EXPERIMENTAL AND CALCULATION DETERMINATION OF THE CONCENTRATION OF HARMFUL MATERIALS IN THE WORK ZONE AIR IN COVERED-ELECTRODE WELDING

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Investigation results are presented on dependence of the concentration of harmful materials in the work zone air in manual rutile-cellulose electrode welding upon the distance to the welding arc under different ventilation conditions (general, local and without ventilation), as well as analytical dependencies of the concentration of harmful materials at different points of the work zone upon the intensity of formation of welding fumes and power of the welding arc.

Keywords: *arc welding, covered electrodes, welding fumes, manganese, ventilation, content of fumes in air, forecast*

Pollution of a work zone air with toxic materials in the form of welding fumes (WF) formed during the electric arc process is one of the main harmful industrial factors in welding engineering. Protection of welders and industrial environment against the WF action is performed by using different ventilation systems, which should provide a content of harmful materials in the work zone air not higher than the maximum allowable concentration (MAC). Experimental data on the content of harmful materials in the work zone air under different ventilation conditions are necessary for selection of the system of ventilation and increase of its efficiency in work places of the welders. Obtaining of such data using conventional methods [1, 2] is a time- and labor-consuming task. Thus, it takes virtually one working shift to take a sample of WF only at one point of the welder's work zone when using a specific welding consumable grade. At that the permissible relative error of the data obtained, in accordance with the requirements [3], is ±25 %. This allows providing a selective determination of the material content at a level of not higher than 0.5 MAC. Taking into account that a large amount of domestic and foreign grades of welding consumables has been used at present in welding engineering, such data are easier to forecast from the index of the WF formation intensity, for the determination of which it is necessary to take no more than 3–5 WF samples during a couple of minutes [1].

The aim of present study is to experimentally investigate dependence of the WF concentration in air of the work zone in covered-electrode welding of low-carbon steel upon the WF formation intensity and/or the arc power, distance to the welding location (welding arc) and type of the ventilation system.

Experiments carried out under laboratory conditions at a typical work place for manual arc welding with and without general and local ventilation. The WF samples were taken around the arc at three points at a different distance from it: 55 cm — welder's breathing zone, 100 and 150 cm — work zone. To compare the efficiency of general and local ventilation systems, its productivity was selected to be the same — 1500 m^3/h. A typical axial fan was used in the system of general ventilation, and a welder's table with built-in exhaust device of the type of a uniform suction inclined panel (Figure 1) was used as a local ventilation system. The samples of WF and gases were taken during the process of deposition of beads by using 4 mm diameter rutile-cellulose electrodes ANO-36 on plates of steel St3sp (killed). The process was performed at the direct current of reverse polarity. The welding current was varied in a range of I_w = = 130–230 A, and arc voltage — in a range of U_a = = 24–40 V to determine dependence of the WF emission intensity upon the arc power. Standard methods [1, 2] were used to take the WF samples in the work zone air and determine the content of manganese as the most toxic component in a composition of WF, formed in low-carbon steel welding, and the WF formation intensity. Reliability of the obtained experimental data was checked according to the accepted instructions [3]. Analytical and statistical processing of the established mathematical dependencies was performed by using the special regression analysis-based software developed by the National Research Institute of the Labor Safety [4, 5].

The investigation results on dependencies of the concentration of WF in the work zone air upon the distance to the welding arc (Figure 2, *a*) showed that this concentration is maximal and decreases with increase in the distance to the arc in welding without ventilation, that it is much lower and increases in the presence of general ventilation, and that it is minimal and hardly changes when using local ventilation. The above-said proves the fact that the local ventilation, which in this case also provides reduction of the manganese concentration below the MAC level (not more than 0.2 mg/m^3) both in the breathing zone (at a distance of 55 cm from the arc) and at other points of the work zone (Figure 2, *b*), is the most effective. This is explained by the fact that the WF plume is localized by the local exhaust device already in the welding arc zone and does not propagate in the work zone air.

When using general ventilation, the suction port of which is at some distance from the welder's work place, the WF concentration is much higher than in the previous case, and rises even higher with increase in distance from the welding position. This indicates that air, which is polluted with fume in the arc zone, is transferred in a direction to the location of the suction port of the general ventilation system. The manganese concentration in the work zone air at a small (approximately up to 70 cm) distance from the arc is below the MAC level (see Figure 2, *b*).

Dependence on the WF formation intensity and manganese content at different distances from the welding arc and type of applied ventilation was investigated to predict the content of WF and, in particular, manganese as a decisive toxic element formed in general-purpose electrodes welding of low-carbon steel (see Figure 2). Proportionality coefficients (ratios) K_f for WF and K_{Mn} for manganese between the concentration of the given materials at all points of the work zone, where the WF samples were taken, and intensity of their emission were calculated as follows:

$$K_{f(Mn)} = C_{f(Mn)}/V_{f(Mn)}, \qquad (1)$$

where $C_{f(Mn)}$ is the concentration of WF and manganese, respectively, in the work zone, mg/m^3; and $V_{f(Mn)}$ is the intensity of emission of WF and manganese, equal to 0.807 and 0.036 g/min, respectively.

Processing of the experimental data shown in Figure 2, performed by using the Lagrange interpolation formula [6], allowed deriving the following dependence of the proportionality coefficients upon distance L to the welding arc:

in welding without ventilation

$$K_{f(Mn)} = 0.0039L^2 - 0.019L + 0.0563; \qquad (2)$$

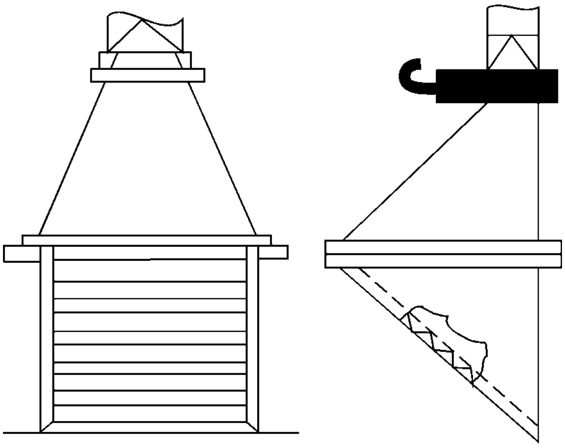


Figure 1. Built-in exhaust device of the type of uniform suction inclined panel over the welder's work table

in welding with general ventilation

$$K_{f(Mn)} = -0.0085L^2 + 0.0295L - 0.011; \qquad (3)$$

and in welding with local ventilation

$$K_{f(Mn)} = -0.0005L^2 + 0.0014L - 0.0003. \qquad (4)$$

The relative error in the developed mathematical models is no more than 1.8 %.

The C_f and C_{Mn} values are found from formula (1):

$$C_{f(Mn)} = K_{f(Mn)}V_{f(Mn)}. \qquad (5)$$

Substituting dependencies (2)–(4) to formula (5) yields the mathematical models for prediction of the concentration of WF and manganese depending upon the intensity of their emission and distance to the welding arc:

in welding without ventilation

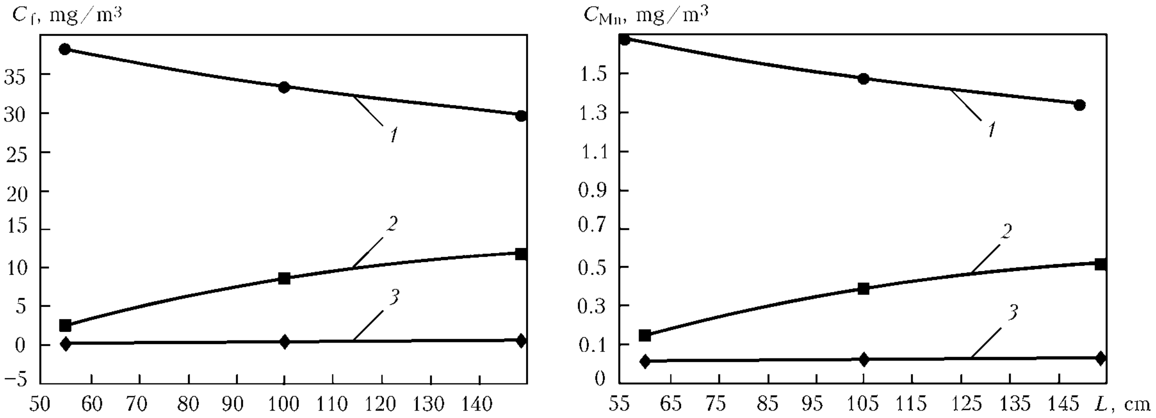
$$C_{f(Mn)} = V_{f(Mn)}(0.0039L^2 - 0.019L + 0.056); \qquad (6)$$

in welding with general ventilation

$$C_{f(Mn)} = V_{f(Mn)}(-0.0085L^2 + 0.0295L - 0.011); \qquad (7)$$

and in welding with local ventilation

$$C_{f(Mn)} = V_{f(Mn)}(-0.0005L^2 + 0.0014L - 0.0003). \qquad (8)$$



a *b*

Figure 2. Dependence of WF C_f (*a*) and manganese concentration C_{Mn} (*b*) in the work zone air upon distance L to the welding arc in arc welding without ventilation (*1*), with general (*2*) and local (*3*) ventilation

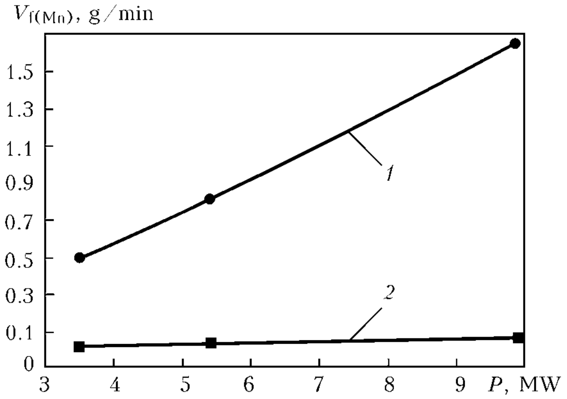


Figure 3. Dependence of the intensity of formation of WF V_f (*1*) and manganese V_{Mn} (*2*) on arc power *P*

Thus, the concentration of these materials at different points of the welder's work zone with or without ventilation can be easily calculated at a high reliability level from the experimental data on the intensity of emission of WF or manganese, the determination of which involves no particular difficulties [1, 2]. Otherwise, if it is impossible to obtain these data, then other, less accurate method, based on the experimentally established dependence of the intensity of formation of WF and manganese upon the welding arc power, can be employed (Figure 3). Analytical processing of these data by the regression analysis method allowed deriving the following dependencies:

$$V_f = -0.178 + 0.187 I_w U_a, \quad (9)$$

$$V_{Mn} = 0.0014 + 0.0058 I_w U_a, \quad (10)$$

where I_w is the welding current, A; and U_a is the arc voltage, V. The relative errors in dependencies (9) and (10) are 2.1 and 3.7 %, respectively; and the ultimate correlation coefficients are 0.999 and 0.994.

Checking accuracy of the calculation data, compared with the experimental ones, showed that their relative error did not exceed 5.3 % (Table).

Generalization of our experimental and calculation data [7] showed that the intensity of emission of WF did not exceed 0.4 g/min in welding with rutile electrodes and 1.0 g/min in welding with cellulose ones. The content of manganese oxides in WF formed in rutile electrode welding was no more than 10.2 %, and in cellulose electrode welding — 5.5 %. The experimental part of this study was performed with the rutile-cellulose electrodes widely used at present. At the same time, the intensity of WF formation under optimal conditions (I_w = 180 A, U_a = 30 V) was 0.81 g/min (more than for the rutile coverings, but less than for the cellulose ones), and the manganese content was 4.45 % (not more than in study [7]).

Results of verification of the calculation data on the content of manganese in the work zone air in welding with electrode ANO-36

Type of ventilation	*L*, m	C_{Mn}, mg/m^3		Relative error, %
		Calculation	Experimental	
Without ventilation	0.55	1.700	1.700	0
General	1.00	0.360	0.380	5.3
Local	1.50	0.024	0.023	4.3

Given that the relative error of the WF content in the work zone air, according to the requirements [3], is ±25 %, the developed mathematical models can be applied for an approximate estimation of pollution of the work zone air with manganese in welding of low-carbon steel by using rutile and rutile-cellulose electrodes of different grades.

Considering that manganese is the main harmful component in composition of WF, determining the labor conditions in manual rutile-cellulose electrode welding of low-carbon steels, to decide on the type of ventilation (general or local) it is necessary to use the data on the concentration of manganese in the work zone air, and to calculate the efficiency of ventilation it is necessary to use the data on its emission intensity.

Results of the investigations proved that the local ventilation is much more efficient than the general one. It allows reducing the manganese concentration below the MAC level in the welder's breathing zone and work zone of the production area (see Figure 2).

Prediction of the WF and manganese content in the work zone to select the type of ventilation and its optimum parameters can be performed from formulae (6)–(8), firstly by experimentally determining the intensity of their emission [1, 2] or calculating it depending on the welding conditions (welding current and arc voltage) from expressions (9) and (10).

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