IOP Conf. Series: Materials Science and Engineering **400** (2018) 022028 doi:10.1088/1757-899X/400/2/022028

Experimental assessment of gases and fumes developed during gas metal arc welding

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Abstract: Selecting the appropriate welding technique, the optimum parameters and the proper welding wire - shielded gas couple, the gases and fumes can be reduced and, consequently, the risks for the welder's health and the impact on the environment are diminished. The main goal of this research was focused on the evaluation of carbon monoxide concentration and of microparticles amount that are produced during Metal Active Gas Welding, Flux-Cored Arc Welding and Metals-Cored Arc Welding processes, using different filler metals and applying different feed wire speeds. Eleven wires (solid, basic and rutile flux-cored, low fume flux-cored, metal-cored, low fume metal-cored), in combination with shielding gas such as carbon dioxide or Corgon 18, a two-gases mixture of carbon dioxide and argon, have been used in the experimental research. Combining the wire type, the shielding gas and modifying the wire feed speed, forty-five samples were performed by deposition welding. The experimental data in terms of carbon monoxide concentration and microparticles amount produced during welding were processed and comparatively discussed. The investigations revealed that the lowest risk on the welder's health and the lowest impact on the environment are achieved during Metal-Cored Arc Welding with low fume metal-cored wire and Corgon 18 shielding gas.

1. Introduction

Welding produces various gases and fumes that cause both short and long-term health effects if the process is not properly controlled. The risk on the welder's health and the impact on the environment are strongly influenced by [1], [2], [3]:

- a multitude of factors such as heat, radiation, noise, smoke, gas, risk of burns and electric shock, and even the uncomfortable conditions of this kind of activity (closed spaces);
- a large diversity of fumes and gases chemical composition that depends on welding method, base and filler materials, shielding gas and welding environment;

Due to the interest increasing for the occupational safety and health, strict rules, regulations and standards have been developed at international level, as well as at European level. Starting with the accession of Romania to the European Union (2007), the national legislation in terms of reducing the gases and fumes generated during welding had to be harmonized with the European legislation. Consequently, five standards specific to this topic, SR EN ISO 15011/1 to SR EN ISO 15011/5, have been implemented last decade in the welding field.

Due to the great advantages provided by the Gas Metal Arc Welding (GMAW) technique, its applicability in industry of aeronautics, automotive, shipbuilding, pipelines fabrication and transport has consistently increased. Researchers worldwide, especially from highly industrialized countries, investigated the fumes and gases produced by fusion Metal Inert Gas - Metal Active Gas (MIG-MAG) welding processes and reported scientific results connected to this topic [4]-[14]. However, there are still aspects that have not been reported and a comparative investigation on carbon monoxide and microparticles generated in the welding variants of GMAW - such as Metal Active Gas Welding (MAG), Flux-Cored Arc Welding (FCAW) and Metal-Cored Arc Welding (MCAW) - provides new useful and significant information. The paper presents the comparative results achieved by assessing the CO concentration and the microparticles amount, produced during deposition welding by MAG-C, MAG-M, FCAW and MCAW, in a variety of filler metals - shielding gases combinations. Additionally, the wire feed speed influence on the CO and the microparticles amount was investigated.

2. Materials and Methods

The investigations were performed in the *Advanced Research in Welding Centre - SUDAV* from "Dunarea de Jos" University, Department of Manufacturing Engineering. The materials used in the experimental programme are listed and described below:

- *base material*: two sheets of 500x150x14mm dimensions, made of EH 36 steel grade that is a High Strength Low-Alloy Steel (HSLA) used in shipbuilding. The chemical composition, according to the analysis certificate of chemical composition provided is presented in table 1.
- *filler metals:* eleven solid, flux-cored and metal-cored wires, ordinary and low fume wires with diameter of 1.2 mm. The chemical composition of the deposited metaldepending on the welding wire type, is presented in table 2.
- *shielding gas:* carbon dioxide (C1) and Corgon 18 (M21).

Table 1. Chemical composition of EH36 shipbuilding steel.

Base material	C	Mn	Si	P	S	Cu	As	Ti	V
	Cr	Ni	Mo	Al	Nb	V	B	N_2	Ca
EH36	0.152	1.41	0.36	0.015	0.006	0.037	0.004	0.014	0.001
	0.03	0.027	0.003	0.046	0.03	0.001	0.0001	0.0065	0.0001

For determining the CO concentration and the microparticles amount, two devices were employed, the Multiyzer NG gas analyzer and a MicroDust Pro microparticles analyser, shown in figure 1 and figure 2, respectively. They were positioned at distance of 500 mm from the sheets surfaces that is, usually, the same distance maintained during welding between the worker and the electric arc. Before starting the experiments, a light source was positioned inside of the chamber to ensure the proper control and a good visibility on the process.

As figure 3 illustrates, an experimental stand was designed and built in the *Welding Research Laboratory* whose main elements are Aristo Lud 320 power supply, Railtrac FW 1000 welding equipment and air-tight chamber. The weld beads were achieved by deposition welding on EH34 steel sheets, in PA position, DC^+ reverse polarity, applying MAG-C, MAG-M, FCAW and MCAW procedures. The process parameters which were maintained constant the entire experimental programme are presented in the table 3. Combining six filler metal types, two shielding gases and modifying the value of the feed wire speed from 5.0 to 6.0 m/min, 45 samples have been achieved. These parameters combinations and the codes of the samples subjected to the gases and fumes analysis are available in table 4.

Table 2. Chemical composition of deposited metal.

Welding wire code	Welding wire type	C	Mn	Si	P	S	Al	Cr	Ni
		Mo	V	Cu	Nb	N	B	Ti	-
S1 - ER70S6	solid	0.065	1.44	0.825	0.014	0.008	0.003	0.025	0.015
		0.004	0.003	0.101	-	-	-	-	-
B1 - E70T5CJH4	basic flux-cored	0.043	1.22	0.280	0.0087	0.0061	0.0005	0.0367	0.0106
		0.0039	0.002	0.0564	0.0012	-	-	-	-
R1 - E71T1CJH4	rutile flux-cored	0.049	1.180	0.379	0.011	0.010	0.006	0.041	0.027
		0.013	0.012	0.013	0.014	0.0037	0.006	0.034	-
R2 - E71T1MH4	rutile flux-cored	0.046	1.488	0.540	0.010	0.010	-	-	-
		-	-	-	-	-	-	-	-
R3 - E71T1MH4	rutile flux-cored	0.058	1.140	0.302	0.014	0.008	0.005	0.034	0.023
		0.005	0.012	0.094	0.013	-	-	-	-
R4 - E71T1CH8	low fume flux-cored	0.026	1.44	0.51	0.011	0.013	-	-	-
		-	-	-	-	-	-	-	-
R5 - E71T1H4	low fume flux-cored	0.047	0.70	0.498	0.015	0.007	0.013	0.047	0.070
		0.027	0.018	0.099	0.016	-	0.007	0.061	-
P1 - E70C6MH4	metal-cored	0.070	1.600	0.423	0.013	0.018	-	0.040	0.026
		0.010	0.002	0.058	0.003	0.0048	-	-	-
P2 - E70C6MH4	metal-cored	0.0787	1.320	0.616	0.0142	0.010	0.0214	0.0184	0.0196
		0.0081	0.006	0.160	-	-	-	-	-
P3 - E70C6MH4	metal-cored	0.070	1.350	0.326	0.011	0.006	0.011	0.034	0.021
		0.007	0.003	0.060	0.003	-	-	-	-
P4 - E70C6MH4	low fume metal-cored	0.018	1.320	0.818	0.009	0.022	-	0.034	0.024
		0.017	0.001	0.032	0.004	-	0.0031	0.030	-

Figure 1. Multiyzer NG device.

Figure 2. MicroDust Pro device.

Table 3. Parameters maintained constant during process.

Parameters of the deposition welding			
wire feed speed, v_e	20 cm/min	welding speed, v_s	20 cm/min
swinging width, L_p	15 mm	gas protection flow, Q_G	18 l/min
swinging speed, v_p	5 mm/s	noozle-plate distance, h_{dp}	15 mm

The experimental data in terms of the maximum concentrations of CO gas and maximum amount of microparticles were collected for each sample, using the Multiyzer NG analyser of gases and, respectively, the Microdust Pro device. In order to avoid the contamination and the modification of the experimental results, the air-tight chamber was ventilated to completely remove the gases and the microparticles remained after performing the previous weld bead. The filler metal was changed in accordance with the welding conditions designed for each sample code and parameters set.

Figure 3. Images recorded during experimental programme [15], [16].
a - general view; b, c - air-tight chamber used in the experimental research (without and hermetically closed, respectively; d - experimental stand; e - collecting the experimental data; f - weld beads.

Table 4. Welding process variables applied in the experimental program.

Set no.	Sample no.	Filler wire code	Shielding gas	r_{feed} , (m/min)	I_{weld}, (A)	U_{wa} (V)
	1			5.0	170	25.5
1	2	S1 - ER70S6	C1	5.5	200	26.0
	3			6.0	230	26.5
	4			5.0	120	19.5
2	5	B1 - E70T5CJH4	C1	5.5	145	20.0
	6			6.0	170	21.0
	7			5.0	130	20.0
3	8	R1 - E71T1CJH4	C1	5.5	155	22.0
	9			6.0	185	24.0
	10			5.0	130	20.0
4	11	R2 - E71T1MH4	C1	5.5	160	22.0
	12			6.0	190	24.0
	13			5.0	130	20.0
5	14	R3 - E71T1MH4	C1	5.5	160	22.0
	15			6.0	190	24.0
	16			5.0	140	21.0
6	17	R4 - E71T1CH8	C1	5.5	160	22.5
	18			6.0	180	24.0
	19			5.0	140	21.0
7	20	R5 - E71T1H4	C1	5.5	165	22.5
	21			6.0	190	24.0
	22			5.0	170	25.5
8	23	S1 - ER70S6	M21	5.5	200	26.0
	24			6.0	230	26.5

	25			5.0	120	19.5
9	26	B1 - E70T5CJH4	M21	5.5	145	20.0
	27			6.0	170	21.0
	28			5.0	130	20.0
10	29	R2 - E71T1MH4	M21	5.5	160	22.0
	30			6.0	190	24.0
	31			5.0	135	20.0
11	32	R3 - E71T1MH4	M21	5.5	160	22.0
	33			6.0	185	24.0
	34			5.0	130	30.0
12	35	P1 - E70C6MH4	M21	5.5	135	31.0
	36			6.0	180	32.0
	37			5.0	130	30.0
13	38	P2 - E70C6MH4	M21	5.5	155	31.0
	39			6.0	180	32.0
	40			5.0	130	30.0
14	41	P3 - E70C6MH4	M21	5.5	155	31.0
	42			6.0	180	32.0
	43			5.0	120	30.0
15	44	P4 - E70C6MH4	M21	5.5	150	30.5
	45			6.0	180	31.0

3. Results and discussion

The experimental data were processed and plotted, as figures 4 and 5 illustrate. It is noticed that increasing the feed wire speed from 5.0 mm/min to 6.0 mm/min, both the CO concentration and the microparticles amount increase, no matter what filler metal type and shielding gas have been employed in the tests. This phenomenon is caused by the increase of filler metal quantity that determines an increase of the melting rate and, consequently, more gases and fumes are produced.

If the C1 shielding gas is replaced with M21 shielding gas, both the CO concentration and the microparticles amount decrease, irrespective of filler metal type. This decrease is explained by the chemical composition of the shielding gas, C1 having 100% CO_2 and M21 consisting in 18% CO_2 plus 82% Ar. Besides, the mixture of CO_2 and Ar is preferred by welders due to better stability of the electric arc achieved during welding.

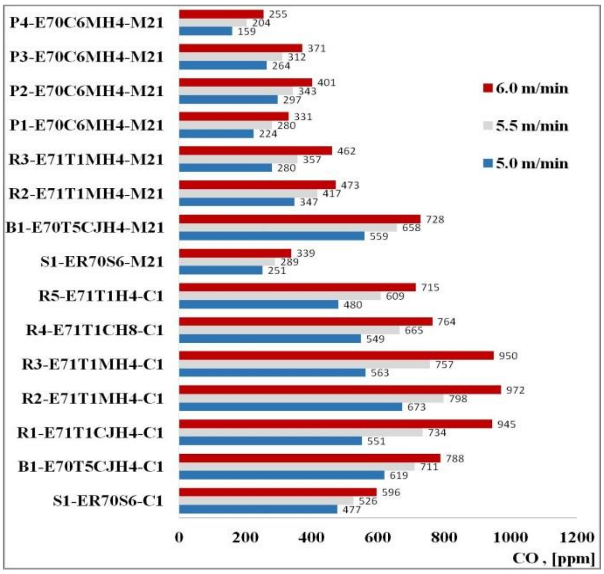

Figure 4. Maximum concentration of CO vs. welding conditions.

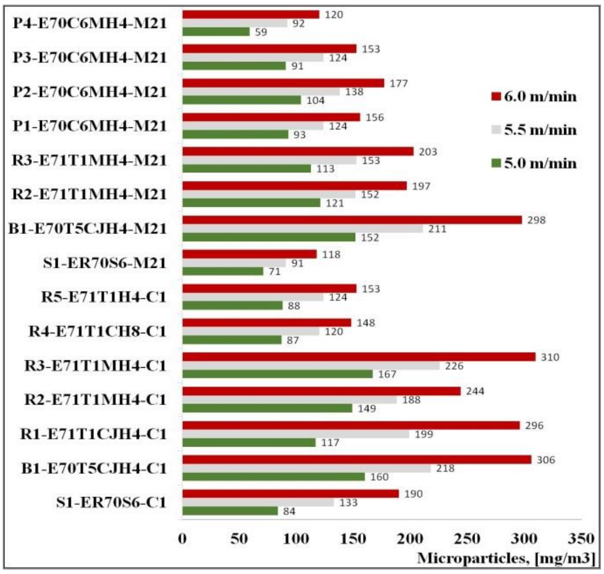

Figure 5. Maximum amount of microparticles vs. welding conditions.

Analysing the chart of the CO concentrations, it is obviously that the highest risk factor on the welder's health is specific to FCAW with largest feed wire speed (6.0 m/min) and the use of the R3 - E71T1MH4 rutile flux-cored wire and C1 shielding gas. This process variant generates the highest 950 ppm carbon monoxide concentration. The "green" variant is provided by MCAW with the smallest feed speed (5.0 m/min) and use of the P4 - E70C6MH4 low fume metal-cored wire and M21 shielding gas. In this case, the maximum CO concentration is the lowest value (159 ppm) from all data analysed.

As regards the microparticles amount, the chart from figure 5 reveals that the most dangerous variant for the welder's health is FCAW and highest feed wire speed (6.0 m/min) with R3 - E71T1MH4 rutile flux-cored wire and C1 shielding gas. The amount of microparticles is the maximum value recorded in all welding variants, being 310 mg/m^3. The "green" variant is represented by MCAW and lowest feed speed (5.0 m/min) with P4 - E70C6MH4 low fume metal-cored wire and M21 shielding gas. In this case, the maximum amount of microparticles is the lowest value, 59 mg/m^3, from all data recorded in the experimental programme.

4. Conclusions

It is well known that the risk factors for welders' health are significant and have to be controlled. That is why the main goal of the research was focused on assessment of CO concentration and microparticles amount developed by welding, in different process conditions. Based on a comparative analysis of the experimental data, which have been discussed in detail in the previous section, this research provides important information, especially, for the industry of welded structures, but also for the materials producers and for the experts who continue to investigate this topic.

According to the results reported and discussed above, the "green" GMAW technique is MCAW and lowest feed speed (5.0 m/min) with P4 - E70C6MH4 low fume metal-cored wire and M21 shielding gas. This process variant generates the lowest level of gas and microparticles.

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