

Emission of Dust and Gases in Tubular Cored Wire Welding of Steel

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The emission of dusts and gases, which are generated during tubular cored wire welding and which are hazardous to health and the environment, were studied. Tests included various kinds of tubular electrode wires used for welding steel, that is, rutile flux cored wires, basic flux cored wires, and metal cored wires for welding unalloyed, low-alloy, and high-alloy steels as well as self-shielded flux cored wires used for welding low-alloy steels. The research results make it possible to assess the influence of the type of wire and welding conditions on the emission volume and to compare chemical hazards generated during tubular cored wire welding with those typical for other arc welding processes.

arc welding	tubular cored wires	emission of dust and gases
	health hazard	

1. INTRODUCTION

Tubular cored wires constitute a group of ancillary welding consumables whose consumption in developed countries has considerably increased nowadays due to numerous advantages of these materials. The reason for this fact are advantages such as higher welding efficiency, usability for all-position welding, good quality and appropriate shapes of weld, lower consumption of weld metal, and shorter time needed for removing spatters and slag. The expansion of tubular cored wires was initially at the cost of covered electrodes; today these consumables most frequently replace solid wires. Tubular

cored wires include a large number of diversified filler metals, which differ as regards their use for certain basic materials, chemical composition, and weld metal properties.

2. GENERAL DESCRIPTION OF APPLIED WELDING METHODS AND TUBULAR CORED WIRES

Tubular cored wires usually take the form of a metal pipe filled with powdered mineral or metal components or, quite often, a mixture of the two (American Welding Society, 1992). As far as their use is concerned, we distinguish between wires for

- welding with consumable electrode in gas shielding (MIG/MAG),
- arc welding without additional gas shielding (a self-shielded arc),
- submerged arc welding,
- surfacing.

The research in question focused on wires for MIG/MAG welding of steel and self-shielded arc welding of steel.

Tubular cored wires for welding in gas shielding are produced in the largest amount and play the most important role as regards their development and position compared with other consumables. The aforementioned materials make up over 90% of the whole production of tubular electrode wires and are characterised by the most dynamic growth. In relation to the chemical composition of a core, tubular cored wires for welding steel in gas shielding are divided into flux cored wires (i.e., rutile flux cored and basic flux cored wires) and metal cored wires.

The main constituents of flux inner core are silicon, manganese, aluminium, titanium, and zirconium (alloying, deoxidising, and nitrogen-fixing elements) as well as chromium, nickel, molybdenum, and vanadium. These elements are added to a core as metallic powders, metallic oxides, or ferroalloys. Besides, in cores we can also find such alkaline metals as calcium, sodium, potassium, and barium; all of them in chemical compounds—mainly carbonates or silicates. The formulas of cores of tubular cored wires are usually composed in a way that makes it possible to weld both in pure carbon dioxide shielding and in typical mixtures such as 80% Ar + 20% CO₂.

Metal cored wires do not contain or contain only a marginal amount of mineral components. The core of those wires consists mainly of metallic powders and ferroalloys.

Tubular cored wires for welding in gas shielding are used with all the basic groups of steel, yet their predominant practical application is the welding of carbon steels and low-alloy steels of higher strength. The emission of dusts and gases during tubular cored wires welding in gas shielding depends mainly on welding conditions and chemical composition of gas shielding and considerably differs from MAG welding with filler wire. In a survey about the use of tubular electrode wires (Suda, 1999) the most frequent postulate concerning desirable improvements was the reduction of fumes. This fact confirms the existence of acute problems connected with occupational hygiene of tubular cored wire welding.

During self-shielded flux cored wire welding, arc and weld pool shielding is provided by gases and fumes of metals created as a result of disintegration of flux core constituents as well as by slag-forming constituents of the core. The elimination of shielding gas is an advantage of this process and is particularly useful for assembly welding and, therefore, tubular electrode wires are widely used for gas pipeline engineering. The disadvantages related to these wires consist in the emission of weld fumes containing, among others, very harmful barium compounds. Self-shielded flux cored wires are used on a considerably smaller scale than those for welding in gas shielding. Their production is limited only to those with rutile or basic flux cores. The possibility of welding without additional gas shielding depends on a proper amount of deoxidising and nitrogen-fixing constituents, first of all, aluminium, titanium, zirconium, and alloy components such as manganese, nickel, and silicon. Arc and pool shielding during the welding process is created by low-melting, easily evaporating and boiling in the arc iodides, bromides, chlorides, and fluorides of alkaline-earth metals and alkali metals.

3. EMISSION OF DUSTS AND GASES DURING TUBULAR CORED WIRE WELDING

From the metallurgical point of view the flux core of tubular cored wires plays the same role as a covered electrode. Chemical reactions proceeding in the process of tubular cored wires welding are the same as in the case of covered-electrode welding. The same can be said about the pollution emission connected with these two consumables (Hewitt & Hirst, 1992). As a result of high temperature of the electric arc tubular cored wire constituents melt and partly evaporate and metal fumes oxidise. In the atmosphere of lower temperature, through condensation, solid particles (dusts) are created; they are

0.1–0.5 μm in diameter. The diphase-system aerosol generated then is a mixture of these fine dispersion dusts and gases. The dusts generated during tubular welding are composed of oxides, silicates, fluosilicates, fluorides, chlorides, bromides, iodides, metallic, and non-metallic carbonates (Hilton, 1992), whereas gases mainly consist of nitric oxides (NO_x), carbon monoxide (CO), ozone (O_3), gaseous fluorine compounds, and hydrogen fluoride (HF).

The analysis of dust generation during tubular welding and modelling related to forecasting of concentration and chemical composition of dusts generated during tubular welding have proved that the emission of dusts in an arc takes place in two different manners:

- through melting and partial evaporation of metal coating constituents; this is how metal oxides (such as iron, chromium, nickel, manganese, and molybdenum oxides) pass into the air,
- through melting and evaporation of flux core components; this is how titanium, calcium, sodium, potassium, and barium compounds as well as oxides of alloy additions pass into the air.

Tubular cored wire welding is very often characterised as hazardous to workers due to the toxicity and high emission of welding dusts; especially noxious working conditions are associated with welding by means of self-shielded wires. The amount of toxic substances emitted during the aforementioned welding process is far greater than that during covered electrode welding (despite a smaller amount of powder mixture in self-shielded flux cored wires than the amount of coating mixture in covered electrodes; Wegrzyn, 1992). The toxicity of self-shielded wires is mainly connected with a large amount of fluorides (LiF , NaF , CaF_2 , BaF_2 , MgF_2) contained in the filling (Boniszewski, 1992). Tubular welding of high-alloy steels is connected with the emission of carcinogenic-rated hexavalent chromium (Dennis, 1997).

4. METHODOLOGY OF INVESTIGATING DUST AND GAS EMISSION DURING TUBULAR WELDING

The Institute of Welding, Poland, carried out research (Matusiak & Rams, 2000) in order to determine the qualitative and quantitative emission of dusts and gases given off during tubular cored wire welding of steel. The selection of tubular wires used for the research was based on the analysis of the range of the aforementioned wires used for specific steel groups. The tests included

basic flux cored wires, rutile flux cored wires, metal cored wires for welding in gas shielding, and self-shielded flux cored wires. During the investigation two shielding gases were used: CO₂ and 82% Ar + 18% CO₂ (MIX 18).

For testing the influence of welding conditions (welding current, type of shielding gas: Ar + CO₂, CO₂) on the emission of total dust, nitrogen oxides, and carbon oxide during steel welding process, we used wires of renowned producers such as Lincoln Electric (USA), Böhler (Germany, Austria), ESAB (Sweden), and Drahtwarenfabrik Stein (Germany).

For comparative analysis and research-related purposes the following designations were given to tubular cored wires for carbon-steel welding and low-alloy steel welding in gas shielding:

- Z1 basic flux cored wire; all-position welding in shipbuilding; typical chemical composition of weld metal: C 0.06%, Si 0.6%, Mn 1.15%;
- Z2 basic flux cored wire; all-position welding of unalloyed and low-alloy steels in CO₂ shielding or in Ar + (8–25)% CO₂; typical chemical composition of weld metal: C 0.1%, Si 0.4%, Mn 1.0%;
- R1 rutile flux cored wire; all-position welding of low-carbon and low-alloy steels; typical chemical composition of weld metal: C 0.05%, Si 0.5%, Mn 1.4%;
- M1 metal cored wire; typical chemical composition of weld metal: C 0.05%, Si 0.75%, Mn 1.5%;
- M2 metal cored wire; typical chemical composition of weld metal: C 0.07%, Si 0.25%, Mn 1.3%, Cr 1.2%, Ni 2.3%, Mo 1.0%.

For research-related purposes self-shielded flux cored wires were given the following designations:

- W1 rutile flux cored wire for welding austenitic steels of CrNi and CrNi (Mo) type; typical chemical composition of weld metal: C ≤ 0.03%, Mn 1.5%, Cr 19%, Ni 12%, Mo 2.8%;
- W2 rutile flux cored wire for welding austenitic steels of CrNi type; typical chemical composition of weld metal: C ≤ 0.03%, Mn 1.5%, Cr 22.8%, Ni 12.5%;
- W3 wire for welding ferritic-austenitic steels (Duplex); typical chemical composition of weld metal: C ≤ 0.02%, Mn 1.7%, Cr 22.5%, Ni 9.2%, Mo 3.2%.

For the purpose of research, self-shielded flux-cored wires were given the following designations:

- S1 basic and fluoride self-shielded flux cored wire; typical chemical composition of weld metal: C 0.15%, Si 0.19%, Mn 0.75%, Al 0.65%;
- S2 basic and fluoride self-shielded flux cored wire; typical chemical composition of weld metal: C 0.6%, Si 0.21%, Mn 1.65%, Al 1.0%, Ni 0.9%.

Tests were carried out in a hermetic test chamber, which made it possible to conduct mechanised welding on a horizontal welding positioner and fix a welding clamp on a stable base. Figures 1 and 2 show the test station layout.

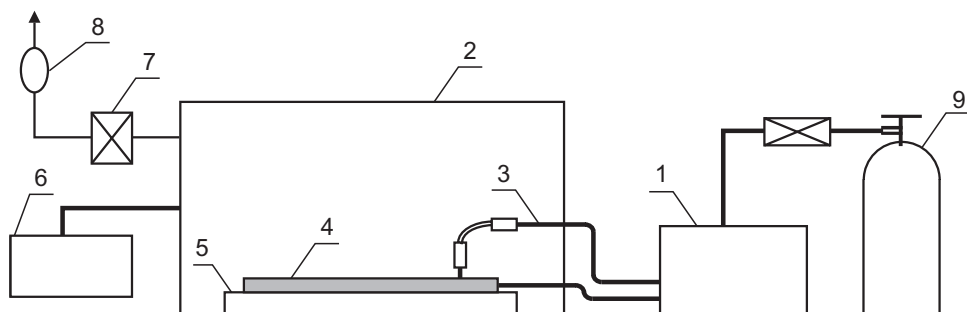


Figure 1. Layout of test station for investigating dust and gas pollution during tubular cored wire welding of steel. Notes. 1—arc welding power source, 2—test chamber, 3—welding torch, 4—welding material, 5—welding manipulator, 6—gas analyser TESTO-33 (Testoterm, Germany), 7—dust measurement filter, 8—exhaust fan, 9—shielding gas cylinder.



Figure 2. Test station for investigating dust and gas emission during tubular cored wire welding.

The qualitative and quantitative determination of dusts emitted during tubular welding of steel was conducted at the station showed in Figures 1 and 2. The welding process was carried out inside the chamber with the fume extractor switched on. For the quantitative determination of dusts we used the gravimetric method, which consists in stopping generated dusts on previously weighed filters made of unwoven fabric, the filters being placed on extracting nipples. On the basis of the weight of the stopped dusts we were able to determine

- the weight emission of total dust (mg/kg of filler metal),
- the temporal emission of total dust (mg/s).

The chemical constituent of emitted dusts included the following elements: Fe, Mn, Cr, Ni, Si, F, Cu.

The emission of gases (nitrogen oxides and carbon oxides) during tubular welding of steel was determined by means of a gas analyser TESTO-33 (Testoterm, Germany). A sampling probe was placed inside the test chamber and for 60 s a tubular welding process was continued with the fume extractor switched off. The measurement results were registered after the concentration read-out of every gas had reached stability. The measurement included

- nitrogen oxide concentration (ppm, mg/m^3),
- carbon dioxide concentration (ppm, mg/m^3),
- carbon monoxide concentration (ppm, mg/m^3),
- the temperature inside the chamber.

The following values were determined: weight emission of NO, NO₂, CO (mg/kg of filler metal); temporal emission of NO, NO₂, CO (mg/s).

5. TEST RESULTS

Tables 1–4 show selected results of dust and gas emission for specific tubular cored wires (average values). Figures 3–6 present a comparative analysis of pollution emission indexes during tubular cored wire welding of steel in gas shielding, welding with self-shielded flux cored wires and solid wires.

TABLE 1. Dust and Gas Emission During Welding of Carbon Steel and Low-Alloy Steel in Gas Shielding by Means of a Tubular Cored Wire Electrode Wire of 1.2-mm Diameter; Emission Measured at Various Current Intensity, I (A)

Shielding Gas		Pollution Emission (mg/s)								
		Dusts			NO _x			CO		
		I = 200	I = 250	I = 300	I = 200	I = 250	I = 300	I = 200	I = 250	I = 300
Basic Flux Cored Wire Z1										
CO ₂	\bar{x}	5.67	8.86	19.60	0.03	0.05	0.03	4.57	8.96	13.00
MIX 18	\bar{x}	4.70	7.42	14.37	0.03	0.00	0.00	4.76	6.45	7.78
Basic Flux Cored Wire Z2										
CO ₂	\bar{x}	5.59	10.56	21.10	0.04	0.05	0.03	7.56	12.13	14.47
MIX 18	\bar{x}	5.12	8.77	17.79	0.03	0.03	0.03	4.10	5.66	9.28
Rutile Flux Cored Wire R1										
CO ₂	\bar{x}	7.29	13.50	14.86	0.06	0.05	0.04	7.10	9.29	16.88
MIX 18	\bar{x}	5.64	9.60	9.75	0.02	0.02	0.02	2.72	6.36	9.58
Metal Cored Wire M1										
MIX 18	\bar{x}	3.14	3.75	4.53	0.02	0.02	0.02	3.02	3.61	4.02
Metal Cored Wire M2										
MIX 18	\bar{x}	14.78	18.75	14.74	0.08	0.08	0.10	5.15	7.51	9.21

Notes. MIX 18—CO₂ and 82% Ar + 18% CO₂, \bar{x} —average value.

TABLE 2. Dust and Gas Emission During Welding of High-Alloy Steel in Gas Shielding by Means of a Tubular Cored Wire of 1.2-mm Diameter; Emission Measured at Various Current Intensity, I (A)

Shielding Gas		Pollution Emission (mg/s)							
		Dusts			NO _x			CO	
		I = 150	I = 200	I = 250	I = 150	I = 200	I = 250	I = 150	I = 200
Rutile Flux Cored Wire for Welding Austenitic Steel W1									
MIX 18	\bar{x}	5.36	6.32		0.00	0.00		2.36	3.37
Rutile Flux Cored Wire for Welding Austenitic Steel W2									
MIX 18	\bar{x}	4.07	5.86		0.00	0.00		1.65	2.24
Wire for Welding Ferritic and Austenitic Steel (Duplex) W3									
MIX 18	\bar{x}	6.14	10.65	13.54	0.02	0.05	0.08	3.23	5.78

Notes. MIX 18—CO₂ and 82% Ar + 18% CO₂, \bar{x} —average value.

TABLE 3. Dust and Gas Emission During Welding of Low-Alloy Steel by Means of a Self-Shielded Flux Cored Wire; Emission Measured at Various Current Intensity, I (A)

	Pollution Emission (mg/s)								
	Dusts			NO _x			CO		
\bar{x}	Self-Shielded Flux Cored Wire S1								
	I = 170	I = 220	I = 250	I = 170	I = 220	I = 250	I = 170	I = 220	I = 250
	18.62	24.86	32.56	0.44	0.81	1.37	0.03	0.06	0.09
\bar{x}	Self-Shielded Flux Cored Wire S2								
	I = 200	I = 250	I = 300	I = 200	I = 250	I = 300	I = 200	I = 250	I = 300
	29.16	41.62	55.11	0.30	0.62	1.50	0.02	0.03	0.04

Notes. \bar{x} —average value.

TABLE 4. Chemical Composition of Dusts During Tubular Welding of Steel

Composition of Shielding Gas	Chemical Composition (% m/m)						
	Fe	Mn	Cr	Ni	Si	F	Cu
Basic Flux Cored Wire Z1							
CO ₂	43.69	10.92	0.028	0.01	3.33	12.36	0.044
MIX 18	40.01	9.28	0.026	0.01	1.83	13.06	0.044
Basic Flux Cored Wire Z2							
CO ₂	46.21	8.33	0.033	0.155	2.67	14.11	0.071
MIX 18	43.68	8.72	0.021	0.108	2.99	14.19	0.036
Rutile Flux Cored Wire R1							
CO ₂	34.72	11.00	0.02	0.01	4.00	5.26	0.047
MIX 18	29.20	11.19	0.018	0.01	4.43	6.23	0.039
Metal Cored Wire M1							
MIX 18	45.98	14.65	0.09	0.17	4.44	—	0.16
Metal Cored Wire M2							
MIX 18	38.63	17.20	0.83	1.68	3.23	6.56	0.31
Rutile Flux Cored Wire For Welding Austenitic Steels W1							
	Fe	Mn	Cr	Ni	Si	F	Mo
MIX 18	14.81	8.57	8.25	2.50	3.31	—	0.57
Rutile Flux Cored Wire For Welding Austenitic Steels W2							
MIX 18	13.16	8.41	5.28	2.04	1.41	—	—
Wire for Welding Ferritic And Austenitic Steel (Duplex) W3							
MIX 18	13.80	5.20	7.68	1.23	3.49	12.93	0.86
Self-Shielded Flux Cored Wire S1							
	Fe	Mn	Cr	Ni	Si	F	Ba
—	50.01	3.27	0.02	0.38	0.99	9.7	1.67
Self-shielded flux cored wire S2							
—	11.50	2.70	0.01	0.12	0.41	26.01	19.15

Notes. MIX 18—CO₂ and 82% Ar + 18% CO₂.

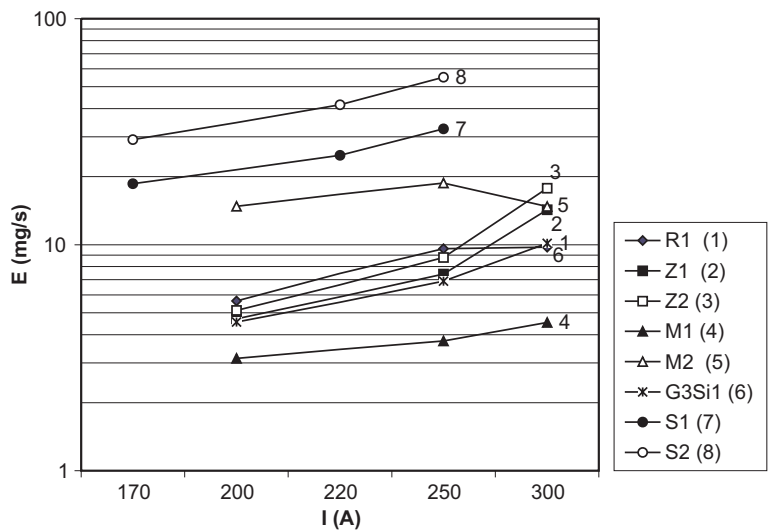


Figure 3. Emission of dusts during tubular cored wires arc welding.

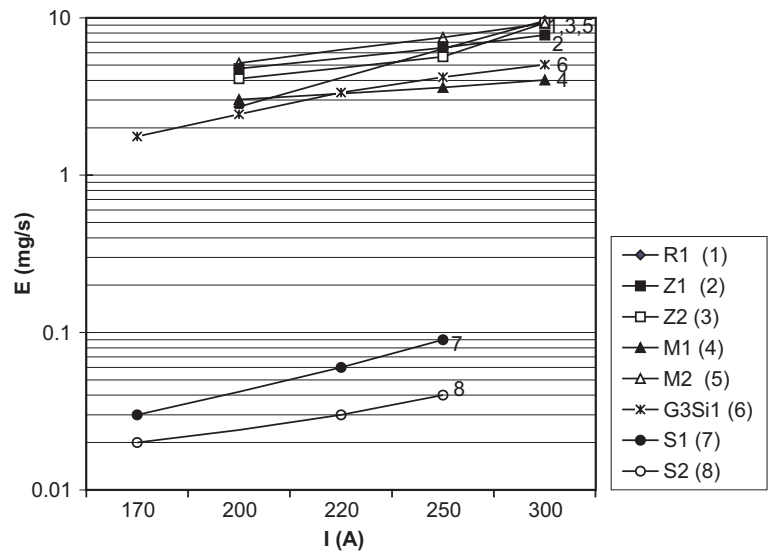


Figure 4. Emission of carbon monoxide (CO) during tubular cored wires arc welding.

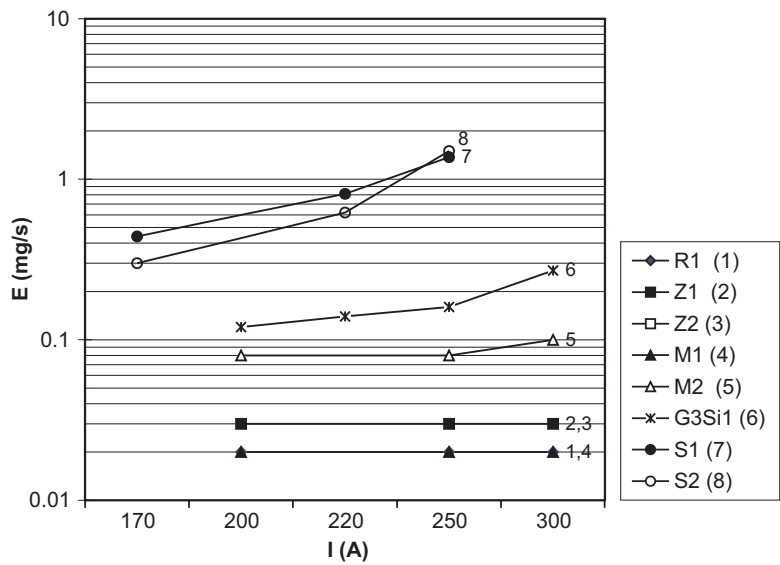


Figure 5. Emission of nitric oxides (NO_x) during tubular cored wires arc welding.

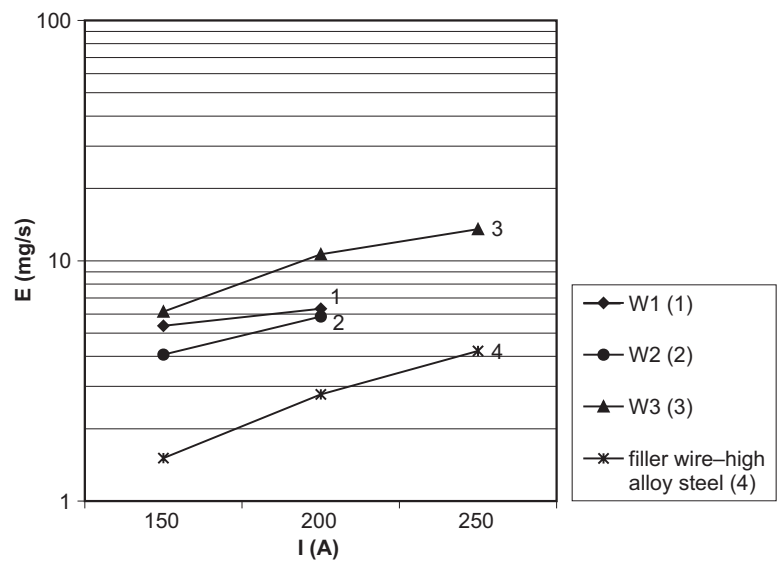


Figure 6. Emission of dusts during tubular cored wires arc welding of high-alloy steels.

5.1. Analysis of Pollution Emission Tested During Tubular Cored Wire Welding in Gas Shielding

Time and weight emission of dust and carbon monoxide during tubular welding in MIX 18 shielding is lower than in the case of welding in CO₂. The application of a gas mixture makes it possible to reduce the amount of emitted pollution by 20–45%, especially at higher current parameters (250–300 A, Table 5).

TABLE 5. Emission of Dust (\bar{x}) and Carbon Monoxide (\bar{x}) During Welding of Steel by Means of Gas Shielded Tubular Cored Wires at Current $I = 300$ A, for CO₂ and MIX 18

Type of Tubular Cored Wires	Total Dust Emission (mg/s)		CO Emission (mg/s)	
	CO ₂	MIX 18	CO ₂	MIX 18
Rutile flux cored wire (R1)	14.86	9.75	16.88	9.58
Basic flux cored wire (Z2)	21.10	17.79	14.47	9.28
Basic flux cored wire (Z1)	19.60	14.37	13.00	7.78

Notes. MIX 18—CO₂ and 82% Ar + 18% CO₂; \bar{x} —average value.

Emission of nitric oxides during tubular cored wire welding is a few times (even 10 times) lower than in the case of welding with a solid wire G3Si1 (Table 6, Figure 5).

TABLE 6. Emission of Nitric Oxides During Welding by Means of Tubular Electrode Wires and Solid Wires

Type of Tubular Cored Wires	Emission of NO _x (mg/s)
Rutile flux cored wire (R1)	0.02–0.05
Basic flux cored wires (Z1, Z2)	0.02–0.05
Metal cored wires (M1, M2)	0.02–0.10
Solid wire (G3Si1)	0.14–0.62

The factors of pollution emission for different types of tubular electrode wires and for two values of welding current, which have been compiled in Table 7, confirm that emission is predominantly influenced by current parameters of the welding process. It still remains rather problematic to evaluate to what extent the chemical constitution of the flux core affects pollution emission. In low current conditions tubular cored wires are characterised by a higher dust emission than in the case of rutile or basic flux cored wires.

TABLE 7. Emission of Total Dust (\bar{x}) and Carbon Monoxide (\bar{x}) During Welding by Means of Different Types of Tubular Cored Wires in MIX 18 Shielding (82% Ar + 18% CO₂)

Type of Tubular Cored Wires	Total Dust Emission (mg/s)		CO Emission (mg/s)	
	I = 200	I = 300	I = 200	I = 300
Rutile flux cored wire (R1)	5.54	9.75	2.72	9.58
Basic flux cored wire (Z2)	5.12	17.79	4.10	9.28
Metal cored wire (M2)	14.78	14.74	5.15	9.21

Notes. \bar{x} —average value, I—welding current (A).

Emission of dust and carbon monoxide during welding by means of shielded tubular electrode wires is higher than in the case of solid wires (G3Si1; Table 8, Figures 3–4).

TABLE 8. Emission of Total Dust and Carbon Monoxide During Welding by Means of Tubular Cored Wires and Solid Wires

Type of Tubular Cored Wires	Total Dust Emission (mg/s)	CO Emission (mg/s)
Rutile flux cored wire (R1)	7.29–14.86	7.10–16.88
Basic flux cored wire (Z2)	5.59–21.10	7.56–14.47
Metal cored wire (M2)	14.74–18.75	5.15–9.21
Solid wire (G3Si1)	1.39–10.15	1.19–5.04

Chemical composition of dust depends mainly on the constitution of the flux inner core of a tubular wire. Table 9 shows a comparison of the percentages of some dust constituents generated during welding with different shielded tubular cored wires, solid wire (G3Si1), and covered electrodes (ER 146, EB 146).

TABLE 9. Chemical Constitution of Dust (% m/m) Generated During Welding by Means of Tubular Cored Wires, Solid Wire, and Covered Electrodes

Type of Tubular Electrode Wires	Mn	Si	F	Cr	Ni
Rutile flux cored wires	11.2	4.5	6.2	0.02	0.01
Basic flux cored wires	8.7	2.6	14.2	0.02	0.03
Metal cored wires	17.2	3.2	6.5	0.80	1.68
Wire for welding ferritic and austenitic steel	5.2	3.4	12.0	7.68	1.23
Rutile flux cored wire for welding austenitic steels	8.5	3.3	—	8.25	2.50
Solid wire (G3Si1)	11.0	3.5	—	0.03	0.03
Rutile electrode ER 146	6.3	8.2	1.1	—	—
Basic electrode EB 146	4.2	2.2	11.5	—	—

Test results of the chemical constitution of dusts from tubular cored wires with different inner core constitution proved that metal cored wires are characterised by a large amount of manganese oxides (17% m/m of pure Mn), chromium (0.8% m/m), and nickel (1.68% m/m) in emitted dust. At the same time a considerable content of fluorides in the dust was found in the case of basic flux cored wires (14% m/m F). A comparison of the chemical composition of dusts from tubular cored wires and solid wires proves tubular cored wire welding to be definitely disadvantageous because of greater toxicity of generated dusts. This is due to a large content of manganese, fluorine, chromium, and nickel. A separate group is formed, as far as health hazard is concerned, by tubular wires for welding austenitic steel as well as ferritic-austenitic steel. Dusts generated while welding with these wires are characterised by a high concentration of chromium (8.25% m/m) and nickel (2.5% m/m).

Tubular welding of high-alloy steel in mixed gas shielding entails a far (several times) greater emission of dust to the environment than in the case of filler wire—high-alloy steel welding (Figure 6).

5.2. Analysis of Test Results Related to Pollution Emission During Welding of Steel by Means of Self-Shielded Flux Cored Wires

Current parameters have a substantial influence on the volume of dust and gas pollution during welding of steel by means of self-shielded flux cored wires; the increase in welding current results in an increase in pollution emission (Figures 3–5).

During welding with self-shielded flux cored wires the emission of carbon monoxide is low: CO emission factors are even 100 times lower than in the case of shielded tubular cored wires and solid wires.

Emission of dusts and nitric oxides during welding by means of self-shielded flux cored wires is a few times higher than that in the case of shielded tubular cored wires and solid wires (Table 10).

Toxicity of self-shielded flux cored wires is connected with a large content of fluorides in the dust. The tests revealed the content of pure fluorine in the dust from S2 wire at the level of 26.01% m/m, and for S1 wire at the level of 9.7% m/m. Dust of both self-shielded flux cored wires examined showed the presence of barium produced as a result of break-down of barium fluoride BaF_2 added to the inner core. The content of barium in the dust from S2 wire amounted to 19.15% m/m, whereas the content of barium in the dust from S1 wire was only 1.67% m/m.

TABLE 10. Comparison of Total Dust Emission (\bar{x}) and Carbon Monoxide Emission (\bar{x}) During Welding of Steel With Shielded Tubular Cored Wires, Self-Shielded Flux Cored Wires, and Solid Wires

Type of Wire	Total Dust Emission mg/s)		NO _x Emission (mg/s)	
	I = 150	I = 300	I = 150	I = 300
Rutile flux cored wire (R1)	3.63	9.75	0.04	0.06
Basic flux cored wire (Z2)	3.68	17.79	0.02	0.03
Metal cored wire (M2)	10.60	14.74	0.09	0.10
Self-shielded flux cored wire (S2)	29.16	55.11	0.30	1.50
Solid wire (G3Si1)	2.75	10.15	0.06	0.27

Notes. \bar{x} —average value, I—welding current (A).

6. CONCLUSIONS

On the basis of research on the emission of dusts and gases generated during tubular cored wire welding of steel it is possible to draw the following conclusions:

1. The process of tubular cored wire welding in gas shielding and self-shielded flux cored wires is dangerous for workers due to a very high emission of welding fumes.
2. The chemical constitution of pollution generated during welding with rutile and basic flux cored wires depends mainly on the constitution of the flux inner core of a tubular electrode wire.
3. The emission of pollution from tubular cored wires for welding in gas shielding is greater than in the case of solid wires and covered electrodes.
4. The composition of the shielding gas and the parameters of the arc influence the volume of dust and gas emission during tubular cored wire welding of steel in gas shielding. The increase in welding current entails an increase in pollution emission, whereas the use of mixed gases makes it possible to reduce the volume of emitted pollution.
5. Toxicity of shielded tubular cored wires is connected with a high content of manganese, fluorine, chromium, and nickel in dusts.
6. The amount of toxic substances emitted during welding with self-shielded flux cored wires is a number of times higher than that during welding by means of covered electrodes, solid wires, and gas shielded tubular cored wires.
7. Current parameters influence the volume of dust and gas emission during welding of steel with self-shielded flux cored wires.

8. While assessing health hazards during tubular welding of steel, among the most potent chemical factors one can rate fluorides, hexavalent chromium, and barium compounds.

7. SUMMARY—HEALTH HAZARD RELATED TO DUSTS AND GASES EMITTED DURING TUBULAR CORED WIRE WELDING

The emission of dusts and gases, which are related to tubular cored wire welding and which are hazardous to health and the environment, was the subject of this research. The tests included various kinds of tubular cored wires used for welding steel, that is, rutile flux cored wires, basic flux cored wires, and metal cored wires used for welding unalloyed, low-alloy, and high-alloy steels as well as self-shielded flux cored wires for welding low-alloy steel. The research results make it possible to assess the influence of the type of wire and welding conditions on emission volume and compare the chemical hazards generated during tubular cored wire welding with those typical for other arc welding processes. This comparison shows that tubular welding is one of the most environmentally burdensome welding processes. At the same time numerous written sources say that the consumption of these welding consumables in all countries have been constantly increasing and there is no evidence that this process will soon come to a conclusion. Despite the unquestionable technical advantages of the consumables in question their end-users emphasise the existing issue of noxious emission. Should therefore a relatively high level of emission of noxious dusts and gases accompanying tubular cored wire welding justify preventing the application of these materials? Having taken into consideration all the characteristics of alternative welding methods we must object.

The hazard to health and the environment related to tubular cored wire welding can be lessened in many ways:

- by selecting wires that meet technical requirements but are less harmful,
- by ensuring welding conditions that minimise pollution emission,
- by implementing appropriate ventilation systems.

Pressed by end-users requiring less noxious consumables, manufacturers of tubular electrode wires are developing new formulas. As a result more and more specialists notice positive changes in this field (Tashibana, 2000). Some opportunities to reduce pollution emission during tubular welding in gas

shielding can be found in less noxious wires such as metal cored wires, which are particularly convenient for high current conditions. Research has shown that arc shielding composed of mixed gases rather than of CO₂ can also considerably decrease unwanted emission. Another possibility lies in the reduction of current, which although deteriorating work efficiency in individual cases may be worth considering. The aforementioned measures ensure a substantial reduction of emission, however in order to ensure appropriate working conditions it is absolutely necessary to provide stations for tubular welding with local ventilation systems.

The tests with self-shielded flux cored wires prove that these consumables cause a substantially greater emission of noxious agents than other tubular cored wires. The said wires are used almost exclusively for assembly work and their total consumption is not big, but a high weight emission factor and considerable concentration of toxic constituents in dust (barium and fluorine compounds) demand elaborate precautions. It is of especially great importance in cases when a welding process takes place in rooms with a limited change of air such as closed spaces of building structures or welding booths (tents), which might even require permanent monitoring of noxious substances in the atmosphere.

Closing we can say that currently available devices and technologies make it absolutely possible to ensure that this modern and efficient method of tubular cored wire welding is safe both for human health and the environment.

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