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Assessment of Negative Influence of Manganese in Welding Fumes on Welder's Health and Ways to Reduce it

The article presents the results of a theoretical study (literature review of publications), which allowed to establish the negative impact of welding aerosol (manganese and other elements) on the human body: you can use special welder protection equipment (ventilation and individual welder protection); reduce the quantitative and qualitative content of manganese welding aerosols (welding technology, power sources, modern welding materials); reduce the content of manganese in the human body, removing it with medicines.
Experimental studies have shown that the use of an inverter power source, compared with a diode rectifier, contributes: to ensuring the drop-by-drop transfer of electrode metal to reduce the time of their formation by 46% and the transition by 28%; ensures the transition of alloying elements from welding materials to the weld metal by 6% and reduces its losses from the fusion line by 6% and HAZ by 3%; to reduce the intensity of education (g / min) SA and their components by 23%; to reduce the specific allocation of CA and their components by 23%.

Keywords: *welding, welding fumes, welder's health, welding process optimization, inverter power supplies.*

1. INTRODUCTION

Welding works are known to be dangerous for human health as far as a certain amount of welding fumes is emitted into the working area alongside with noise and light irradiation. Apart from gases contained in the welding fumes, a great amount of welding dust resulted from oxidation of the evaporated metal as well as shielding gas, alloyed metals and flux reach environment. Chemical composition of the solid part in the welding fumes primarily depends on the type of filling materials. When the welding arc contacts the metal, evaporations emitted into the air above the working area are gradually oxidized producing fine dust [1-3].

In 2013 American Conference of Governmental and Industrial Hygienists (ACGIH) reconsidered its recommendations on quantitative composition of welding fumes and suggested reducing limiting concentrations [4]. This might become a regulation, and make welding materials manufactures follow new standards. These changes are caused by the problem of harmful influence of welding fumes on people's health. In many countries, particularly in the USA, there are lawsuits between welders who suffer from occupational diseases and manufactures of welding materials [5].

By origin, welding fumes fall into the category of condensation aerosols. They can be described as a disperse system in which the disperse phase is formed by small solid particles (welding fumes solid-state component), and the disperse medium is formed by gas mixture (welding fumes gaseous component). Welding fumes solid-state component is especially hazardous not only due to its toxic level, but also due to microscopic dust particles with low sedimentation rate (no more than 0.08m/s), and are equally distributed in the airspace at the breathing level in a radius of 5 m, inevitably getting into the body of the welder or any human nearby [6, 7].

Excessive amount of welding fumes metals in a body causes negative health conditions [8, 9].

Penetration of nano- and micro-dust particles of iron, manganese and silicon oxides into a human body triggers natural protective mechanisms, which in turn can not only activate macrophages, but also lead to inflammatory processes and consequently develop a number of diseases [10-12].

Particles up to 10 μm and more are retained on the surface of the bronchial tree mucosa, while small solid particles (up to 5 μm) penetrate much deeper. While passing through the alveoli membranes, small-sized particles can get into blood which is of the utmost danger [13-16]. When passing from one medium to another, heavy metals can change their chemical structure and cause deficiency of essential elements replacing them in metal-containing protein structures. They can not only enter metabolic cycles but also accumulate in human the body and hair [17-21].

Some metals [22, 23] released during welding are able to associate with functional groups of proteins (SH, NH-, NH2-, COO-), change a configuration of the enzymes active centers thereby violating protein functions and suppressing proteins activity, which also causes health disorders.

Manganese oxides are the most harmful chemicals [23-26] released during welding (40% of the total dust).

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They can cause organic damage of human nervous system, disrupt lungs, liver and blood circulatory system. Silicon compounds inhaled by humans also disrupt body function and cause silicosis. Chromium compounds, although released in smaller quantities, accumulate in the body causing headaches, diseases of digestive system and anemia, while titanium oxide can cause lung disease.

An influence of manganese (Mn) [27, 28] is worth special attention since it accounts for a large proportion of the entire toxic content of welding fumes solid component. Manganese is an essential microelement that greatly contributes to normal body functioning. It takes part in regulating various types of metabolism in cells and body´s tissues, blood clotting, growing of bones and connective tissue. It also regulates functioning of reproductive organs and affects spermatogenesis.

Manganese is essential for synthesis and exchange of neurotransmitters [23, 29]: it increases excitability of adrenoreactive systems and sensitivity of chemoreceptors, enhances protective inhibition in the cortex of the cerebral hemispheres. Manganese is also a cofactor for some enzymes (hydrolases, transferase, lyases, glutamine synthetases, etc.). In oxidation states (II) or (III), manganese enters the active site of a types of superoxide dismutase and catalase, which are the enzymes necessary for neutralization of a active oxygen intermediate.

Manganese stimulates synthesis of cholesterol, fatty acids, vitamin C and insulin. It is believed [27, 30] that manganese competes with iron when interacting with proteins and enzymes that include iron in the active site (for example, mitochondrial complex I and aconitase) and if in excess it replaces magnesium in cellular enzymatic reactions.

There is evidence [15, 19, 31] that nano compounds of elements oxides containing manganese found in welders' lungs induce development of certain types of fibrosis as well as interstitial inflammation. This explains the potential risk to respiratory health caused by repeated exposure to welding fumes.

Manganese in oxidation states (+4, +6, +7) is most dangerous for humans [23] because it causes oxidative stress due to oxidation of dopamine and other catecholamines. There is evidence that the content of iron carriers in the body such as transferrin and ferritin increases significantly with excessive intake of manganese, while the content of transferrin receptor decreases. This can be a signal of iron deficiency [23, 32-34].

Changes in iron metabolism can decrease hemoglobin contents and stimulate irritation of the erythrocyte lineage of the bone marrow, which can lead to some changes in red blood cells (eg, microcytosis) [32, 35, 36].

Manganese [37-40] intensifies the process of cell membranes lipid peroxidation by generating free radicals as a result of binding glutathione sulfhydryl groups and blood (tissues) proteins. It breaks the antioxidant defence of the body which maintains homeostasis.

Subsequently, lipid peroxidation products accumulate leading to disruption of functions and integrity of cell membranes and intracellular metabolism in general.

According to many authors [41-46], the main negative effect of the excess intake of manganese is central nervous system damage.

This fact [37, 41, 47-49] can be explained by a high rate of oxidative metabolism in nervous tissue and less active antioxidant protection than in other tissues. Manganese easily penetrates to neurons through the blood-brain barrier inhibiting activity of mitochondrial enzymes and accumulating in mitochondria. This again increases lipid peroxidation and causes damage to neuron membrane due to a number of biochemical processes.

It is believed that astrocytes regulate the manganese content of in the brain. Being damaged first, these nervous tissue cells may lose some of their functions, in particular, capture of glutamate (which excites amino acid). It increases glutomate content in blood and the content of γ-aminobutyric acid which is the main inhibitory mediator of the brain decreases accordingly [49, 50].

In addition, another brake mediator – dopamine falls under the excessive influence of manganese. Accelerating dopamine oxidation (while reducing its concentration), manganese stimulates accumulation of a neurotoxic compound which destruct a specific type of receptor on the surface of nerve cells [23, 49, 51-53].

Researches by a number of authors [19, 54] demonstrate that divalent metallic manganese can alter stability of prion proteins suggesting that stabilization of prion protein caused by manganese can play a role in the pathogenesis of prion diseases.

Thus, [30, 55, 56], bioconcentrarion of manganese can lead to a wide range of occupational diseases in latent and active forms due to disturbance in oxidation-antioxidant and metabolic processes, development of central nervous system specific disorders and other negative influences on workers' health.

Based on a literature review we found out that the following can reduce negative influence of manganese and other elements on human body:

1. Using special means of protection of respiratory system of the welder (ventilation and personal protective equipment).
2. Reducing an amount of manganese and its compounds in welding fumes (welding technology, power sources, modern welding materials).
3. Reducing bioconcentration of manganese in human body by removing it with medicines.

The research objective is to assess reduction in qualitative and quantitative content of manganese in welding fumes of manual metal arc welding (MMA) with modern inverter power supplies.

2. EXPERIMENTAL PART

Welding stability was assessed by means of statistic analysis of oscillograms of welding current and voltage generated by power supplies with different dynamic characteristics.

We analyzed the following power supplies: welding rectifier of VD-306E type and inverter power supply of Nebula 315 type. To study their dynamic characteristics we compared current and voltage oscillograms obtained with the help of a digital "AKIP-4122 / 1V" storage oscilloscope, "Pintek Electronics" DP-50 " differential probe, "current probe PR 1030"; and "OWON_ Oscilloscope_2.0.8.26" software.

3. RESULTS AND DISCUSSION

The results are shown in Table 1 and in Figure 1.

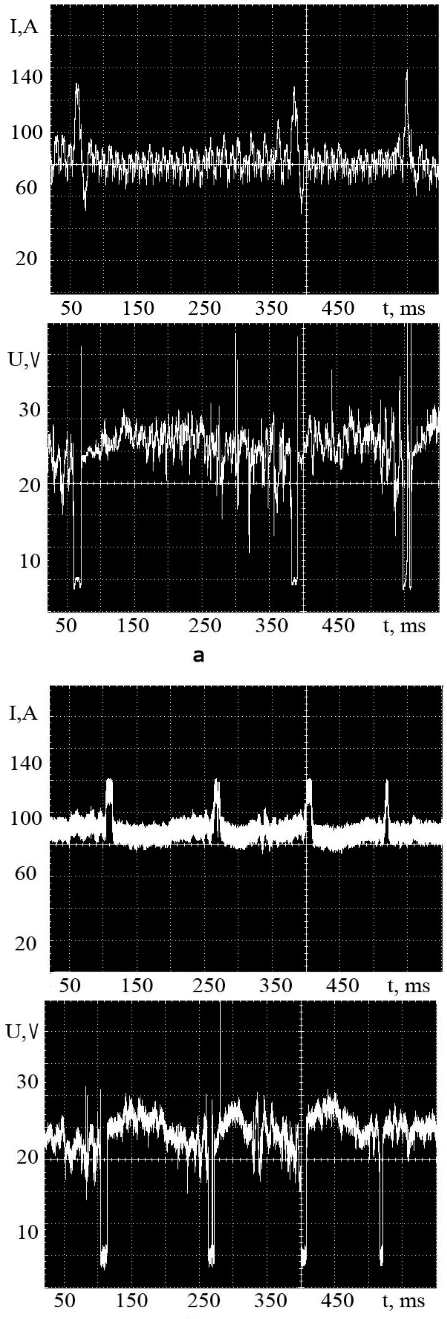

Figure 1. Oscillograms of droplet transfer current and voltage (3mm in diameter E19.9NbB20 electrodes): a - diode type; b – Inverter type

An analysis of the oscillograms in Fig. 1 (Table 1) shows that the droplet transfer time is reduced and the number of short circuits increases when using a high frequency energy conversion power supply (inverter). In this case the transferred electrode metal droplets are smaller in size which influences the weld metal composition [58]. To confirm this, a microradiography analysis of the composition (Fig. 2) of sections 1,2,3 shown in Fig. 3 and Table 2 was carried out.

In MMA with E19.9NbB20 coated electrodes, deoxidation (alloying) of weld metal occurs in a combined way – through the electrode coating.

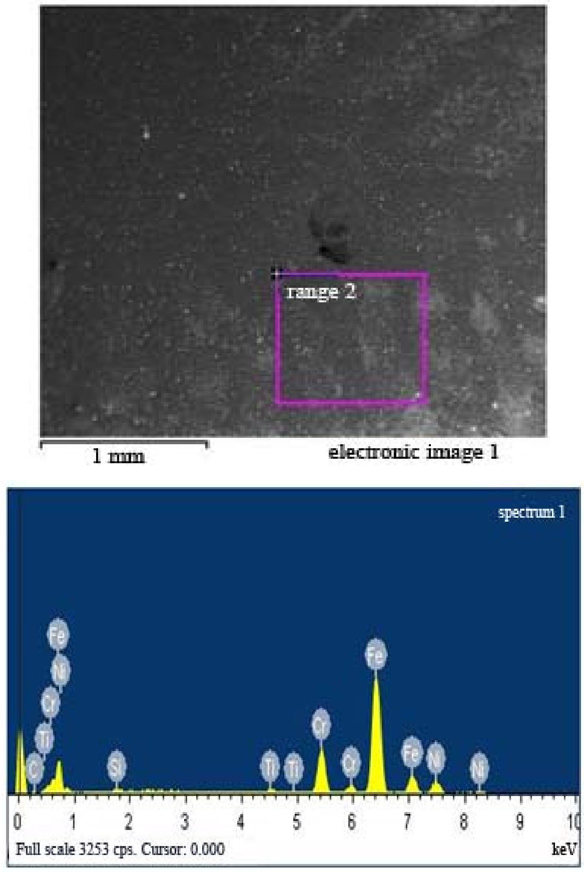

Figure 2. Images obtained by micro-X-ray analysis with INCA (Oxford Instruments)

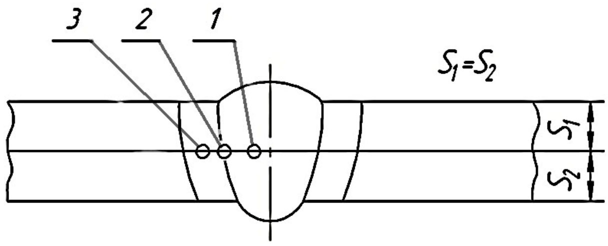

Figure 3. Micro-X-ray spectral analysis graph: 1 - weld metal; 2 – weld fusion line; 3 – heat affected zone

An analysis of the data in Table 2 shows that the content of alloying elements increases in all areas of the weld when an inverter is used, which can be explained by fine-droplet transfer (Table 1).

Samples of the welding fumes for hygienic assessment of electrodes were taken during bead welding of steel plates with X12CrNiTi18-9 electrodes. Diode and inverter rectifiers were used as welding arc power supplies. The welding was performed with constant reverse polarity current in the modes shown in Table 1. Welding fumes were captured by a special cover isolating the welding zone. At the same time, according to technological guidelines (MU 1927-78 1980; MU 4945-88 1990), welding fumes were deposited on filters made from FPP-15-1.5 tissue to evaluate the level of fuming and on AFA-HA-18 filters for the following chemical analysis of the welding fumes samples. The emitted fume and their components were weighed. For this purpose, at least five welding fumes samples were taken. The results of the tests (Tables 4-6) were subjected to statistical processing [11].

The results (Table 4-5) of the research showed that inverter rectifiers provide better health conditions for a MMA welder compared with diode rectifiers as far as the amount of emitted hazardous chemicals is reduced (welding fumes from 0.257 to 0.2 (19%), manganese from 0.007 to 0.005 (23%), chromium oxide from 0.012 to 0.09 (24%)) Thus, the risk of toxic poisoning and inflammation of the airways mucous membrane of welders and indirect workers is lower.

Table1 . Welding modes with TsL-11 electrodes from various power supplies and static data of coated electrodes metal droplets transfer [57].

Power supply - rectifier	Electrode	Average welding mode parameters	Number of short circuits	Arc gap short circuit time ts.c., ms	Short circuit time Ts.c., ms	I_{max}, A	I_{min}, A
Diode type	E19.9Nb B20	Current 86±2,7A Voltage 24.5±0,6V Welding speed 0.27 m/min	12	12±3.76	249±76.3	132.1 ±4.7	54.9 ± 4.75
Inverter type			24	8.7±3.52	140±45.8	123 ± 1.63	78 ± 1.06

Table 2. Chemical composition of weld metal of X12CrNiTi18-9 steel produced by E19.9NbB20 electrodes.

Element content	Power Supply			
	Diode rectifier		Inverter	
	Weight %	Atomic %	Weight %	Atomic %
Weld metal (1)				
Si K	0.36	0.71	0.38	0.75
Ti K	1.44	1.45	1.90	1.91
Cr K	18.54	19.66	19.21	20.37
Fe K	67.71	66.85	69.45	68.57
Ni K	10.19	9.57	10.81	10.15
Weld fusion line (2)				
Si K	0.50	0.98	0.56	1.10
Ti K	0.60	0.69	0.65	0.75
Cr K	16.45	17.45	17.40	18.42
Fe K	70.52	69.53	71.44	70.77
Ni K	10.87	10.11	11.01	10.20
Heat affected zone (3)				
Si K	0.50	0.97	0.53	1.05
Ti K	0.61	0.70	0.76	0.88
Cr K	17.19	18.21	17.41	18.45
Fe K	70.96	70.00	70.70	69.73
Ni K	10.63	9.98	10.71	10.05

Table 3. Emission (g/min) of welding fumes and their components.

Electrode type (diameter, mm)	Power supply - rectifier	Welding fumes	CrO_3	Cr_2O_3	Mn	Ni	F Soluble	F Insoluble
E19.9NbB20 (3)	Diode	0.257	0.012	0.006	0.007	0.006	0.012	0.013
	Inverter	0.2	0.09	0.004	0.005	0.0045	0.01	0.01

Table 4. Specific emissions (g / kg) of welding fumes and their components.

Electrode type (diameter, mm)	Power supply - rectifier	CA	CrO_3	Cr_2O_3	Mn	Ni	F Soluble	F Insoluble
E19.9NbB20	Diode	10.48	0.48	0.26	0.31	0,26	0.50	0.51
	Inverter	8.07	0.37	0.20	0.24	020	0.42	0.42

Table 5. Toxic level of welding fumes (TLVf) and air exchange (NHL).

Electrode type (diameter, mm)	Power supply - rectifier	TLV_f , mg / m^3	NHL, m^3 / h
E19.9NbB20 (3)	Diode	0.15	1480
	Inverter	0.1	1000

4. CONCLUSION

The research showed that inverter power supplies compared with diode rectifiers:

1. ensure electrode metal fine-droplet transfer, reduce time of droplet generation by 46% and time of droplet transfer by 28%.
2. transfer of alloying elements from welding materials into the weld metal which reduces its loss from the welding line by 6% and the heat affected area by 3%;
3. decrease welding fumes emission rate (g/min) by 23%.
4. decrease specific emission of welding fumes by 23%.

APPENDIX

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ПРОЦЕНА НЕГАТИВНОГ УТИЦАЈА КОНЦЕНТРАЦИЈЕ МАНГАНА У ГАСОВИМА ОД ЗАВАРИВАЊА НА ЗДРАВЉЕ ЗАВАРИВАЧА И КАКО ДА СЕ ТАЈ УТИЦАЈ СМАЊИ

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Рад приказује резултате теоријских истраживања негативног утицаја аеросола од заваривања (мангана и других елемената) на људски организам. Заштита заваривача се може обезбедити специјалном опремом (вентилацијом и индивидуалном заштитом), редуковањем квалитативне и квантитативне количине мангана у аеросолу (технологијом заваривања, изворима напајања, савременим материјалима за заваривање), коришћењем медикамената за редуковање садржаја мангана у организму.

Експериментална истраживања су показала да употреба инвертера извора напајања уместо исправљача са диодама омогућава пренос метала са електроде кап-по-кап чиме се редукује време формирања шава за 46% а пренос метала за 28%, пренос легирајућих елемената на шав за 6% и губитак са линије спајања за 6%, из зоне утицаја топлоте за 3%, интензитет обуке и њених компонената се редукује за 23%, а расподела средстава такође за 23%.