Slovak international scientific journal

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№46, 2020
Slovak international scientific journal
VOL.1

The journal has a certificate of registration at the International Centre in Paris – ISSN 5782-5319.
The frequency of publication – 12 times per year.
Reception of articles in the journal – on the daily basis.
The output of journal is monthly scheduled.
Languages: all articles are published in the language of writing by the author.
The format of the journal is A4, coated paper, matte laminated cover.
Articles published in the journal have the status of international publication.

1000 copies
Slovak international scientific journal
Partizanska, 1248/2
Bratislava, Slovakia 811 03
email: info@sis-journal.com
site: http://sis-journal.com

EXPERIMENTAL PHARMACOLOGY AND TOXICOLOGY

TOXIC IMPACT OF NANOFRACTIONS OF SOLID COMPONENT OF WELDING FUMES WHICH FORMED DURING WELDING BY HIGH-ALLOY ELECTRODES WITH LOWER CHROMIUM CONTENT

Lugovskiy S.
Doctor of Medical Sciences, Deputy Director
Demetska O.
PhD, head of laboratory
Didenko M.
PhD State Institution «Kundiiev Institute of Occupational Health of the National Academy of Medical Sciences of Ukraine»
Lukianenko A.
PhD, E.O. Paton Electric Welding Institute of NASU
Primin M.
Doctor of technical sciences, head of department
Nedayvoda I.
Researcher, V.M. Glushkov Institute of Cybernetics of NASU

Abstract

Some questions of the dependence of biological aggressiveness of the welding fumes on the main physical and chemical properties (dispersity of particles of solid component of welding fumes (SCWF) etc) have not yet been finally clarified.

Objective of investigations was determination of the toxicity of SCWF nanosized fractions. Two grades of high-alloyed test electrodes with rutile type of coating and different types of binding with lower chromium content (YI) were used. In order to study the toxic action of SCWF of test electrodes 14-25 and 14-32, we performed a single intratracheal injection of 0.5 ml of TCWF nanoscale fractions (selected during welding in deionized water) to rats. Magnetic fields were measured using a superconducting quantum interference device, SQUID magnetometer. Chemical composition of the samples was studied by inductively coupled plasma atomic emission spectrometry (AES-UIP). Ultrastructural changes were investigated using a scanning electron microscope Tescan MIRA3 (Tesla).

Changes in the liver of animals can be explained in terms of development in the body of diffuse and / or focal dystrophic and / or destructive changes, which may be related to accumulation of compounds of metals capable of exhibiting magnetic properties.

Keywords: welding electrodes, solid component of welding aerosol, nanosized fractions, chromium (YI).

Introduction

Emission of nanoparticles into the working zone air can accompany both the production processes, where nanomaterials are the final product, and processes that are not directly related to nanotechnologies, in particular electric welding [1-3].

The welding process is accompanied by a complex of unfavourablechemical, physical and psychophysiological factors that pose a health hazard to welders [4, 5]. It is important to note that during the welder's labour activity it is important to emphasize that during the work of the welder, the combination of production factors that affect his body can change more than once, as the working conditions can differ significantly not only in different industries, but also in separate sections of the same enterprise.

Depending on the kind of production operation, kind of metal, type of welding consumables, and production technologies, the welder is under the impact of various inherently harmful production factors. Studies of the presence of harmful substances in the air of the working area and breathing zone of workers engaged in various types and processes of welding showed that the most adverse factor is exactly the chemical one. Performance of welding operations is accompanied by the formation of harmful factors of a chemical nature, the basis of which are the toxic components of the welding fume (CF), as well as flux dust. In its turn, their quantitative and qualitative composition depends on welding method, metal composition, etc.

Welding fumes (WF), as a professional hazard, have been studied for a rather long time. However, a number of questions of the dependence of their biological aggressiveness on the main physicochemical properties (dispersity of particles of the solid component of welding fumes (SCWF), their structural parameters, solubility of individual compounds) have not been finally clarified.

Currently, it is suggested that the high incidence rate in electric welders is due not only to toxicity of WF components with irritant and mutagenic effect, but also to the ability of nanoscale particles to deeply penetrate into the tissues [6].

Nanosized particles are the main elements of all SCWF. Here, the integral chemical composition of SCWF nanosized particles essentially depends on the type of electrode coating.

This circumstance is extremely important in terms of the potentially hazardous interaction of WF with the human body, and makes it necessary to study SCWF nanosized fractions in the welder's breathing zone.

The objective of the studies is to determine the toxicity of SCWF nanosizedfractions that formed during welding by high-alloy electrodes with lower chromium content.

Materials and methods of investigation

SCWF nanoparticle toxic impact was evaluated using two grades (14-25 and 14-32) of high-alloy test electrodes with rutile coating type and different types of binder with lower chromium (YI) content (Table 1).

Table 1

Hygienic characteristics of welding electrodes

Electrode designation	Binder type	Weight fraction of the main WF components, %					
		Cr^{6+}	Cr^{3+}	Ni	Mn	F_{D}^{-}	F_{H}^{-}
14-25	K-Na	1.96	2.62	1.47	4.81	11.68	1.30
14-32	Li	Not detected	3.91	1.39	5.20	5.76	1.56

Sampling of air was performed in the breathing zone of the welder (permanent workplace). Air was aspirated with a flow rate of 0.5 l / min using a TAIFUN P-20-2 sampler through Zaitsev absorber containing 10 ml of deionized water. The selected sample was filtered with a syringe to which a filter holder with a 25 mm diameter Domnick Hunter membrane filter with 100 nm pore size (England) was attached.

Chemical composition of air samples was studied by inductively coupled plasma atomic emission spectrometry (AES-UIP), using Optima 2100 DV instrument (Perkin-Elmer, USA).

To study the SCWF nanofraction of test electrodes 14-25 and 14-32, we conducted a single intratracheal injection to rats of 0.5 ml of SCWF nanosized fractions (selected during welding in deionized water).

Magnetic fields were measured using a Superconducting Quantum Interference Device (SQUID), the principle of which is based on measurement of the magnetic susceptibility of magnetic carriers present in biological objects (organs and tissues, for example, of laboratory rats) [7]. Registration of weak magnetic fields was performed in experimental rats over the region of the liver location 1 month after a single injection into the trachea of animals of suspensions of SCWF nanofractions obtained by welding with electrodes of grades 14-32 and 14-25. To measure the magnetic fields, the rats pre-anesthetized with nibutal (20 mg / kg), were placed in the "right side" position on the coordinate table, which allowed moving the animals in the coordinates of the matrix of measurement points and the magnetic signal was recorded.

Internal organs of rats from which 0.5 cm thick pieces of 1 × 1 cm in size were cut out, were used for histological examination. Cut out pieces of the organs were immersed into 10% solution of neutral formalin for 72 hours. After that, they were rinsed in water and dehydrated in an ethanol series (70%, 80%, 96%, and 100%), clarified in xylene and paraffinized. Paraffin-embedded organs were used to prepare microtome sections, 7-10 mm thick, stained with hematoxylin and eosin.

Ultrastructural changes were investigated using a Tescan MIRA3 (Tesla) scanning electron microscope with Local Elemental Energy-Dispersion Microanalysis System Oxford Advanced Aztec Energy (IE350) / X-max 80.

Results and their discussion

In the samples selected in the welder's breathing zone in welding with test electrode 14-25, nanosized chromium (YI), manganese, zinc, iron, cobalt, copper, silicon, magnesium, aluminium were found. At the same time, iron, chromium, cobalt, copper were absent after application of electrode 14-32 (Table 2).

Table 2

Concentration of nanosized metals (mg/m^3) in air samples in welding with test electrodes

Metals, mg/m^3	Mn	Zn	Fe	Co	Cu	Cr	Si	Mg	Al
electrode 14-25	0.001	0.1	0.003	0.0003	0.0011	0.0014	0.007	0.01	0.001
Electrode 14-32	0.0011	0.00051	-	-	-	-	0.003	0.0033	0.004

Toxicity was determined by studying the magnetic signal and spatial orientation of the magnetic field of the liver of rats, exposed to the impact of SCWF nanofractions, with subsequent histological examination.

During performance of comparative analysis of magnetic signals by the data of averaged values of their energy characteristics, it was found that practically during the entire measurement period the magnetic signal over the area of the liver of rats exposed to the impact of nanofractions of SCWF of electrodes 14-25, was higher than the similar values in rats, exposed to the impact of nanofractrions SCWF of electrodes 14-32.

Studying the maps of magnetic signal distribution in the liver of rats of group 14-25 and group 14-32, respectively (Fig. 1), allowed stating that:

a) in the control rat group, similar to studying various physical models, the magnetic map in "global maximum" point is characterized by is characterized by spatial ordering and often has a dipole distribution (two regions with positive and different magnetic signal values, respectively);

b) unlike the control group rats, rat group 14-32 is characterized by a predominantly non-ordered spatial orientation of the magnetic signal compared to animal group 14-25. Here, in group 14-32 just one rat showed ordered spatial orientation of the magnetic signal characteristic for group 14-25.

As one can see from the Figure (Fig. 1.), magnetic maps of the majority of the experimental rats in group 14-32 have spatial heterogeneity. The maps show several zones with positive / different values of the magnetic signal, which are uniformly oriented in space (along the direction of the magnetization field) and equally spaced.

Such properties of the magnetic signal are more often associated with the fact that the source of magnetic signal is non-uniformly distributed in the volume of the studied object, in which the presence of several independent “activity zones” is noted. The data of determining the spatial structure of the sources of magnetic signal in the liver of experimental rats # 5 and # 1 of group 14-32 which are shown in the Figure (Fig. 2) support these results.

One can see that two “activity zones” of the magnetic signal are determined in the liver of rat № 5 (group 14-32). On the other hand, in rat № 1 (same group 14-32) the magnetic signal “activity zone” in the liver is localized in one area of this organ.

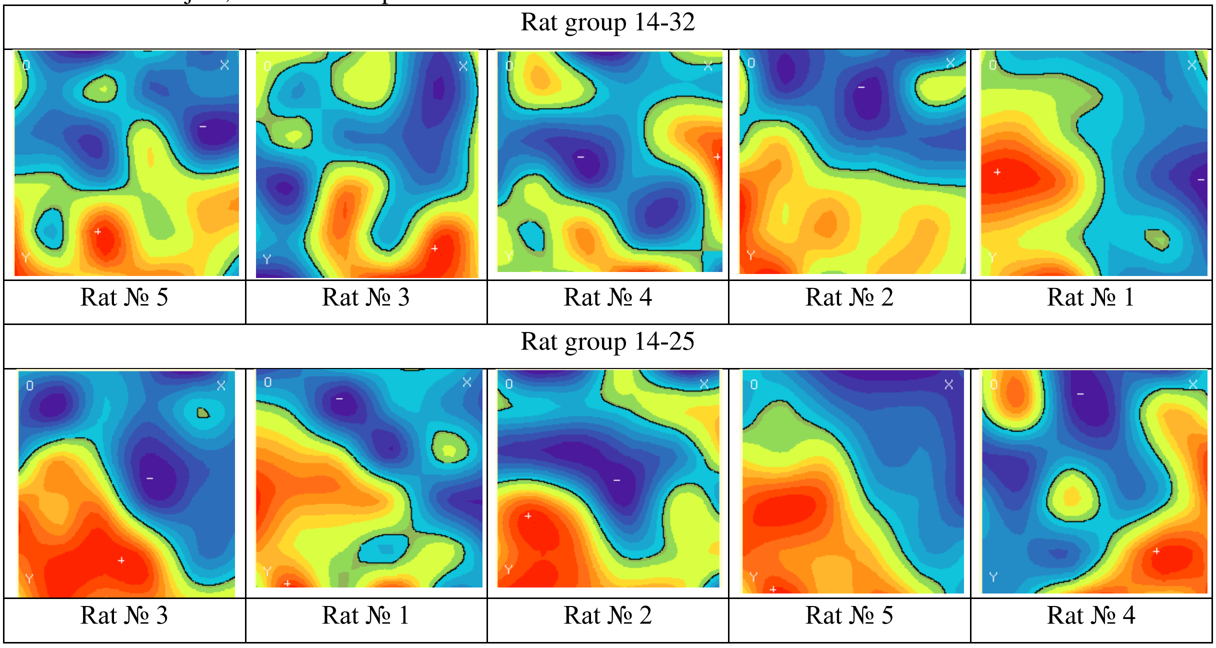

Figure 1. Magnetic maps of the liver of experimental rats of group 14-32 and 14-25. (One magnetic map is shown for each animal, arranged in the order of decrease of magnetic signal energy characteristic)

Thus, the results of the conducted magnetometric studies showed that the experimental rat group, exposed to nanofractions of SCWF of electrodes 14-32, demonstrates a difference not characteristic for rats exposed to the impact of nanofractions of SCWF of electrodes 14-25 on the body. This difference is characterized by the fact that at increase of the magnetic signal over the area of rat liver, an increase of spatial heterogeneity of the magnetic signal in the organ is noted.

From biological positions, changes in the liver revealed in magnetometric studies, can be explained in terms of development of diffuse and / or focal dystrophic and / or destructive changes in the organ, which may be associated, in particular, with accumulation of compounds of metals capable of exhibiting magnetic properties, in the parenchyma, elements of the organ stroma and cells of reticuloendothelial system (RES). In the case of formation of fibrotic changes in the liver, these can be, primarily, iron compounds.

Revealed facts necessitate performance of morphological studies of the liver of experimental rats of group 14-32 and group 14-25.

At histological examination of the liver of rats exposed to nanofractions of SCWF of electrodes 14-25, complete preservation of the trabecular structure characteristic of the organ, was noted. Blood vessels, mainly central veins and sinusoidal capillaries, often appeared unevenly expanded and were filled with moderate amounts of blood. In hepatocytes located on the periphery of the central veins (3rd zone of the hepatic acini) a significant lightening of the cytoplasm was often noted, especially in its perinuclear zone, where formation of small and light vacuoles was found quite often. At the same time, hepatocytes with nonuniform patterns of irregular, often amorphous basophilic granules in their cytoplasm, were frequently noted in the 1st and 2nd zones of hepatic acini. Such changes in the cytoplasm of hepatocytes were probably caused by changes occurring in the mitochondria of cells, manifected in that they take a condensed form.

It should be noted that hyperplasia and hypertrophy of individual stellate macrophagocytes was often found in the parenchyma of the liver of rats exposed to the impact of nanofractions of SCWF of electrodes 14-25 on the body against the background of moderate expansion of the gaps of sinusoidal capillaries. In this case, the cytoplasm of some of them acquired a noticeably dense appearance, which revealed small-sized excessively basophilic, rounded, or irregular, often elongated nucleus. The number of such cells per unit area of the slice, as a rule, significantly exceeded the control.

Results of histological examination of rat liver, exposed to nanofractions of SCWF of electrodes 14-32, showed that the organ completely retained the characteristic trabecular structure, which practically did not differ from the control group and the previous group of experimental animals (14-25). The parenchyma of the organ, as in animal group 14-25, showed a moderate expansion of the lumens of the central veins and sinusoidal capillaries, which in some cases also had a moderate blood flow. However, in the parenchyma of the organ, single hepatocytes or groups of cells with marked sealing of their cytoplasmwere often found,together with hepatocytes with moderately expressed basophilic granular cytoplasm. However, such cells were small in size, and had dense, rounded basophilic nuclei. Such a nature of changes in hepatocytes indicated development of dystrophic changes in them that are capable of developing at the subcellular level of their organization.

Against this background, in the parenchyma of the liver of experimental rats exposed to nanofractions of SCWF of electrodes 14-32, stellate macrophagocytes with signs of their expressed hyperplasia and hypertrophy were often revealed on the endothelium of enlarged sinusoidal capillaries. In such cells, a small amount of markedly enlightened cytoplasm was observed, often against the background of marked hypertrophy of the nucleus, which was characterized by pronounced basophilia and irregular shapethat could be evidence of cell dystrophy.

Similarly, in the sinusoidal capillaries of the rat liver, development of dystrophy of endothelial cells was noted, in which the nuclear zone of the cytoplasm, together with the basophilic nucleus of an elongated shape, deeply protruded into the lumen of the capillaries. Such morphological changes in the cells of vascular endothelium were defined as dystrophic, which acquired some meaning in order to explain those changes that occur in the liver of rats when their body is exposed to SCWF nanofractions.

Thus, the results of histological examination of the liver of rats exposed to nanofractionsof SCWF of electrodes 14-25 and 14-32 revealed dystrophic changes of hepatocytes in it, which were mainly diffuse.

At the same time, the organ under the influence of nanofractions of SCWF of electrodes 14-25 and 14-32 showed marked hyperplasia and hypertrophy of stellate macrophagocytes with signs of their pronounced dystrophy, which probably developed in the cells due to an increase in their functional activity.

It should be noted that the nonuniform nature of filling of blood vessels in the liver with blood, dystrophic changes in hepatocytes, as well as hyperplasia, hypertrophy, and dystrophic changes in stellatemacrophagocytes, whose main function is the absorption, metabolism, and elimination of substrates that are foreign to the body, constitute the morphological substrate that creates the source of an enhanced magnetic signal that has been detected by SQUD magnetometer over the area of experimental rat liver.

Conclusions

Changes in the liver of animals, which were detected in magnetometric studies, can be explained from the standpoint of development in the body of diffuse and / or focal dystrophic and / or destructive changes, which may include those associated with the accumulation in the parenchyma, elements of the stroma of the organ and cells, of RES compounds of metals capable of exhibiting magnetic properties. In the case of formation of fibrotic changes in the liver, these can be primarily iron compounds. Therefore, the more intense magnetic signal over the liver area and spatial homogeneity of the magnetic maps of the majority of experimental rats of group 14-25 compared to rat group 14-32 may be explained by agglomeration of nanoparticles in selected SCWF samples containing Fe and Co.

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