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METHODOLOGY AND LABORATORY TESTING STANDS FOR DETERMINATION THE WELDING FUMES DUE TO ARC WELDING OF STEELS

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Abstract:
The welding processes are identified as dirty, dusty and dangerous process. The base materials, welding consumables materials and physical and chemical phenomena, which are connected with high temperature and UV radiation, are emission source of welding fumes. The particulate solids - dust and various gases are included in welding fumes. During welding of stainless steels the forming welding fume includes the significant amount of typical of stainless steels elements, mainly chromium and nickel. These elements cause particular health hazard of welders. Some chemical compounds of chromium and nickel are classified as carcinogenic pollutants.
The toxicity of welding fume and health hazards are connected with fume emission rates, fume concentration at work places, fraction of fume and chemical compositions. The quantity of welding fume, system of ventilation and welding technological conditions influence to fume's concentrations in air. The chemical compositions depends on the base materials, welding consumables, shielded gases, welding methods and welding parameters

Key words:
Arc welding, steel, dust pollutants, laboratory stands, welding methods

1. INTRODUCTION

Welding processes of steel joining conducted in high temperature and with limited possibilities to control metallurgical processes and physical and chemical phenomena belong to the category of processes which have an adverse impact on the work environment. Welding of metals is perceived as a 3D process: dirty, dusty and dangerous. While welding gaseous and dust pollutants containing numerous substances hazardous to workers' health are emitted to work environment. Toxicity of those pollutants as a result of an undesirable physical and chemical actions after penetration into a human body causes large number of occupational diseases in welders' circles.

Welding of metals generates hazardous substances, i.e. substances which pose a threat to human health and are classified to at least one of following categories: very toxic, toxic, noxious, irritating, allergenic, carcinogenic or mutagenic. Chemical substances occurring in air in welding processes constitute a polyphase system – an aerosol, and their absorption into the human body depends largely on the form of a particular substance. Welding fume arises from the parent and filler metals, protective coatings of parent metal, shielding gases and ambient air under the influence of high temperature and radiation of welding arc [2-10]. Welding fume (diphase condensation aerosol) is a mixture of fine-dispersed solid particles (welding dusts) and different gases which form a dispersion phase. Welding dusts generated through the action of arc plasma on parent and filler metals [10,11] consist of simple and complex oxides, silicates, fluosilicates, fluorides, chromates, dichromates as well as metal carbonates [8]. The size of the average aerodynamic diameter of a particle of welding dusts varies from 0.01 to 1 μm [8, 9, 12].

The chemical composition of welding dusts depends on the type of welded metals as well as the method and technological parameters of welding. In case of welding with covered and tubular cored electrodes, the composition of dusts is more complex and has a more complicated structure than in case of dusts generated during gas-shielded welding with solid electrodes. In case of welding of unalloyed steels by means of solid electrodes, the basic components of dusts are iron, manganese and silicon dioxide [8, 9, 13,14], whereas welding of high-alloy steels causes emission of dusts containing also chromium, nickel, molybdenum and niobium compounds [8, 15,16]. Welding of steel with covered and tubular cored electrodes is aditionally accompanied by the emision of sodium, potassium, calcium and magnesium compounds [16,17]. The source of the aforementioned elements is the coating of an electrode and flux powder composed of various mineral resources (such as silicates, carbonates, simple and complex fluorides, metal oxides, sodium or potassium glass) as well as organic components. The chemical composition of dusts emitted during welding of steel is presented in Table 1.

Table 1. Chemical composition of dust during gas-shielded welding of steel [16,17]

Welding process/filler metal/ shielding gas	Parent metal	Chemical composition of dust [% m/m]				
		Fe	Mn	Si	Cr	Ni
MAG / solid electrode/ 80%Ar+20%CO_2	unalloyed steel low-alloy steel	57,2	11,6	3,57	0,03	0,03
MAG/ solid wire/ 80%Ar+15%CO_2+5%O_2	unalloyed steel low-alloy steel	59,7	11,8	3,4	0,03	0,03
MAG/basic cored electrode/CO_2	unalloyed steel low-alloy steel	43,6	10,9	3,3	0,03	0,01
MAG/ rutile cored electrode/ CO_2	unalloyed steel low-alloy steel	34,7	8,3	4,0	0,02	0,01
MAG/ metal cored electrode/ 82%Ar+18%CO_2	unalloyed steel low-alloy steel	45,9	14,6	4,4	0,83	1,68
Self-shielded tubular cored electrode	unalloyed steel low-alloy steel	50	3,2	0,9	0,02	0,38
MIG/solid electrode/Ar	high-alloy steel	38,0	12,0	5,0	20,0	5,0
MAG/solid electrode/99%Ar+1%O_2	high-alloy steel	39,0	11,0	5,0	19,0	5,0

The main sources of emission of gases during welding are as follows [8]:
- decomposition of covering of electrodes, decomposition of fluxes,
- thermal reactions in arc-surrounding atmosphere,
- photochemical reactions in arc-surrounding atmosphere (UV radiation),
- shielding gas used for protection of an arc.

As a result of thermal decomposition of materials protective coatings such as: paints, lacquers, plastics and anticorrosive while welding organic compounds e.g. aliphatic alcohols, formaldehyde, phenol, aliphatic ketone are created [8]. Presence of phosgene ($COCl_2$) in air surrounding welding stations is explained by the decomposition under the influence of ultraviolet radiation of some solvents used for cleaning of welded surfaces.

The effect of a long-term exposure of welders to welding fumes are various diseases of a respiratory system [8,9,14]. The airways are the main route by means of which dusts enter a human body. Pneumoconiosis may affect welders as early as after several years of work and is considerably more common in case of welders working in small or badly ventilated rooms rather than in case of those who work outdoors. Amongst welders growing asthma and bronchitis incidence rate can be observed. Apart from bronchus or lung complaints which to a sgnificant extent are the casue of occupational diseases of welders, other illneses may occure simultanously, e.g. diseases of nervous, cardiovascular or digestive systems [8,9, 20].

International Agency for Research on Cancer (IARC) has stated that welding fumes belong to the group of pollutants probably carcinogenic to human. It has been confirmed that such components of welding fumes as nickel, chromium VI, beryllium and cadmium have a carcinogenic effect. Silicon dioxide, also present in welding dusts, increases lungs' predisposition to TB and a number of infectious diseases. Pulmonary tissue's fibrosis is related to the influence of chromium and nickel compounds emitted during welding of high-alloy steels. Inhaling copper, zinc, magnesium or nickel vapours may expose welders to a disease known as zinc-fume fever.

Figure 1 presents the general classification of dusts and gases produced during welding of metals as regards their action on a human organism [8, 16, 18, 19].

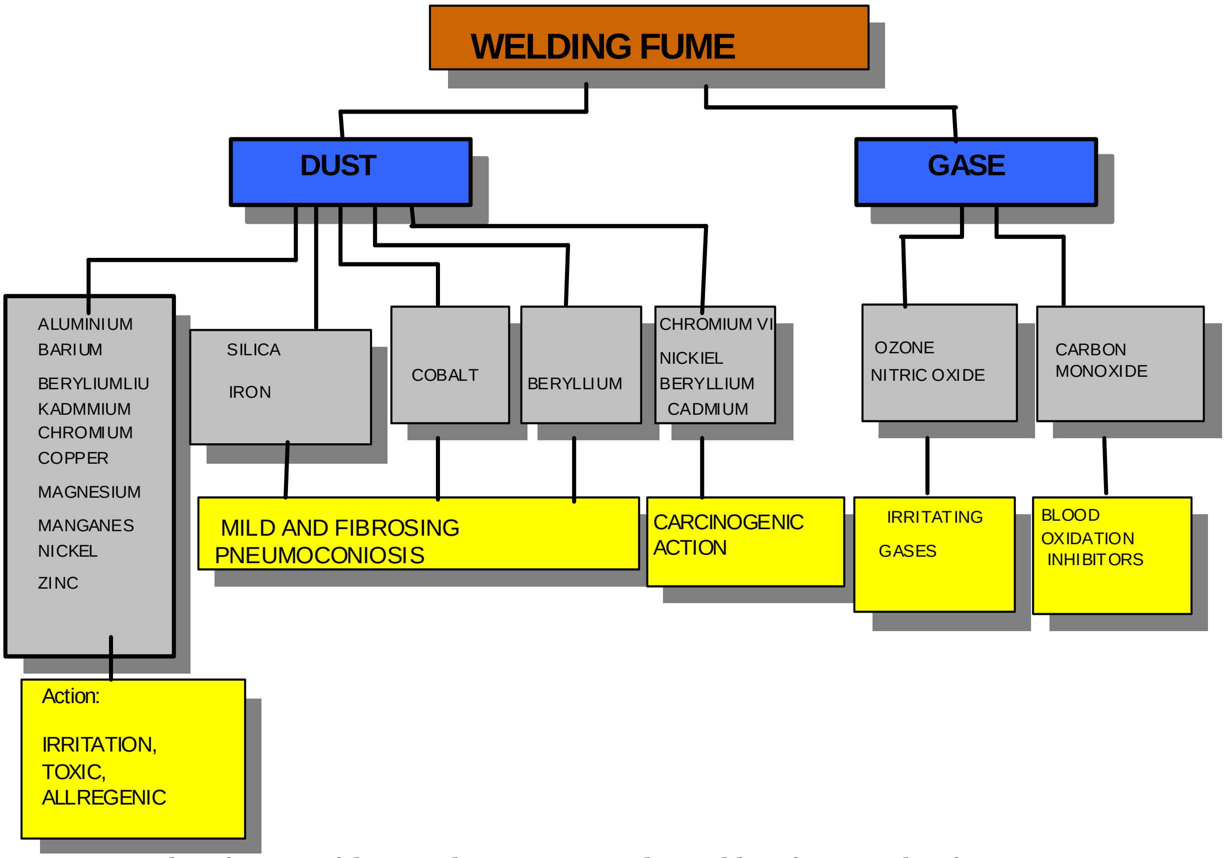

FIGURE 1. Classification of dusts and gases contained in welding fumes with reference to impact on human organism

This publication presents laboratory stands for drawing of samples of welding dusts depending on welding methods and consumables used in those processes taking into consideration harmful effect of welding dust on welders' health.

2. DESCRIPTION AND CHARACTERISTIC OF LABORATORY STANDS

Laboratory experimental stand for drawing samples of dust emitted during MIG/MAG welding of steel consists of experimental hermetic chamber, inside which welding process is conducted. Parent metal is located on a horizontal welding positioner, whereas welding torch is mounted on a stationary basis. Welding process inside the chamber was conducted automatically without anybody's participation from outside. MAGOMIG-401C welding power source was used in the experiments.

Stand for samples drawing of dust emitted while TIG welding of steel comprises three subassemblies:

- experimental chamber,
- exhaust equipment,
- TIG welding equipment – KEMPPI PRO 5000.

FIGURE 2. Laboratory stand for sampling of dust during MIG/MAG welding of steel

FIGURE 3. Experimental stand for samples drawing of dust emitted while TIG welding of steel

TIG welding process was conducted manually inside the chamber.

Testing stand for drawing samples of dust emitted during MMA welding consist of experimental hermetic chamber inside which welding process is conducted manually using covered electrodes. Welding arc was supplied by welding rectifier of PSP-630 type.

FIGURE 4. Experimental stand for drawing samples of dust generated during MMA welding with covered electrodes

3. METHODOLOGY OF TOTAL DUST EMISSION DETERMINATION

Methodology of samples drawing in welding processes has been developed in accordance with the requirements of EN ISO 15011: "Health and safety in welding and allied processes – Laboratory method for sampling fume and gases generated by arc welding – Part 1: Determination of emission rate and sampling for analysis of particulate fume". Separate stages of the methodology for total dust estimation during welding are shown in figure 5.

Mass of emitted dust during welding was calculated from a formula (1):

$$m_p = m_2 - m_1 \qquad (1)$$

where:

m_p – mass of dust, [mg] (accuracy of 0.1 mg); m_1 – mass of a clean filter, [mg]; m_2 – mass of a filter with retained dust, [mg]

whereas calculation of generation of dust Ec is conducted according to a formula (2):

$$E_c = m_p / t \quad [mg/s] \; ; \text{(accuracy of 0.01 mg/s)} \qquad (2)$$

where:

m_p – mass of retained dust, [mg] (accuracy of 0,1 mg); t – time of process, [s] (accuracy of 1s)

Determination of total dust emission due to MIG/MAG, TIG and MMA welding of stainless steel

Preparation of materials for testing

- before testing a filler metal (solid electrode, tubular cored electrode, rod, covered electrode), tested plate and shielding gases were prepared,
- type and diameter of filler metal was noted,
- material of tested plate was selected in accordance with testing guidelines,
- samples of diameter of 500 mm for MIG/MAG welding were taken from the plate of 10 mm in thickness,
- samples of dimension of 250 x 100 mm for TIG and MMA welding were taken from the plate of 8 – 10 mm in thickness.

Preparation of measuring filters

- Whatmana cellulose filters of dimension of 185 mm were prepared,
- a set of filters for single measurement (2 separate filters) was weighted on analytical balance with accuracy of readings up to 0.1 mg,
- marked set of filters were placed into an exsiccator,
- before the testing, filters were taken out from exsiccator and weighted again,
- filters closed in a container were carried to testing stand.

Testing measures in drawing samples of dust for emission determination

- process current parameters were selected in accordance with testing guidelines,
- measuring filters were placed on exhaust connectors of the chamber,
- welding process lasted 60 s,
- in case of welding with covered electrode the whole electrode was consumed,
- exhaust equipment was turned on for 10 minutes,
- exhaust equipment was turned off,
- measuring filters after testing were placed in the closed container,
- samples of dust were taken 5 times,
- filters were placed into the exsiccator again,
- set of filters was weighted on analytical balance with accuracy of readings up to 0.1 mg.

FIGURE 5. Determination of total dust emission while welding of stainless steel with MIG/MAG, TIG and MMA processes

4. METHODOLOGY OF DRAWING OF DUST SAMPLES FOR CHEMICAL ANALYSIS

Testing procedure for dust sampling for chemical analysis comprises following activities:

- prepare weight and mark a container for dust,
- prepare Whatmana cellulose filters of a diameter of 185 mm,
- place measuring filters on exhaust connectors of the experimental chamber,
- set welding parameters,
- turn on the exhaust system,
- conduct welding for 3 minutes,
- turn off the exhaust system,
- remove filters with dust,
- transfer dust from filters to a container with the use of small brush,
- weight a container (mass of dust for analysis should amount to at least 2g, depending on a number of components determined in a dust),
- if it is founded that mass of dust is insufficient samples drawing should be repeated.

Demanded chemical constitution is determined from the mass of dust emitted during welding of steel.

5. CONCLUSION

Laboratory stands presented in this article make possible to conduct complex testing of dust emitted during welding both in reference to mass and its chemical constitution. It allows for determination of many relations concerning dust emission, in the aspect of applied welding processes, selection of consumables and technological conditions of welding. Quantitative relations determined on this ground and their detailed analysis are the base for modification of welding processes in the aspect of reduction of a content of harmful substances, especially those, which are particularly hazardous to welders' health.

REFERENCES

1. Matusiak J.: Wpływ warunków technologicznych spawania łukowego stali nierdzewnych na toksyczność pyłu spawalniczego (The influence of technological conditions of arc welding of stainless steel on welding fume toxicity), Poland, Silesian University of Technology, Katowice 2007, PhD thesis
2. Heile R.F., Hill D.C.: Particulate fume generation in arc welding processes, Welding Journal, t. 54 nr 7, 1975, s. 201-210
3. Gray C.N., Hewitt P.J., Dare P.R.: New approach would help control welding fumes at source (MIG, MAG), part 2: MIG fumes, Welding and Metal Fabrication nr 11, 1982, s. 393-397
4. Gray C.N., Hewitt P.J., Dare P.R.: Control of particulate emissions from electric arc welding by process modification, Annals of Occupational Hygiene nr 25, 1982, s. 431-438
5. Mendez P.F., Jenkins N.T., Eagar T.,W.: Effect of electrode droplet size on evaporation and fume generation in GMAW. Proceedings of the Gas Metal Arc Welding for the 21st Century Conference, Orlando, December 6-8, 2000, s. 20-28
6. Dennis J., Hewitt P., Redding C., Workman D.: A model for prediction of fume formation rate in gas metal arc welding (GMAW), globular and spray models, DC electrode positive, Annals of Occupational Hygiene t.45, nr 2, 2001, s. 105-113
7. Quimby B., Ulrich G.: Fume formation rates in gas metal arc welding. Welding Journal, Welding Research Supplement nr 4, 1999, s. 142-149
8. Matczak W., Gromiec J.P.: Zasady oceny narażenia spawaczy na dymy i gazy, wyd. Instytut Medycyny Pracy im. J. Nofera, Łódź 2003
9. Voitkevich V.: Welding Fumes. Formation, properties and biological effects, Abington Publishing, Cambridge 1995
10. Mendez P.F., Jenkins N.T., Eager T.W.: Effect of electrode droplet size on evaporation and fume generation in GMAW, The 21st Century Conference – Proceedings of the gas metal arc welding, Orlando, 2000, s.53-59
11. Redding C.: Fume model for gas metal arc welding, Welding Journal, Welding Research Supplement nr 6, 2002, s. 95-103
12. Jenkins N.T., Pierce W., Eager T.W.: Particle size distribution of gas metal and flux cored arc welding fumes, Welding Journal, Welding Research Supplement nr 10, 2005, s. 156-163
13. Jenkins N.T., Eager T.W.: Chemical analysis of welding fume particles, Welding Journal, Welding Research Supplement nr 7, 2005, s. 87-93
14. Pires I., Quintino L., Miranda R.M., Gomes J.F.P.: Control of gaseous emissions in arc welding, EUROJOIN 6 – 16as Jornadas Tecnicas de Soldadura, Santiago de Compostela, 2006, s. 323-328
15. Jordan D.E.: Safety and welding of stainless steels, EUROJOIN 4, 4th European Conference on welding and cutting. "Development of welding and allied processes at the beginning of the new millennium", Cavtat-Dubrovnik, 2002, s. 137-144
16. Matusiak J., Rams B., Machaczek S.: Emisja zanieczyszczeń pyłowych i gazowych przy procesach spawania i lutowania, Katalog charakterystyk materiałów spawalniczych pod względem emisji zanieczyszczeń, wyd. WAM - Instytut Spawalnictwa 2004
17. Matusiak J., Rams B.: Emission of dust and gases in tubular cored wire welding of steel, International Journal of Occupational Safety and Ergonomics t. 9, nr 3, 2003, s. 333-350
18. P.Hewitt.: Occupational health in metal arc welding, Welding in the World, t. 43, nr 5, 1999, s. 12-19, (IIW Doc. VIII-1816-97)
19. International Agency for Research on Cancer: Monographs on the Evaluation of Carcinogenic Risk to Humans, Vol. 49. Chromium, Nickel and Welding, France, Lyon, 1987-2002
20. McMillan G.: Burning questions in risk assessment of manganese in welding fume. EUROJOIN 6 – 16as Jornadas Tecnicas de Soldadura, Santiago de Compostela, 2006, s. 619-621