WELDING FUME — FACTORS OF INFLUENCE, PHYSICAL PROPERTIES AND METHODS OF ANALYSIS (Review)

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Properties of welding fume, such as dispersion degree, morphology of particle and methods used to analyze physical properties and element composition of colid component of the welding fumes, are considered. Factors affecting emission of the welding fume are presented.

Keywords: *arc welding; welding fume, morphology of particles, electrode coating, methods of analysis*

Interaction of molten metal with slag takes place in a process of arc welding. At that, a welding fume (WF) consisting of solid (PCWF) and gaseous (GCWF) components is formed. Welders and workers of related professions can get the professional diseases as a result of influence of welding fume on organism. The investigations of processes of PCWF and GCWF formation and their affect on health of the welders have been carried out at the E.O. Paton Electric Welding Institute of the NAS of Ukraine and Institute of Occupational Medicine of NAMS of Ukraine during many years. Low-toxic welding consumables, got wide distribution in industry and building, were developed based on these investigations. Works [1–16] show published results of the investigations.

Physical methods became widely applicable for PCWF investigations. Standard ISO-15011 was developed for methods of investigation of welding fumes. Many of these methods are not available for domestic scientists and welder-engineers.

At the same time the welding electrodes being imported from South-Eastern Asia appeared in the market of CIS countries. Their application results in poisoning of welders by manganese. Prevention of professional diseases of welders remains one of the priority directions of investigation in the filed of welding and related technologies. The present paper provides a review of investigations dedicated to WF.

Factors affecting formation of PCWF. High-temperature vapor, which is formed during evaporation of metal drop on a tip of electrode and weld pool, is a source of WF. The drop has large specific surface and is heated up to higher temperatures. Fraction of vapor being formed during evaporation of weld pool metal makes 10–15 % of PCWF [8, 17].

Processes of fume formation, i.e. evaporation with further condensation (with/without oxidation), chemically intensified evaporation and spattering, are also studied in study [17]. The intensity of evaporation depends on metal, slag and weld pool temperature as well as properties of materials being evaporated. Work [1] gives the results of investigations of heat content and metal temperature in the arc welding.

The following factors having influence on PCWF emission, i.e. electrode coating and flux core composition; mode of welding (current and voltage); kind of current and polarity; composition of the base and electrode metal; thickness of electrode coating, and diameter of the electrode were studied in [6, 8, 18].

It was determined that the temperature near the surface of drops formed using industrial grade electrodes lies in the ranges from 2150 to 2500 K and depends on current intensity and composition of the coating. The acid-coated electrodes have the highest temperature, and lower temperature is observed in basic- and rutile-coated electrodes [1].

Figure 1 shows amount of PCWF emitting in welding by electrodes with different coating types. Increase of basicity of the slag phase promotes intensive evaporation of potassium, sodium, magnesium and calcium, and at that the beginning of this process is removed in the area of lower temperatures [6].

Rate of fume formation (RFF) is mainly determined by type of a binder and its content in the electrode coating. RFF maximum is observed at potassium binder application, and lithium shows minimum one. Sodium binder takes an intermediate place. Change of K–Na binder by lithium provides the possibility to

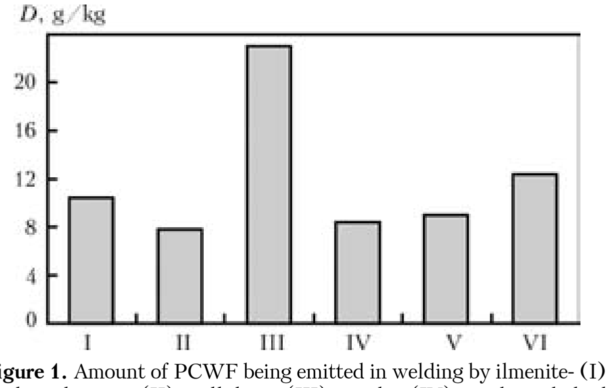

Figure 1. Amount of PCWF being emitted in welding by ilmenite- (I), rutile-carbonate- (II), cellulose- (III), rutile- (IV), acid- with high content of iron powder (V) and basic-coated (IV) electrodes [6]

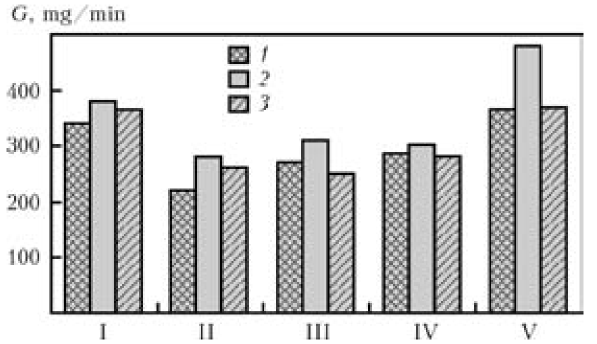

Figure 2. Dependence of intensity of PCWF emission on kind and polarity of current during welding by 4 mm diameter ilmenite- (I), rutile-carbonate- (II), cellulose- (III), rutile- (IV), acid- with high content of iron powder (V) and basic-coated (IV) electrodes [6]: *1* — AC; *2* — DCRP; *3* — DCSP

reduce RFF by 50 % without declining technological characteristics of the electrodes. Application of lithium binder in the electrodes for stainless steel welding results in reduction of gross emissions of WF as well as significant cut of content of hexavalent chromium in PCWF [19].

The increase of welding current intensity results in a rise of drop temperature and intensification of the process of evaporation. Growth of coating thickness promotes some reduction in temperature of the drops of electrode metal and improvement of slag protection of the drop. Increase of electrode diameter leads to rising of PCWF emissions [8].

Figure 2 shows an influence of kind and polarity of current. The highest intensity of fume formation is observed in welding at reversed polarity current, that is conditioned by higher temperature of the drops.

Speed of coated-electrode welding has virtually no influence on the fume formation.

Structure of PCWF particles and dispersion degree. Dimensions of separate particles of PCWF vary from several nanometers to tens of micrometers [11–13, 15, 17, 20], i.e. primary particles (< 100 nm), particles of accumulation range (100 nm–1 μm) and large particles (> 1 μm). Work [14] indicates that the majority of primary particles have dimensions from 5 to 40 nm. The coarser particles accumulate in clusters and small ones tend to form the chains.

PCWF consists of particles and agglomerates of spherical and aspheric shape. Most of the particles have inhomogeneous structure (consist of nucleus and shell) [6, 8, 13, 21]. Partially sintered agglomerates, agglomerates with «open» structure (being formed due to Van der Waals forces, adsorption forces of atmospheric moisture and electromagnetic forces) and linearly agglomerated nanosized particles [10, 14, 21] are observed.

The nucleus of particle with inhomogeneous structure is enriched by iron and manganese, and the shell contains combinations of silicon, potassium and sodium. Such an inhomogeneity of structure of PCWF particles related with sevectivity of the process of evaporation and condensation. High-temperature vapor has complex composition, and separate components condensing at various temperature. The elements with higher vapor pressure (sodium, potassium, etc.) condense after the elements with lower vapor pressure (manganese, iron).

Figure 3 shows WF particles obtained with the help of transmission (TEM) and scanning (SEM) electron microscope.

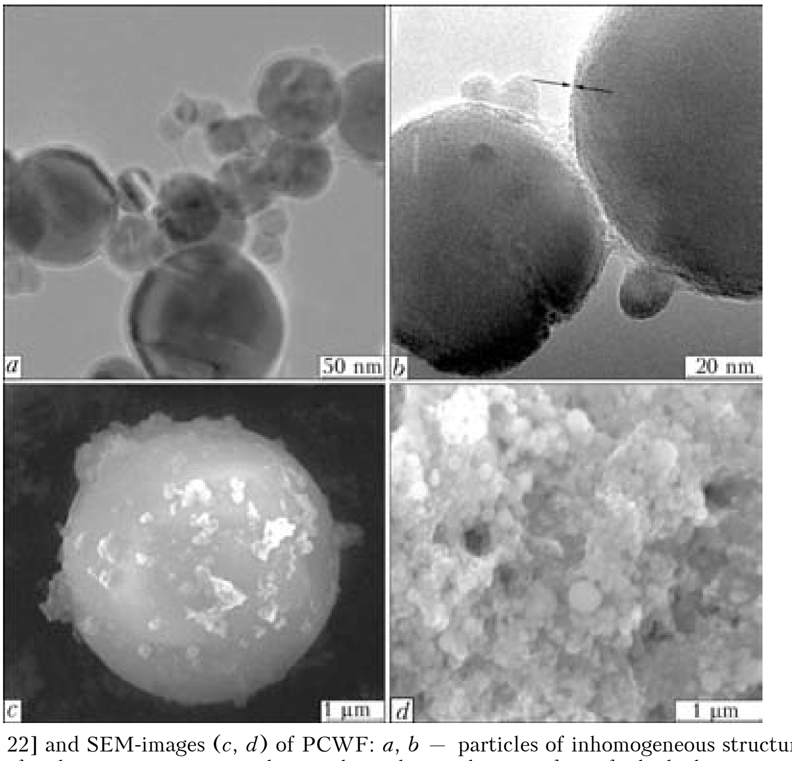

Figure 3. TEM- (*a*, *b*) [17, 22] and SEM-images (*c*, *d*) of PCWF: *a*, *b* — particles of inhomogeneous structure (nucleus is more dark, and shell is light); *c* — safe for the respiratory organs large spherical particle on surface of which the nanosized particles are situated; *d* — conglomerate of nanosized particles

Methods for determination of particle sizes

Method	Size range, μm	Equipment
Electron microscopy	0.002–50	SEM, TEM, electron probe (EPMA)
Optical microscopy	1–400	Optical microscope
Laser granulometry	0.01–3000	Analyzers (different types)
Aerodynamic separation	0.05–20	Impactors (different types)

Various size particles have different affect on organism of welder. Particles of less than 20 μm diameter can remain suspended in the air [11], and particles of more than several micrometers are deposited on the walls of airways of human organism and released outside with the mucus. Around 30 % of particles of 0.1–1.0 μm size are deposited in the lungs. Particles of less than 0.1 μm (100 nm) are also inhaled and deposited in the lungs. 100 % of less that 1 μm particles use airways [17] to enter the organism. The inpour of nanosized particles through the skin [23] is also possible. Thus, they can enter in the brain through nerves in the nasal sinuses [24, 25].

Figure 4 shows frequency characteristics of distribution of particle sizes in welding with cellulose- (E6010) and basic-coated (E7018) electrodes [12]. Study [25] indicates that the size as well as shape of nanoparticles determine their toxicity. The nanoparticles of dendrite and spindle forms have higher cytotoxicity then the particles of spherical form.

Methods of PCWF analysis. International standard ISO 15011–1 [26] determines specific requirements to structure of fume chamber, types of filters, pump, timer and scale. Data on methods of study of particle dimensions are given in the Table. Given data indicate variety of methods and equipment being used for analysis of particle size, mass and dimension distribution of PCWF.

The size of each particle and their distribution are difficult to measure due to large range of particle sizes. Specific preparation of the samples (deposition on a substrate) and complexity of obtaining of mass and quantity distribution of WF particles are the disadvantages of PCWF analysis by electron microscopy method.

Failure of the clusters at their passing through separate levels of impactor is a significant disadvantage in using the method of aerodynamic separation.

The disadvantage of PCWF analysis by method of laser grain size analysis consists in dispersion by ultrasonic oscillations in dispersing medium (liquid) taking place before or during the analysis.

Besides, measurement equipment for WF with standard settings to spherical particles [11] is difficult to calibrate since WF particles are mainly the agglomerates of complex and inhomogeneous form and surface.

Chemical composition of the particles along with their dispersion degree is a key factor determining a harmful affect of WF components on health of welder.

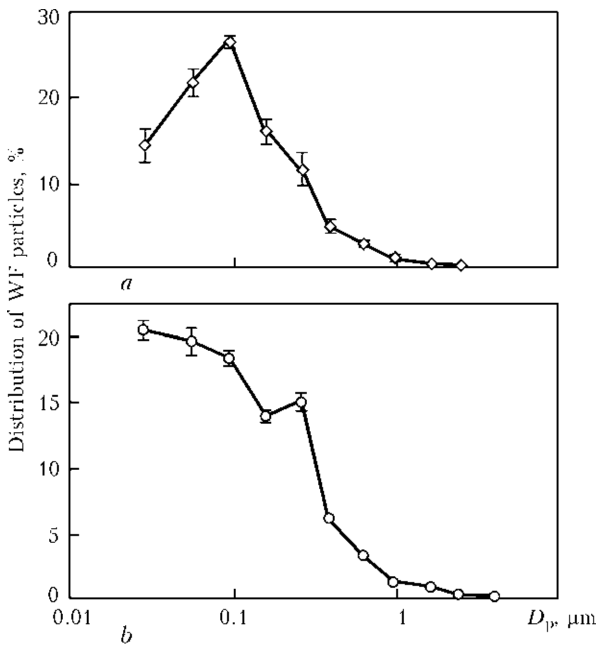

Figure 4. Quantitative distribution of WF particles by dimensions for cellulose- (*a*) and basic-coated (*b*) electrodes

ISO 15011–1 [26] recommends the following analytical methods for determination of element composition of PCWF: inductively coupled plasma — Auger electron spectrometry (ICP — AES); inductively coupled plasma — mass spectrometry (ICP — MS); atomic-absorption spectrometry (AAS); atomic-fluorescent spectrometry (AFS); X-ray fluorescent spectrometry (XRF) for determining aluminum, barium, beryllium, cadmium, cobalt, chromium, copper, iron, manganese, molybdenum, nickel, lead, vanadium, zinc etc.

Ion chromatography and spectrometry are used for determination of hexavalent chromium. It is important that the filter used is to be appropriate for collection of hexavalent chromium. Number of filtering materials (for example, combined cellulose-etheric membrane filters) make a reaction with hexavalent chromium and as a result the valency of the latter is reduced up to three and obtained results have low validity. The filters from quartz fiber, glass fiber and polyvinylchloride obtained successful and wide application.

Ion chromatography and ion-selective electrode (ISE) are used for determination of fluorine.

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ELECTRON BEAM WELDING OF THIN-SHEET THREE-DIMENSIONAL STRUCTURES OF ALUMINIUM ALLOYS

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Variants of improvement of the technology for manufacture of three-dimensional welded structures from thin-sheet elements are considered. Examples of small-size mock-ups of specific products are presented. Recommendations for reducing residual deformations in thin-sheet welded structures are given. Variants of the welded T-joints used in manufacture of stringer panels are shown. Resistance of welded joints to intercrystalline corrosion is estimated.

Keywords: *electron beam welding, aluminium alloys, thin-sheet three-dimensional structures, dissimilar welded joints, mechanical properties, intercrystalline corrosion, crack resistance*

Wide application of aluminium alloys in different fields of industry is determined by a number of their advantages as compared to other structural materials.

Aluminium alloys are characterized by a large range of ultimate tensile strength (100–750 MPa) and high specific strength (due to small density of 2.7 g/cm^3). Besides, they have high heat and electric conductivity and corrosion resistance in different aggressive environments. Aluminium alloys are characterized by good manufacturability, easily subjected to pressure treatment, allow producing intricate shaped sections of them. Parts of aluminium alloys are widely used in different types of structures in ship, automobile and aircraft building and in transport. Here, the riveted and bolted joints are characteristic for the products of aircraft engineering, manufactured of aluminium alloys.

The riveted joint is the main type of joints in the design of a planer, aircraft and helicopter. It operates well at static, fatigue and repeated loadings and allows manufacturing products without distortions and keeping a rigid configuration.

The significant disadvantage of a riveted joint is weighting of a structure, high labor consumption in performing the operations and, as a result, high economic costs.

The application of a bolted joint in aluminium structures is caused by need in periodical dismantle