

Health concerns in welding industry

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Abstract: Welding is an important process used in the iron based industries. About two percent of the working population is engaged in some type of welding. The procedure of welding is simple but its health implications are complex. Welding generates enormous amounts of gases and metal fumes. Depending on the substrate and welding type, the composition of resultant gases and fumes changes. Therefore, welders are exposed to a number of complex mixtures of compounds which pose a serious threat to their health. Various studies have shown the effect of welding process on the health of the workers. These studies include the analysis of blood and urine for different parameters like micronucleus test, comet assay, trace metal analysis (Pb, Cr, Cu, Fe, Ni, Mn etc.), chromosomal aberrations and sister chromatid exchanges. These studies give evidences about the serious occupational risk posed to the welders which should be minimized using personal protection equipments.

Keywords: Welders, iron industry, micronucleus test, comet assay, trace metal analysis.

Introduction

Welding is one of the key components of numerous manufacturing industries, which pose potential physical and chemical health hazards. Welders are exposed to a number of genotoxic metals, gases, fumes and radiations. Welding fumes consist of a wide range of complex metal oxide particles which can be deposited in all regions of the respiratory tract. The welding aerosol is not homogeneous and is generated mostly from the electrode wire. Welding procedures may result in the production of various gases (metal oxides, CO₂, CO, O₃, NO₂, hydrocarbons) and welding fumes. According to OSHA¹, the welding fume may contain manganese (Mn), beryllium (Be), cadmium (Cd), chromium (Cr), vanadium (V), antimony (Sb), zinc (Zn), nickel (Ni), molybdenum (Mo), mercury (Hg), lead (Pb), iron (Fe) and cobalt (Co). The chemical composition of the welding fumes depends upon various factors like type of welding, metal coating, material of the electrode and type of metal being weld. Welding fume pulmonary effects have been associated with bronchitis, metal fume fever, cancer and functional changes in the lung². Welders are exposed to a variety of metal fumes, including manganese that may elevate the risk for neurological diseases³. Biological monitoring of occupational exposure to toxic compounds enables an early detection of adverse health effects⁴. This paper emphasizes on the health aspects of welders which will help to create awareness about the importance of improved working methods and safe industrial environments.

Numbers of different epidemiological studies have proved the relationship between welding and serious health disorders namely malignancies. Occupational exposure to welding fumes has been associated with several diseases including lung cancer⁵. Metal workers were found to have a significantly increased risk of death from lung cancer (proportional mortality ratios PMR = 134)⁶. Chronic exposure to welding light without adequate precaution may cause ocular disorders⁷. The welding fumes are ranked, according to the classification of IARC (International Agency for Research on Cancer), into the group of 2B⁸. The oxidative status of cells is influenced by welding fumes. So, calculating an oxidative stress index may be useful in predicting disease outcomes⁹.

Chromium (Cr) and nickel (Ni) are widely used industrial elements. Welders in India are inclined to possible occupational Cr and Ni exposure. The carcinogenic potential of metals is a major issue in defining human health risk from exposure¹⁰. Hexavalent chromium is an established carcinogenic agent, which is not directly reactive with DNA. Its genotoxicity involves a reduction step, producing reactive oxygen species and radicals. It also produces lower valence forms which form stable complexes with intracellular macromolecules. The trivalent form of chromium may directly react with the genetic material and has also been shown to generate oxidative damage in vitro¹¹. Therefore, an understanding of possible adverse health effects of exposure to welding fumes is essential to risk assessment and the development of prevention strategies¹².

Many researchers have studied the health effects on welders using different models. Workers have been tested for blood, urine and effects of light and noise. Borska *et al.*⁴ found statistically significant reduction in the number of phagocytosis capable cells in the group of welders as compared to the control group.



Blood and Urine metal studies

Lead levels

Study of blood lead levels in welders proves to be of high significance. Blood lead levels are found to be in correlation with many health hazards. Li *et al.*¹³ studied the welders from vehicle manufacturing unit. Control subjects were chosen from a nearby food factory. Blood lead concentrations in welders were found to increase by 2.5-folds but serum zinc levels decreased 1.2-fold. Wang *et al.*¹⁴ explored the relationship between metals exposure and nervous impairment in welders. It was a comparative study of 82 welders and 51 operators for blood Pb which was found to be 117.31 $\mu\text{g/L}$ (0.5 - 327.6) and was significantly different from operators. Cadmium was also found in the range of 0.2-12.5 $\mu\text{g/L}$ (Mean: 3.54 $\mu\text{g/L}$).

Chromium, cadmium and nickel levels

External and internal chromate exposure of 103 stainless steel welders who were using manual metal arc welding (MMA), metal inert gas welding (MIG) and both methods, were measured by ambient and biological monitoring by Angerer *et al.*¹⁵. Chromium levels in plasma and urine in the order of 10 and 40 $\mu\text{g/L}$ corresponded to an external exposure of 100 μg chromium trioxide/ m^3 . Higher Cd concentrations in blood and urine of welders were also detected by Botta *et al.*¹⁶. DNA-protein cross-links in peripheral blood lymphocytes have been assessed in individuals who had higher exposure to chromate, including welders in two Bulgarian cities (Jambol and Burgas). Chromium levels in red blood cells of controls living in Burgas were in the order of 1 to 2 ppb. The chromium levels in Jambol controls ranged from about 2 to 7 ppb in red blood cells and about 22 ppb in chrome platers¹⁷. Danadevi *et al.*¹⁰ analyzed 102 welders and an equal number of control subjects for DNA damage in blood leucocytes utilizing the comet assay. Welders had higher Cr and Ni content when compared with controls (Cr: 151.65 Vs 17.86 $\mu\text{g/L}$; Ni: 132.39 Vs 16.91 $\mu\text{g/L}$; $P < 0.001$). Droste *et al.*¹⁸ investigated the relation between lung cancer and exposure to occupational carcinogens in a highly industrialized region in western Europe. A total of 478 cases and 536 controls, recruited from 10 hospitals were interviewed. Exposure to chromium was significantly associated with lung cancer.

Elias *et al.*¹⁹ assessed the levels of Cr in serum and urine and found significant higher levels in welders as compared to controls. Halasova *et al.*²⁰ found levels of chromium in the blood of welders ranging between 0.032 and 0.182 $\mu\text{mol/L}$ and was significantly higher than that in controls (0.07 ± 0.04 $\mu\text{mol/L}$ Vs 0.03 ± 0.007 $\mu\text{mol/L}$). Scheepers *et al.*²¹ assessed inhalation exposure to total and hexavalent chromium (TCr and HCr) by personal air sampling and biological monitoring in 53 welders and 20 references. Median inhalation exposure levels of TCr were 1.3, 6.0, and 5.4 $\mu\text{g}/\text{m}^3$ for welders of mild steel, high alloy steel and stainless steel respectively. Median concentrations of TCr in urine, blood plasma and erythrocytes were elevated in all welders, compared with the corresponding median concentrations in the reference group ($p < 0.005$). Tejral *et al.*²² investigated a group of 20 stainless steel welders and grinders in a factory and found substantially increased chromium and nickel concentrations in grinders. Gube *et al.*²³ investigated the effect of welding as well as the impact of smoking and protection measures on biological effect markers in exhaled breath condensate. Additionally, biomonitoring of chromium and nickel in urine was performed to quantify internal exposure. Although internal exposure to nickel and chromium in this study was low, welders showed significantly increased concentrations of all these parameters at baseline compared to non-exposed controls. Popp *et al.*²⁴ found a significant correlation between the frequency of SCE and of individual DNA strand breakage and the concentration of chromium in the urine while working on a group of 39 electric welders exposed to chromium and nickel. Tola *et al.*²⁵ followed five welders working with high alloy Cr-Ni steel and one working with mild steel for one work week. The urinary chromium concentration was found to be a good indicator of short-term exposure to water-soluble chromium, when exposure was above the current threshold limit value of 0.05 mg/m^3 .

Manganese levels

Elias *et al.*¹⁹ assessed the exposure to welding fumes by measuring the levels of serum and urine Mn and found significantly higher values in the exposed group. Exposure to welding fumes was determined in the 96 welders, while the concentration of elements in whole blood and urine was also determined. The concentration of Mn in whole blood (B-Mn) was about 25% higher in the welders compared to the controls (8.6 Vs 6.9 $\mu\text{g/L}$; $p < 0.001$), while the difference in the urinary Mn concentrations did not attain statistical significance²⁶. Wang *et al.*¹⁴ explored the relationship between metals exposure and nervous impairment in welders. The metal exposure was evaluated for blood Mn by atomic absorption spectrometry, and the nervous system impairment was evaluated with the neurobehavioral core test battery and electromyography. Significant difference of nervous performance in welders existed in different concentration groups of Mn. Hoet *et al.*²⁷ investigated the levels of Mn in plasma (Mn-P) and urine (Mn-U) as biomarkers of exposure in a group of 28 welders. In welders, the after-shift Mn-P values correlated well with Mn-air above 10 $\mu\text{g}/\text{m}^3$. Compared to controls, the welders showed 33% higher Mn-P values (1.5 Vs 2.0 $\mu\text{g/L}$).

Cytogenetic analysis

DNA-protein crosslinks (DPC) quantification was carried out in lymphocytes of a group of tannery workers exposed to trivalent chromium, a small group of manual metal arc stainless steel welders exposed to hexavalent chromium and a control group. The results indicated a significant increase in the formation of DPC in tannery workers compared with controls (0.88 ± 0.19 versus $0.57 \pm 0.21\%$; Mann-Whitney test, $P < 0.001$) and an even higher level of DPC in welders ($2.22 \pm 1.12\%$, $P = 0.03$)²⁸.



Chromosomal aberrations and sister chromatid exchanges

Elias *et al.*¹⁹ found statistically significant increase in chromosomal aberrations in cultured lymphocytes from 55 welders and 55 matched controls. There was a significant correlation between the length of welding employment of these welders and the frequency of chromosomal breaks, although there was no such correlation between age and the frequency of chromosomal aberrations. Halasova *et al.*²⁹ studied chromosomal damage related to chromium exposure, considering the role of polymorphisms in relevant DNA repair genes. 39 male welders exposed to chromium for 10.2 ± 1.67 years and 31 male controls were assayed for structural chromosomal aberrations and found higher CA in exposed individuals (1.96%) than in controls (1.55%). Chromosomal type breaks were almost two-fold higher in exposed than in control individuals. Then again in 2011, Halasova *et al.*²⁰ studied the welders and found that parameters of chromosomal damage were similar in both the exposed and the control individuals (1.89% Vs. 1.70% for total chromosomal aberrations, 0.97% Vs. 0.88% for chromosome-type and 0.92% Vs. 0.80% for chromatid-type, respectively). Significantly higher total chromosomal aberrations were detected in individuals with homozygous variant polymorphism in XRCC1 Arg399Gln gene as compared to those with heterozygous and homozygous wild-type genotypes (2.20, 1.89 and 1.48%, respectively; $P = 0.01$). Cytogenetic damage was studied in lymphocytes from 42 welders using the manual metal arc (MMA) method on stainless steel (SS)³⁰. A subgroup of 20 welders was studied before and after 1-4 months of MMA/SS welding. A matched reference group I, and a larger reference group II were established for comparison. A significant increase in chromatid breaks (1.4 Vs 0.9 and 0.8 for group I and II) and for cells with aberrations (2.2 Vs 1.6 in group II) was found in the welders. Chromatid breaks were also found to be associated with cumulated welding fume exposure. Knudsen *et al.*³¹ worked on stainless steel welders in a Danish metal industry and measured chromosomal aberrations (CA), sister-chromatid exchanges (SCE), unscheduled DNA synthesis (UDS) in peripheral lymphocytes. SCE was found to be lower in welders working with both MMA and TIG welding than in reference persons. N-Acetoxy-N-acetylaminofluorene (NA-AAF)-induced UDS was lower in 23 never-smoking welders than in 19 unexposed never-smokers. CA, SCE, NA-AAF binding to DNA and UDS was found to increase significantly with age. Werfel *et al.*³² found significantly elevated SCE values in 39 welders as compared to controls. But on the contrary, Dominici *et al.*³³ studied 21 workers enrolled from two different welding companies in Central Italy and found a significant decrease in SCE frequency in exposed subjects (3.73 ± 0.21) compared to controls (4.89 ± 0.12). Similarly, Husgafvel-Pursiainen *et al.*³⁴ studied 23 welders and 22 control subjects and found insignificant differences in chromosomal aberrations and SCE frequencies but smokers (both welders and controls) showed a significantly higher SCE rate than non-smokers. Myslak and Kosmider³⁵ tested the genotoxic effects of nickel and chromium on 39 stainless steel welders and 22 controls. The frequency of SCEs was found to be higher in the welders. Smoking was found to be positive predictor for SCE only in controls. No correlation was found in between urine nickel and SCE frequency. But, Popp *et al.*²⁴ studied 39 electric welders and 18 controls and found significant correlation between SCE frequency and concentration of urine chromium.

DNA damage studies using comet assay

Sardas *et al.*³⁶ evaluated whether welding fume and solvent base paint exposure led to DNA damage in construction-site workers in Turkey using comet assay. Significant increase in the mean %DNA (Tail) ($p < 0.01$) was observed in all exposed subjects (12.34 ± 2.05) when compared with controls (6.64 ± 1.43). Also %DNA (T) was significantly higher ($p < 0.01$) in welders (13.59 ± 1.89) compared to painters (11.10 ± 1.35). Similarly, welders showed a significantly higher rate of DNA single strand breakages in lymphocytes as compared to controls³². Zhu *et al.*³⁷ worked on 346 employees (106 women and 240 men) from six job categories (welders, mechanics, painters, assemblers, auxiliary and managerial workers) in a bus manufacturing factory in Guangzhou. Significant differences of tail moment among the six job categories were found ($P = 0.003$) with adjustment for age and gender. Smoking was found to increase the tail moment significantly ($3.14 \mu\text{m}$ Vs $2.79 \mu\text{m}$; $P = 0.023$). Analysis of covariance showed that occupational exposure ($P = 0.001$) and smoking ($P = 0.019$) had significant effect on tail moment after adjusting for all factors, whereas age and gender had no effect on DNA damage. In another study, Sudha *et al.*³⁸ found a significant increase in the mean comet tail length in 66 welders as compared to the controls. Sellappa *et al.*³⁹ enrolled 93 welders and 60 control subjects with similar mean ages, smoking prevalence and alcohol consumption and found similar results.

Micronucleus test

Dominici *et al.*³³ assessed individual occupational exposure to magnetic fields of extremely low frequencies (ELF-MF) and found a significantly higher frequency of MN (6.10 ± 0.39) as compared to the control group (4.45 ± 0.30). Similar results were found by Sudha *et al.*³⁸ in 66 welders and 60 control subjects. Sellappa *et al.*³⁹ analyzed the DNA damage in blood leucocytes of welders by micronucleus assay and found a significant increase in micronucleated cells compared to controls with respect to their smoking habits and alcohol consumption, age and years of exposure ($P < 0.05$).

Cancer studies

Various studies have shown the association of welding and cancer. Gordon *et al.*⁴⁰, in a case-control study on 150 male subjects in southern Israel, with histologically proven transitional cell cancer (TCC) of the bladder, found significant associations between certain occupations including welding and the risk of future TCC. Sorensen *et al.*⁴¹ analyzed metal workers employed at a Danish stainless steel industry from



1964 to 1984 and found 75 cases of primary lung cancer. The standardized incidence ratio (SIR) for lung cancer was found to be more in welders [SIR = 1.35 (1.06-1.70)].

Oxidative status

Goulart *et al.*¹¹ conducted a comparative study on hexavalent and trivalent chromium-exposed workers (welders and leather tanning workers), focusing on the total oxidative status by quantifying the level of lipoper oxidation products in urine. Both groups had a significant increase in lipid peroxidation products expressed as malondialdehyde (MDA) in urine (tanners: $1.42 \pm 0.61 \mu\text{mol/g}$ creatinine, welders: $1.67 \pm 1.13 \mu\text{mol/g}$ creatinine Vs controls: $0.81 \pm 0.26 \mu\text{mol/g}$ creatinine; $P < 0.005$). Li *et al.*¹³ conducted a study on welders from a vehicle manufacturing industry and found 24% less and 78% higher values of erythrocytic superoxide dismutase (SOD) and serum malondialdehyde (MDA) than controls. Plessis *et al.*⁹ evaluated the oxidative status of male welders ($n = 15$) occupationally exposed to welding fumes. Lipid peroxidation was measured by the decrease of fluorescence and intracellular glutathione (GSH) levels. It was found that ROS and lipid peroxidation levels were elevated by approximately 87% and 96%, respectively ($p < 0.001$). Investigation by Leonard *et al.*² focused on the generation of free radicals and reactive oxygen species from stainless and mild steel welding fumes generated by a gas metal arc robotic welder. The welding fume suspension showed the ability to cause lipid peroxidation and H_2O_2 generation in cells. The chemical composition of the steel had a significant impact on the ROS generation capacity with the stainless steel containing Cr and Ni causing more damage than the mild steel.

Korczynski⁴² studied the welding industry in Manitoba. Eight welding companies participated in this study. Monitoring involved an assessment of noise levels, fume composition, and carbon monoxide and ozone concentrations. Exposures to manganese were found in the range of $0.01\text{--}4.93 \text{ mg/m}^3$ and to iron from $0.04\text{--}16.29 \text{ mg/m}^3$. Noise exposures ranged from 79-98 dBA. Flynn and Susi³ examined several large data sets to characterize manganese, iron, and total particulate mass exposures resulting from welding operations. The analysis suggested that exposure to manganese was at or above the threshold limit value of 0.2 mg/m^3 . The data also suggested that higher exposures were associated with a greater degree of enclosure.

Conclusions

Welders are a class of workers who are exposed to a number of complex compounds formed as a result of various industrial processes. Higher blood trace metal (Cr, Ni, Pb, Mn etc.) values in different studies clearly indicate the elevated health hazards for the workers. Lack of proper protection equipments and lack of awareness about the health implications of this occupation enhances the risk factor. Various studies have shown increased DNA damage in welders as compared to the controls. This damage may lead to serious health problems including cancers. The cellular oxidative status is also affected as indicated by elevated MDA levels. The only way to reduce the exposure of welders is by using protection equipments including face masks, hand gloves and light filters. Noise and radiation levels should also be minimized. The working environments should be well ventilated and airy. Carry-home exposure should also be reduced. Conclusively, there is a great need to check the health of welders on a regular basis working in different iron based industries to reduce the occupational health risk factor.

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