 4 was 3.64 mg/m^3 (49 air samples; 99% iron oxide according to management). Company management reported that it follows the ACGIH TLV® of 5 mg/m^3 for welding fume. (As of 2004, ACGIH no longer has a TLV® for welding fume.) The OSHA PEL for iron oxide is 10 mg/m^3 TWA. The ACGIH TLV® and NIOSH REL for iron oxide are 5 mg/m^3 TWA. Currently OSHA does not have a specific PEL for welding fume. NIOSH recommends that exposures to welding fume contaminants be reduced to the lowest concentrations technically feasible. Of the 15 welding fume exposure measurements made by the company in January and February 2006, 12 were below 5 mg/m^3. The results for the other three were 5.1 mg/m^3, 5.8 mg/m^3, and 7.9 mg/m^3.

Company management also provided air sampling results for copper, "chrome", carbon monoxide, and several acids. All reported measurements were below existing OSHA PELs and NIOSH RELs. The highest reported copper exposure was 0.07 mg/m^3 TWA (OSHA PEL and NIOSH REL for copper fume is 0.1 mg/m^3). All "chrome" exposures were less than 0.001 mg/m^3 (OSHA PEL is 1 mg/m^3 and NIOSH REL is 0.5 mg/m^3 for chromium metal; NIOSH REL for hexavalent chromium is 0.001 mg/m^3). Results of carbon monoxide measurements in 2001 and 2004 were 5 ppm (parts per million). Results of grab samples in 2006 ranged from 2 to 7 ppm (OSHA PEL 50 ppm TWA for carbon monoxide; NIOSH REL 35 ppm TWA and 200 ppm as ceiling limit).

Company management reported that it provides exposure measurement results to the employees monitored and to the employees' union stewards. If exposures above an ACGIH TLV or OSHA PEL are found, this information is also provided to management and union safety representatives and to the company engineer in charge of the particular work area. Management reported that it uses "hazard replacement and engineering controls, whenever feasible, for long term controls", and uses "administrative controls as a temporary measure until engineering controls can be designed and implemented." It also reported that single use disposable respirators are available to employees at no cost for voluntary use.

METHODS

The NIOSH site visit team on May 3, 2006, consisted of a physician and ventilation engineer from the Division of Respiratory Disease Studies (DRDS) and an occupational medicine resident physician from West Virginia University in Morgantown, West Virginia (on rotation at DRDS). Our goals for the site visit were to:

1. obtain additional information on the ventilation systems in building 4 and on the likely causes of the recent fires in one of the fume collection units;
2. provide an opportunity for Building 4 welders to speak confidentially with a NIOSH team member, if they wished, regarding any concerns they had about conditions in their work area;
3. observe welding processes and the effectiveness of existing local exhaust ventilation in capturing welding fume.

We conducted the following activities during the site visit:

1. held opening and closing meetings with management and union representatives (International Association of Machinists and Aerospace Workers, Tyson Lodge, No. 175), including several health and safety representatives;
2. conducted a walkthrough of Building 4, including observing 4 workers while they performed manual welding.

RESULTS

During the site visit, management reported that, while the cause of the recent fires in the one of the fume collection units was still unclear, the most likely cause was that burning debris had entered through a local exhaust hood, or a welding spark had ignited particulate buildup in the ducts, ultimately leading to a fire in a filter in one of the chambers of a fume collection unit. The unit is able to detect when a fire has occurred and uses carbon dioxide to rapidly extinguish the fire and shut off the system. On February 22, 2006, most welders were told to stop welding when a fire in one fume collection unit led to the shut down of the exhaust ventilation in their manual weld stations. Several welders were allowed to keep welding for approximately 45 minutes after the local exhaust ventilation was shut off because management mistakenly thought that the local exhaust ventilation to their stations was connected to the other fume collection unit that was still operational. Company Management reported that the exhaust ventilation ducts and hoods had not received any preventive maintenance or cleaning in the previous three years because the ventilation systems appeared to be functioning well. After the fire in February 2006, the exhaust ventilation ducts and hoods were cleaned out. Company management also conducted an evaluation of the fume collection unit where the fire occurred and identified the possibility that inadequate sensing of the pressure drop across the filters in the unit might allow some filters to accumulate excessive particulate, increasing the potential for the particulate on the filter to catch fire.

Company management reported that workers receive yearly training on the potential hazards in their work area and how to access MSDSs. New employees, and workers reassigned to a new work area, review a safety checklist. New welders in Building 4 are given a 5-day orientation. Among the topics covered during the orientation are weld parameters and personal protective equipment (PPE). Workers are given a "weld test", and can attend a 1-week welding class (on their own time). Workers do not receive instruction on the potential risk of developing lung disease from inhalation of welding fume and other welding-related contaminants. The company nurse reported that she meets with workers to discuss any exposure measurements that exceed OSHA PELs or other limits that the company uses. She was not aware that any Building 4 welders had any health concerns or illnesses that might be related to exposures in the plant.

Building 4 walkthrough: We noted substantial air inflow upon opening the door to enter the building. Company management pointed out a "build station" where installation of a local exhaust hood was planned. The exhaust ventilation hoods over the robotic weld cells appeared to capture the entire volume of visible welding fume. A local exhaust hood at a manual weld station on the nine-man line did not appear to be as effective at capturing welding fume as the exhaust hoods at manual weld stations on one of the five-man lines. At a manipulator station and a manual welding station, additional local exhaust ventilation ducts that could be positioned close to the weld site were not being utilized. At all four manual weld stations where we observed workers performing manual welding, some welding fume was seen to accumulate in the worker's breathing zone while the rest of the visible welding fume was captured by the local exhaust ventilation hood. No workers requested to speak privately with NIOSH staff regarding health or exposure concerns.

Review of consultant reports: Company management provided for our review copies of two reports prepared by Dentech Incorporated (Brownstone, Pennsylvania). One report, dated April 14, 2006, summarized findings and recommendations resulting from an evaluation of the Torit® fume collector which had caught fire. Dentech recommended replacement of several gaskets, doors, and door handles on the unit, and installation of a control panel that would have a separate differential pressure gauge to monitor the pressure drop at each filter module. The other report contained information from a ventilation survey conducted in April 2006 where air flow was measured at each local exhaust hood for the robotic weld cells and manual-weld stations. The ventilation survey identified "seven areas with insufficient air flow per the recommended practices outlined in the Industrial Ventilation Manual." The seven areas included: one manual weld-station on the nine-station line and one manual weld station on one of the five-station lines; two manipulator stations; and three robotic weld cells.

Management reported that its engineering staff had reviewed the Dentech reports and that they planned to complete the following interventions by the end of 2006:

- rebalance the airflow system, including adding dampers and re-sizing some duct work;
- add exhaust hoods at five build fixture locations, including push fans;
- add an additional Torit® fume collection unit to the network;
- and install differential pressure gauges in each module of the fume collection units to better control pulse cleaning.

Management reported that it had revised preventive maintenance protocols. Prior to the fires in one of the fume collection units, the maintenance protocol called for filters to be replaced if the reading on the pressure gauge exceeded "5.5" during monthly checks. After the fires, the protocol was revised so that filters are changed if the pressure exceeds "1.5", and filters are changed every six months regardless of the pressure reading. Also, all internal surfaces of ventilation ducts and fume hoods are to be cleaned semi-annually.

DISCUSSION AND CONCLUSIONS

Both maintenance and design factors may have played a role in the fires that occurred in one of the fume collection units. The duct cleaning that was performed earlier this year and the interventions that management plans for the fume collection unit (i.e., installation of differential pressure gauges for each filter module), along with enhanced preventive maintenance, may prevent future fires.

It is important to control welding-related exposures in order to minimize the potential for adverse health effects. The potential for disease related to welding-related exposures depends on the type of welding being performed, the characteristics of the metal being welded on and of any coatings present on the metal, the makeup of any consumable electrode in use, and the intensity and duration of the exposures. Certain welding situations are well-recognized for their potential to cause acute respiratory problems (e.g. inadequately-controlled exposures while welding on metals such as zinc can cause metal fume fever, a flu-like illness).[1,2] Chronic respiratory problems have also been associated with welding.[1,2] A study of arc welders documented higher rates of chronic bronchitis symptoms and decreased lung function related to years of welding.[3] Decreased lung function and increased rates of chronic bronchitis symptoms have been found in welders exposed to higher fume concentrations due to work in confined, poorly ventilated spaces (e.g., shipyard welders).[4] Studies have also noted cross-shift declines in lung function in arc welders. In a recent study, this effect was related more to welding on stainless steel as compared to mild steel, and to manual metal arc welding as compared to MIG welding.[5] Some studies have suggested that welding-related exposures may cause asthma.[6,7] Most studies are limited by a lack of information on the types, durations, and intensities of workers' exposures.[1,2]

Welding-related exposures can increase the risk for lung cancer. The review of the relevant scientific literature conducted by NIOSH for its

1988 criteria document for welding indicated that "…collectively these studies demonstrate an elevated risk of *lung cancer* among welders that is not completely accounted for by smoking or asbestos exposure, and that appears to increase with the latent period from onset of first exposure and duration of employment."[1] Some subsequent studies have also demonstrated an elevated risk for lung cancer in welders; two studies estimated an increased risk of approximately 35%.[2]

Excessive acute exposure to manganese (Mn) can cause metal fume fever.[8] Chronic inhalation exposure to Mn from welding has been associated with chronic pulmonary disease and decreased male fertility.[9] Chronic Mn exposure can also cause severe neurologic disease. Early non-specific symptoms due to Mn exposure include apathy, weakness, loss of appetite, headaches, increased sleep, spasms, joint pain, and irritability. Progression of this disease can include difficulty speaking and walking, and excess salivation. Eventually a Parkinson-like syndrome can develop. Recognition of the early symptoms of Mn toxicity in workers is important because recovery from illness can be slow and incomplete.[8] The results of studies that have assessed neurologic, respiratory, and male fertility outcomes in relation to Mn exposure history suggest that adverse effects can occur with chronic exposures as low as 1 mg/m^3 TWA. ACGIH concluded that the lowest Mn exposure at which early adverse effects on the neurologic or respiratory systems may occur is still unknown.[9]

NIOSH does not have a REL for welding fume as "…the composition of welding emissions (chemical and physical agents) varies for different welding processes and because the various components of a welding emission may interact to produce adverse health effects, including cancer. Thus, even compliance with specific chemical or physical exposure limits may not ensure complete protection against an adverse health effect."[1] NIOSH recommends that "…exposures to all chemical and physical agents associated with welding should be reduced to the lowest concentrations technically feasible using current state-of-the-art engineering controls and good work practices. Individual exposure limits for chemical or physical agents are to be considered upper boundaries of exposure."[1]

Exposure limits for welding-related particulate are based on the amount of particulate in the air (mass) without regard to particle size distribution. Studies of the effects of air pollution on respiratory health have shown consistent relationships between the amount of fine particulate in the air (i.e., particles with an aerodynamic diameter less than 2.5 micrometers) and deaths and hospitalizations due to respiratory disease.[10] Ultrafine particles (aerodynamic diameter less than 0.1 micrometers) may also be an important factor in respiratory disease development or exacerbation.[11-14] Both fine and ultrafine particles can be present in high number concentration and yet contribute little to measured particulate mass. Research on the composition of welding fume has shown that it is largely composed of fine and ultrafine particles.[15-17]

Because of the potential for decreased lung function, lung cancer, and neurologic disease (from chronic manganese exposure), company management should aim to reduce welding-related exposures to the lowest concentrations technically feasible. Prior to our site visit, one of two Building 4 workers interviewed reported symptoms he/she felt might be related to welding-related exposures. While no workers requested to speak with NIOSH staff regarding health- or exposure-related concerns during our site visit, decreased lung function and neurologic disease can have a gradual onset and may not be recognized early on. These diseases are often not reversible or treatable. Therefore, it is important to limit exposures that could lead to these conditions. It is also important that welders understand the potential health risks of welding-related exposures and how they can decrease their exposure through optimal use of controls and work practices.

RECOMMENDATIONS

1. After completion of planned improvements to ventilation in Building

4, management should repeat air sampling for welding-related exposures. Work areas with exposures that are above (or only slightly below) applicable exposure limits should be reassessed to identify possible ways to further decrease exposures. This may require the implementation of additional general dilution and local exhaust ventilation (as well as facilitating and requiring its use), and identifying work practices that may be contributing to increased exposures.

2. Management should include training on the potential health hazards of welding-related exposures (including chronic respiratory disease, lung cancer, and neurologic effects from chronic Mn exposure) as part of the training that employees receive prior to starting work as welders. Management should ensure that new welders understand how to use existing controls optimally and how to apply proper work practices to minimize exposures.

REFERENCES

1. NIOSH [1988]. Criteria for a recommended standard: Welding, brazing, and thermal cutting. Division of Standards Development and Technology Transfer, National Institute for Occupational Safety and Health, Department of Health and Human Services, DHHS (NIOSH) Publication Number 1988-110.

2. Antonini JM, Lewis AB, Roberts JR, Whaley DA [2003]. Pulmonary effects of welding fumes: Review of worker and experimental animal studies. Am J Ind Med 43:350-360.

3. Meo SA, Abdul Azeem M, Subhan M [2003]. Lung function in Pakistani welding workers. J Occup Environ Med 45:1068-1073.

4. Bradshaw LM, Fishwick D, Slater T, Pearce N [1998]. Chronic bronchitis, work related respiratory symptoms, and pulmonary function in welders in New Zealand. Occup Environ Med 55:150-154.

5. Sobaszek A, Boulenguez C, Frimat P, Robin H, et al. [2000]. Acute respiratory effects of exposure to stainless steel and mild steel welding fumes. J Occup Environ Med 42:923-931.

6. El-Zein M, Malo J-L, Infante-Rivard C, Gautrin D [2003]. Incidence of probable occupational asthma and changes in airway caliber and responsiveness in apprentice welders. Eur Respir J 22:513-518.

7. Beach JR, Dennis JH, Avery AJ, Bromly CL, et al. [1996]. An epidemiologic investigation of asthma in welders. Am J Respir Crit Care Med 154:1394-1400.

8. Madden EF [1998]. Metal compounds and rare earths. In Rom WN, ed. Environmental and occupational medicine, 3rd ed. Philadelphia, PA: Lippincott-Raven. Pp 1079-1080.

9. ACGIH [2001]. Manganese and inorganic compounds. In: Documentation of the threshold limit values and biological exposure indices. 7th ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

10. Englert N [2004]. Fine particles and human health – A review of epidemiological studies. Toxicol Lett 149:235-242.

11. von Klot S, Wolke G, Tuch T, et al. [2002]. Increased asthma medication use in association with ambient fine and ultrafine particles. Eur Respir J 20:691-702.

12. Peters A, Wichmann HE, Tuch T, et al. [1997]. Respiratory effects are associated with the number of ultrafine particles. Am J Respir Crit Care Med 155:1376-1383.

13. Churg A, Brauer M, Avila-Casado M, et al. [2003]. Chronic exposure to high levels of particulate air pollution and small airway remodeling. Environ Health Perspect 111:714-718.

14. Oberdorster G [2000]. Pulmonary effects of inhaled ultrafine particles. Int Arch Occup Environ Health 74:1-8.

15. Zimmer AT, Biswas P [2000]. Characterization of the aerosols resulting from arc welding processes. Aerosol Science 32:993-1008.

16. Jenkins NT, Pierce W, Eagar TW [2005]. Particle size distribution of gas metal and flux cored arc welding fumes. Welding J, 84:156s-163-s.

17. Antonini JM, Afshari AA, Stone S, et al. [2006]. Design, construction, and characterization of a novel robotic welding fume generator and inhalation exposure system for laboratory animals. JOEH 3:194-203.

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