



Pexels

Hazardous Substances in Welding Fumes

ISSA Symposium

Hazardous Substances in Maintenance:
Risk and Prevention

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Frankfurt, 12/06/2024

Welding

Definition, Processes and Methods

Definition

Welding is a group of joining processes for permanently connecting two or more metal workpieces by melting a work piece along with a filler metal to form a strong joint.

Welding processes

- Gas welding
- (Electric) arc welding
- Energy beam welding (laser and electron beam welding)
- Resistance welding

Methods (examples)

- Gas Welding
 - ▶ Oxyfuel Gas Welding (OFW)
- Electric Arch Welding
 - ▶ Metal Inert Gas Welding (MIG)
 - ▶ Metal Active Gas Welding (MAG)
 - ▶ Shielded Metal Arc Welding (SMAW)
 - ▶ Flux Cored Arc Welding (FCAW)
 - ▶ Submerged Arc Welding (SAW)
 - ▶ Electroslag Welding (ESW)
 - ▶ Tungsten Inert Gas Welding (TIG or GTAW)
 - ▶ Plasma Arc Welding (PAW)

The number of different welding processes is huge.

TOP Four Welding Processes and Key Metals

TOP Four Welding Processes (European Welding Association, EWA)

- 70 % (Electric) Arc Welding
 - ▶ Metal Inert Gas Welding (MIG)/Metal Active Gas Welding(MAG)
 - ▶ Shielded Metal Arc Welding (SMWA)
 - ▶ Flux Cored Arc Welding (FCAW)
 - ▶ Tungsten Inert Gas Welding (TIG)
- 30 % Other technologies
 - ▶ Plasma cutting
 - ▶ Resistance welding
 - ▶ Oxyfuel cutting

Key Metals (European Welding Association, EWA)

- 93 % Steel (unalloyed and low – medium alloyed)
- 5 % stainless steel (cast iron and nickel based)
- 2 % aluminum and aluminum alloys
- Negligible amounts copper and copper alloys

Ref.: ECHA Scoping Study Report ... Welding Fumes ..., 2022

Not to forget: Welding-related Processes

DIN EN ISO 4063

- Welding
- Brazing, soldering
- Thermal cutting
 - ▶ e.g., flame cutting, plasma cutting, laser cutting

ECHA Scoping Study Report ... Welding ..., 2022

- Welding
- Brazing, Soldering
 - ▶ soft soldering (90 – 450 °C)
 - ▶ hard (silver) soldering (> 450 °C)
 - ▶ brazing (450 °C)
- Thermal cutting, gouging
 - ▶ e.g., flame cutting, plasma cutting, laser cutting
- Thermal spraying
 - ▶ e.g. electroplating, physical and chemical vapor deposition
- Flame straightening
- Additive production processes with metal powders

In particular, thermal cutting and related processes can pose similar health hazards as welding.

Number of Exposed Workers

Review

Welding, molybdenum trioxide, and indium tin oxide

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans

Lyon (FR): International Agency for Research on Cancer; 2018.
IARC Monographs on the Evaluation of Carcinogenic Risks to Humans.

PMID: 31268644 Bookshelf ID: NBK543202

Excerpt

...

Worldwide, an estimated 11 million workers have a job title of welder, and around 110 million additional workers probably incur welding-related exposures. Welding can involve exposures to fumes, gases, ultraviolet radiation and electromagnetic fields, and co-exposures to asbestos and solvents. The extent and type of exposure can depend on the process used, the material welded, ventilation, degree of enclosure, and use of personal protection.

IARC, 2022

- 11 mio welders worldwide
- 110 mio workers additionally incur welding-related exposure

European Employment Services (EURES), 2020

- 680.000 welders and flame cutters in the EU

European Welding Association (EWA), 2023

- 2 mio welders in the EU

Ref.: IARC Working Group, IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, 2022



Potential Health Hazards caused by Welding

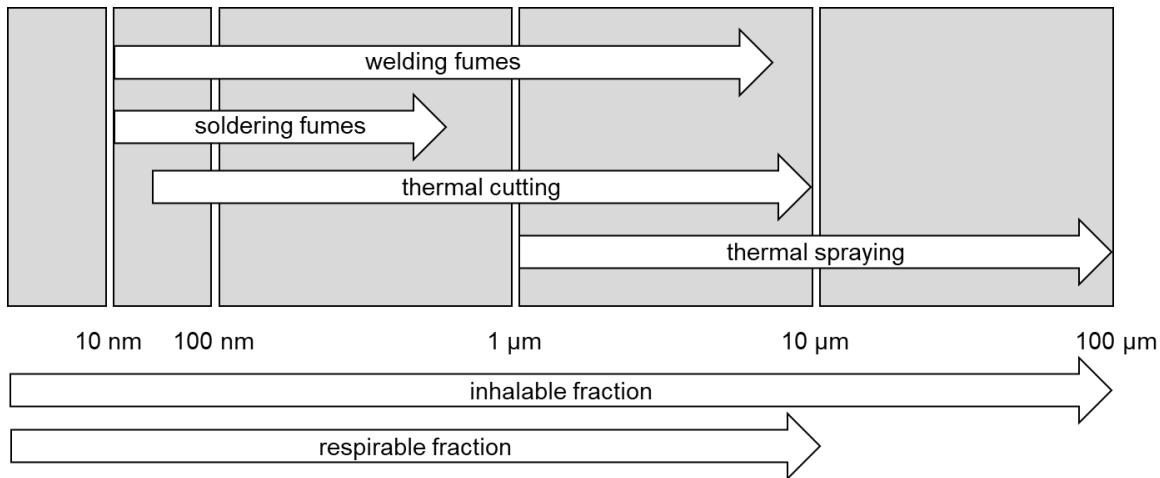
- Local burns to skin
- Thermal stress due to hot surfaces or radiant heat
- Electrical hazards
- UV and IR radiation burns to eyes and skin
- Radioactive radiation using tungsten electrodes containing thorium
- Occupational noise (e.g. during plasma arc welding)
- Chemical hazards caused by welding fumes, chemical cleaners/degreasers, and ionization of atmospheric gases
- Asphyxiation when welding in confined spaces
- ...

The health hazards that can be caused by welding are manifold.

Welding Fumes and Exposure to Hazardous Chemicals

■ Welding fumes consist of...

- ▶ Particulates
- ▶ Gases
- ▶ Vapors (by partial condensation)



■ Welding fumes contain ...

- ▶ Various metals and metal oxides
- ▶ Organic hazardous substances
- ▶ Inert gases (as shield gases)

■ Examples of hazardous chemicals are ...

- ▶ Aluminum, cadmium, chromium, cobalt, copper, lead, manganese, molybdenum, tin, titanium, zinc, ...
- ▶ Acetaldehyd, formaldehyde, nitric oxides, ozone, ...
- ▶ Argon, helium, nitrogen, carbon dioxide, ...

Ref.: e.g. DGUV Fachbereich Holz und Metall (Germany), Rauche und Gase bei schweißtechnischen Arbeiten – Gesundheitsgefahren, 2021

Welding fumes can include a long list of hazardous substances.

Welding Fumes from TOP Four Welding Processes

		Hazardous substances generated	CMRs (1A/1B) or not	Presence of the hazardous substances is known/proven, possible or exceptional	Workers are likely to be exposed or not
1	Fusion welding				
	Gas welding	Metal oxides from the base and filler materials, nitrogen oxides	Yes, depending on the base and filler materials	Base and filler materials: mild steel (Fe, Mn), copper alloys (Cu, Ni, Zn), aluminium (fluorides from the flux)	Yes, usually manual process, but low particle emissions.
	Arc welding - consumable electrode (filler) (MIG, MAG, SMAW, FCAW, SAW, ESW, SW)	Metal oxides mostly from the filler material, nitrogen oxides, carbon monoxide (MAG), ozone (aluminium alloys)	Yes, depending on the filler material, carbon monoxide (MAG)	Base and filler materials: mild steel (Fe, Mn, fluorides), stainless steel (Fe, Mn, Cr(III), Cr(VI), Ni, Co, V, fluorides), cast iron (Fe, Mn, Cr(VI), Ni), nickel-based alloys (Ni, Cr(VI), Fe), copper alloys (Cu, Ni), aluminium alloys (Al, Mg, Mn, Zn, Cu)	Yes, mainly in the craft sector. Automated processes are often used in industrial applications.
	Arc welding - non-consumable electrode (TIG; PAW)	Metal oxides mostly from the filler material, ozone	Yes, depending on the filler material	Base and filler materials: mild steel (Fe, Mn), stainless steel (Fe, Mn, Cr(III), Cr(VI), Ni, Co, V), cast iron (Fe, Mn, Cr(VI), Ni), nickel-based alloys (Ni, Cr(VI), Fe), copper alloys (Cu, Ni), aluminium alloys (Al, Mg, Mn, Zn, Cu), titanium alloys (Ti, Al, V), zirconium alloys (Zr)	Yes, mainly in the craft sector. Automated processes are often used in industrial applications.
	Beam welding	Metal oxides from the base material	Yes, depending on the base material	Base materials: mild steel (Fe, Mn), stainless steel (Fe, Mn, Cr(III), Cr(VI), Ni, Co, V), cast iron (Fe, Mn, Cr(VI), Ni), nickel-based alloys (Ni, Cr(VI), Fe), copper alloys (Cu, Ni), aluminium alloys (Al, Mg, Mn, Zn, Cu), titanium alloys (Ti, Al, V), zirconium alloys (Zr)	Not directly as almost completely automated. However, fume extraction system required to protect workers in the vicinity.

Welding fumes contain ...

- various metal oxides and fluorides (Al, Cr(III), Cr(VI), Co, Cu, Fe, Mg, Mn, Ti, Ni, V, Zn, Zr)
- carbon monoxide, nitrogen, ozone

Ref.: ECHA Scoping Study Report ... Welding Fumes ..., Table 3, p. 10 ..., 2022

Health Effects of Welding Fume Exposure

Acute and Chronic Effects

- IARC

- ▶ Welding fumes: "carcinogenic to human" (IARC: group 1, 2017)
- ▶ Metallic chromium and trivalent chromium: "non-classifiable" (IARC: group 3, 1990)

Ref.: WHO, IARC, IARC Monographs on the Evaluation of Carcinogenic Risk of Humans, Vol. 49, Chromium, Nickel and Welding, 1990

Carcinogenicity of welding, molybdenum trioxide, and indium tin oxide, The Lancet, 2017 18: 581f.

[Carcinogenicity of welding, molybdenum trioxide, and indium tin oxide - The Lancet Oncology](#)

Health Effect	caused by ...
Respiratory irritation	aldehydes, carbon monoxide and dioxide, metal oxides, nitric oxides, ozone
Inflammation	metal oxides
Cancer	beryllium, chromium(VI) compounds, cobalt oxide, formaldehyde, nickel oxide, ...
Metal fume fever	high fume levels from welding galvanised steel

Ref.: TRGS 528 Welding Work
[BAuA - Legislative Texts and Technical Rules - TRGS 528 Welding work - Federal Institute for Occupational Safety and Health](#)

Hazardous substances in welding fumes can have different severe effects on human health.



Acute and Chronic Effects caused by Welding Fumes and Shield Gases

Welding fumes

	Health Effects
Acute Effects	<ul style="list-style-type: none">• Irritation to throat and upper airways• Acute irritant-induced asthma• Metal fume fever• Pneumonia
Chronic Effects	<ul style="list-style-type: none">• Chronic obstructive pulmonary disease• Occupational asthma• Welders lung• Lung cancer

Shield gases

	Health Effects
Argon, carbon oxides and nitrogen	Effects caused by oxygen displacement.

Ref.: BOHS, Health risks from welding
[Welding: Health risks from welding - HSE](#)

Health Effects caused by Oxygen-Deficient Atmosphere

Oxygen Concentration [Vol-%]	Health Effects
21	none
19.5	no evidence of adverse effects
10 – 19.5	<ul style="list-style-type: none">• increased breathing rate• accelerated heartbeat• Impaired attention, thinking and coordination
6 – 10	<ul style="list-style-type: none">• nausea and vomiting• lethargic movements, perhaps unconsciousness• increased risk of brain damage
< 6	<ul style="list-style-type: none">• immediate loss of consciousness• convulsions• cessation of breathing and cardiac arrest
0	Inhalation of a few breaths causes immediate loss of consciousness and death within 2 minutes.

Shield gases displace oxygen (if ventilation is insufficient) and can thus lead to severe acute health hazards including death.

Risk Assessment

Information Requirements

■ Information specific for welding work

- ▶ Type of the welding process and work practice
- ▶ Base metals, flux agents (in case of brazing and soldering) and filler metals used
- ▶ Welding rod composition
- ▶ Paint or coating of the metal to be welded

■ Information about exposure determinants

- ▶ Frequency and duration of welding work (professional welder or occasional welding work)
- ▶ Location of the workplace (outdoor, indoor or possibly in a confined space)
- ▶ Ventilation (e.g., welding in fume hoods, use of vacuum nozzles)
- ▶ etc.

Air Monitoring and Occupational Exposure Limits

Air monitoring (behind the welder's visor) of ...

- fumes (as inhalable and respirable dust fraction and subsequent element analysis, e.g. ICP/AES or /MS)
 - ▶ to assess metal, metal oxide and metal fluoride exposure
- gases (e.g. using direct reading monitors)
 - ▶ to assess nitric oxides, carbon monoxide or ozone

Biomonitoring of ...

- (many) metals (possible)

Country	OEL [mg/m ³]	Remarks
Austria	5	respirable fraction
Denmark	0,5 – 1,7	depending on the welding process
Germany	1,25	respirable fraction
Netherlands	1	

Examples of OELs for welding fumes

Individual OEL BLVs for metals and their inorganic compounds determined, e.g.,

- Cobalt: 0,005 mg/m³ (Germany, TRGS 910, respirable fraction)
- Cr(VI): 0,001 mg/m³ (Germany, TRGS 910, inhalable fraction)

Existing OELs for welding fumes are not health-based.
Individual OELs for metals and their inorganic compounds are extremely low.

Risk Management ^(1/2)

Banding-type Approach (Example: Technical Rule for Hazardous Substances 528)

■ Definition of emission categories

Emission Category	Emission Rate [mg/s]
low	< 1
medium	1 – 2
high	2 – 25
very high	> 25

■ Factors influencing the release rate are ...

- ▶ higher values for welding current and welding voltage
- ▶ alternating current
- ▶ electrode diameter

Ref.: [BAuA - Technical Rules - TRGS 528 Welding work - Federal Institute for Occupational Safety and Health](#)

TRGS 528 - Page 1 of 66 (Version 8 February 2024)

February 2020 edition*)
GMBI 2020 pp. 236-276 [No. 12-13] (of 30 March 2020)
Last amended: GMBI 2020 p. 463 [No. 23] (of 7 August 2020)

Technical Rules for Hazardous Substances	Welding Work	TRGS 528
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The Technical Rules for Hazardous Substances (TRGS) reflect the state of the art, the state of occupational health and occupational hygiene as well as other sound work-scientific knowledge relating to activities involving hazardous substances, including their classification and labelling. They are developed by the

Committee on Hazardous Substances (AGS)

with the participation of the Committee on Occupational Medicine (AfAMed) and published by the Federal Ministry of Labour and Social Affairs (BMAS) in the Joint Ministerial Gazette (GMBI).

This TRGS specifies, within the scope of its application, the requirements of the Hazardous Substances Ordinance (GefStoffV) and the Ordinance on Preventive Occupational Health Care (ArbMedVV). By complying with the Technical Rules, the employer may therefore assume that the corresponding requirements under the ordinances have been fulfilled. Should the employer choose another solution, he must then achieve at least the same level of safety and health protection for employees.

Content

- 1 Scope
- 2 Definitions
- 3 Information gathering and risk assessment
- 4 Protective measures
- 5 Effectiveness check
- 6 Preventive occupational healthcare
- 7 Operating instructions and oral instruction

Annex 1: Glossary
Annex 2: Decision-making aids for the selection of protective measures
Annex 3: Specific information for selected sectors
Annex 4: Notes for measurements
Annex 5: Examples of operating instructions
Annex 6: Information according to fume data sheet pursuant to DIN EN ISO 15011-4

References

*) Note: TRGS 528 has been completely revised, including

- Updating to the current status of the rules and regulations,
- Consideration of experience and suggestions from practice, the state of the art, findings from expert and prevention research communities,
- Inclusion of the air limit values relevant for welding work, e.g. for chromium(VI) compounds, nickel, cobalt, manganese or nitrogen oxides in the risk assessment,
- Consideration of the risk to other workers in the hazardous area,
- New Annex 2 "Decision-making aids for the selection of protective measures" and new Annex 3 "Specific information for selected sectors" to assist practitioners.

- Committee on Hazardous Substances - AGS Management - BAuA - www.baua.de/ags -

Risk Management (2/2)

Banding-type Approach (Example: Technical Rule for Hazardous Substances 528)

- Assessment of the welding process based on emission rate (e.g. for the TOP four welding processes)

Welding Process	Emission Rate [mg/s]	Emission Category
Metal Inert Gas Welding (MIG)	1 – 4	medium – high
Metal Active Gas Welding (MAG)	1 – 4	medium – high
Shielded Metal Arc Welding (SMWA)	2 - 22	high
Flux Cored Arc Welding (FCAW)	6 - > 25	high – very high
Tungsten Inert Gas Welding (TIG)	< 1	low

- Recommendations for ...
 - ▶ control measures
 - ▶ lead substances to be air monitored

Ref.: [BAuA - Technical Rules - TRGS 528 Welding work - Federal Institute for Occupational Safety and Health](#)

Take Home Messages

Why are welding fumes hazardous?

Welding fumes ...

- contain particulate and gaseous hazardous chemicals.
- are classified as possibly carcinogenic to humans. (IARC group 1)

What are effects of breathing in welding fume?

Inhalation of welding fumes ...

- can lead to severe acute and chronic health effects, i.e.
 - ▶ Respiratory irritation
 - ▶ Inflammation
 - ▶ Cancer
 - ▶ Metal fume fever.

What factors are likely to lead to high fume exposure?

- Regular, high volume welding
- Ignorance of the health hazards being caused by welding fumes
- Welding processes which produce large amounts of fume
- Poor OSH practices
In particular,
 - ▶ missing or deficient ventilation
 - ▶ inadequate respiratory protection



We create chemistry