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EVALUATION OF THE EFFECT OF CO AND CO2 GASES GENERATION ON SHORT-CIRCUIT METAL TRANSFER IN THE MIG/MAG WELDING PROCESS

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Abstract: Several works have shown the influence of parameters and shielding gases on the generation of fumes in MIG/MAG welding, but little has been shown on the emission of toxic and asphyxiating gases. This work aims to evaluate the effect of shielding gas composition on gas emission levels in MIG/MAG welding, using pure CO2 and mixtures of Argon with CO2, maintaining the same average current. It was found that the values of CO2 generation in the data acquired in tests with 100%CO2 shielding gas varied with limits above those allowed by NR-15 and OSHA. The data referring to the generation of CO2 during tests with Ar+25%CO2 did not exceed these limits. For CO generation, tests with a voltage of 19V did not exceed the limits of NR-15 and OSHA, for both shielding gases, with the exception of voltages of 21V and 23V.
Keywords: Carbon monoxide, carbon dioxide, voltage, shielding gases, short circuit.

INTRODUCTION

The gas welding processes (Gas Metal Arc Welding) use different mixtures of shielding gases in order to give different characteristics to the electric arc, metallic transfer mode and weld beads, with regard to geometry, penetration, dilution and porosities, making it possible to obtain different geometric characteristics in the weld beads from different concentrations of inert and active gases (WAINER; BRANDI; MELO, 2004).

Certain gases can be formed during welding processes and can affect the respiratory health of welders. The shielding gases used during the MIG/MAG process can increase the ultraviolet radiation produced in the arc, leading to the photochemical formation of potentially harmful gases such as nitrogen oxides and ozone (O3). Carbon dioxide (CO2) can be reduced and converted to carbon monoxide (CO), a highly toxic gas. In addition, the oxidation of vapors from degreasing agents that are sometimes used for cleaning base metals in welding, can produce highly toxic gases (eg phosgene) (ANTONINI et al., 2006).

Zinc fumes in welding generate intense headache and fever and cadmium fumes are fatal. With regard to shielding gases such as mixtures of Argon and CO2, or pure CO2, when used in confined spaces, they generate air displacement, as they are heavier, which generates asphyxia and death, being important to circulate air during the processes of welding, from the use of exhaust fans and fans and also the use of protective masks represents a factor of great importance for welders (MARQUES; MODENESI; BRACARENSE, 2011).

The use of mixtures with CO2 and pure CO2 as shielding gases emit significant amounts of CO2 and CO, capable of generating asphyxia and intoxication, respectively. The generation of these gases is not directly dependent on the arc stability and arc length, in the same proportion that the generation of fumes is sensitive to these factors, with the generation of CO2 and CO being greater according to the increase in the percentage of CO2 in the mixture used as shielding gas (MENESES; LEAL; SCOTTI, 2016).

According to Brazilian Legislation, the regulatory standard NR-15 (Unhealthy Activities and Operations) defines that the elements Carbon Dioxide and Monoxide are characterized as unhealthy chemical agents, with a tolerance limit of 48 hours per week of exposure in a range of 3900 ppm for CO2 and 39 ppm for carbon monoxide. According to the American OSHA standard, which defines the permissible exposure limits (PELs) for contaminants in the air, through the table 1910.1000 TABLE Z-1, for a weighted average exposure time of 8 hours, the exposure limits for CO2 is 5000 ppm and for CO it is 50 ppm (MINISTRY OF LABOR, 2014) (OSHA, 2017).

MATERIALS AND METHODS

To carry out the measurement tests of the gases generated during the welding process, welds were carried out on the plate, in the top position, using as base material flat carbon steel bars with dimensions of 200mm x 50mm x 6mm (length x width x thickness) as shown in Fig. (1). As shielding gas, 100%CO2 and the Ar+25%CO2 mixture were used in different experiments. The welding process was mechanized in order to guarantee greater repeatability and stability of the welding parameters.

The consumable characteristics (AWS/ ASME SFA 5.18 ER70S-6, diameter 1.2mm) are shown in Tab. (1). The solid copper-coated manganese-silicon wire ER70S-6 is intended for MIG/MAG welding of non-alloyed steels, using the mixtures Ar + 20-25% CO2 or pure CO2 as shielding gases.

A multiprocess welding source model IMC Inversal 600 was used, with a torch welding angle of 90º. Technical specifications: Rated current: 320A; Maximum current: 600A; Current at 100%Fc: 320A/30V; Rated power: 13KVA.

To cut the samples to be welded, a band saw brand S. Ramos, model 260 was used; for the measurement of CO2 and CO gases in ppm, Delta Ohm HD21AB17 portable equipment was used. Figure 2 shows the equipment used for cutting and welding the samples. In figure 3, the equipment used to acquire the concentration of gases in ppm.

The welds were carried out in the flat position, in tests of simple deposition on plate, pull technique and short-circuit transfer mode. The power source was operated in "constant voltage" mode and torch welding angle of 90º.

In order to obtain the relationship between the welding voltage and the generation of CO2 and CO gases, the other welding parameters, such as welding speed (mm/min), wire feed speed (m/min), gas flow rate (l/min), were worked steadily. The welding current was kept fixed within a narrow range of 150±5A.

The stick-out length remained fixed, varying only in the voltage range changes, with the objective of keeping the welding current in the range of 150±5A, since the stick-out and welding current are related inversely proportional.

For the experimental design, it was stipulated to carry out welds at voltages of 19V, 21V and 23V, with the current varying by 150±5A, parameters within the wire manufacturer's recommendations. The gas flow was defined as 12l/min, with the recommended flow rate for a wire with a diameter of 1.2 mm (AWS, 1991).

In order to obtain greater accuracy in the gas measurement tests, 3 welding experiments were carried out for each worked voltage, in order to calculate the average generation of gases. 100%CO2 and the Ar+25%CO2 mixture were used as shielding gas, totaling 18 experimental tests. In table 2, the experimental design is presented.

For the process of measuring the gases generated, monitoring was carried out at 3 intervals: 1 - one minute without an open electric arc (with only gas flow); 2 - during the welding process with the opening of the electric arc, for an average period of 1 minute; 3 - after the welding process for a period of 3 minutes, equivalent to the time in which the gases dissipated in the environment. Data acquisition was performed at 5-second intervals.

Figure 4 shows the arrangement used during the gas generation data acquisition process in ppm. The probe responsible for capturing the CO2 and CO gases released during the process was positioned 300mm above the electric arc region, in order to simulate the welder's breathing region (MENESES; LEAL; SCOTTI, 2016).

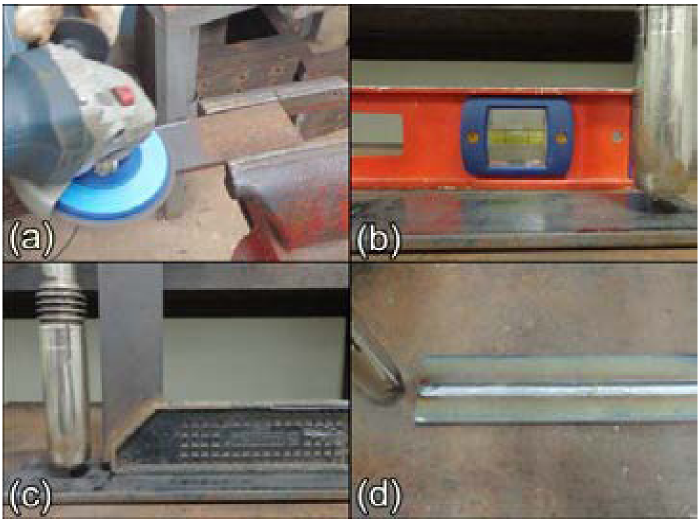

Figure 1. (a) Pre-weld cleaning. (b) Leveling in order to guarantee fixed stick-out length, varying only in voltage range changes. (c) Torch at 90 degree angle. (d) Welding carried out in flat position.

Source: authors (2022).

Composition	C	Si	Mn	Al	P	S
ER70S-6	0,08	0,9	1,5	-	-	-
Mechanical Properties (Ar + 20%CO_2)	Yield Strength (MPa)		Tensile Strength (MPa)		Elongation	
	470		560		26%	

Table 1. Chemical composition (% by weight) and mechanical properties of ER70S-6 wire.

Fonte: ESAB (2022).

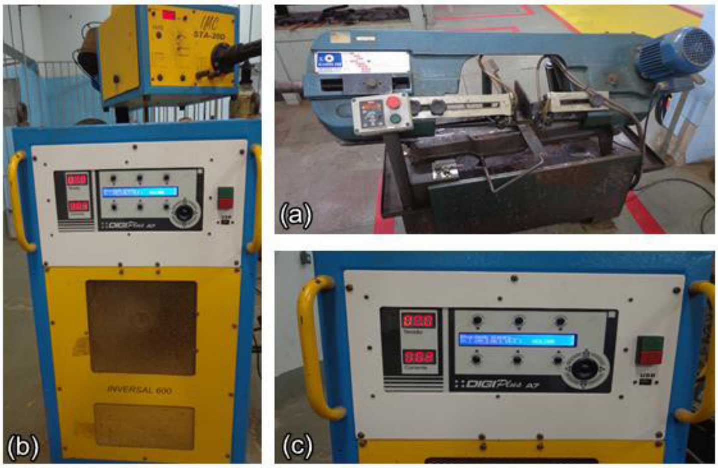

Figure 2. (a) Process of cutting welding specimens. (b) Multi-process machine used during the welding process. (c) IMC Inversal 600 Human-Machine Interface.

Source: authors (2022).

Figure 3. Delta Ohm HD21AB17. Equipment used to acquire the amount of CO_2 and CO gases in ppm.

Source: Delta Ohm Air Quality (2022).

Experiment	Shielding Gas	Regulated Voltage (V)	Current Range (A)	Wire Feed Speed (m/min)	Welding Speed (mm/min)	Stick Out (mm)	Gas Flow Rate (L/min)
1	100%CO2	19	150±5	3.3	200	11	12
2	100%CO2	19	150±5	3.3	200	11	12
3	100%CO2	19	150±5	3.3	200	11	12
4	100%CO2	21	150±5	3.3	200	10	12
5	100%CO2	21	150±5	3.3	200	10	12
6	100%CO2	21	150±5	3.3	200	10	12
7	100%CO2	23	150±5	3.3	200	9	12
8	100%CO2	23	150±5	3.3	200	9	12
9	100%CO2	23	150±5	3.3	200	9	12
10	Ar+25%CO2	19	150±5	3.3	200	11	12
11	Ar+25%CO2	19	150±5	3.3	200	11	12
12	Ar+25%CO2	19	150±5	3.3	200	11	12
13	Ar+25%CO2	21	150±5	3.3	200	10	12
14	Ar+25%CO2	21	150±5	3.3	200	10	12
15	Ar+25%CO2	21	150±5	3.3	200	10	12
16	Ar+25%CO2	23	150±5	3.3	200	9	12
17	Ar+25%CO2	23	150±5	3.3	200	9	12
18	Ar+25%CO2	23	150±5	3.3	200	9	12

Table 2. Experimental Planning.

Source: authors (2022).

Figure 4. (a) Arrangement used to acquire gas concentration data. (b) Equipment positioning layout. The area was isolated with 3 welding screens. (c) Probe positioned 300mm above the welded part.

Source: authors (2022).

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For the analysis of the experimental results, the use of Analysis of Variance (ANOVA) was defined in the statistical planning, with the objective of evaluating the existence of a significant difference between the data acquired for the generation of CO2 and CO.

Once the existence of a significant difference between the gas generation data was proven, a comparison test of means (Tukey's Test) was subsequently carried out, with the objective of evaluating which samples had significantly different means from each other (MONTGOMERY, 2001). Table 3 shows the statistical planning.

RESULTS AND DISCUSSIONS

Table 4 shows the parameters resulting from the welding process. Figure 5 shows the welded seams with 100%CO2 shielding gas. Figure 6 shows the welded seams with the shielding gas Ar+25%CO2.

Through visual inspection, it was observed that the welded beads at voltage levels 19, 21 and 23V did not present discontinuities, with the use of both shielding gases. For the beads welded with Ar+25%CO2 gas, a better surface finish and the presence of few spatters were observed, when compared to the beads welded with 100%CO2 shielding gas.

Figure 7 shows a boxplot referring to the percentages of CO2 and CO generated during the welding processes with 100%CO2 and Ar+25%CO2 shielding gas.

It is observed in the boxplot of Fig.(7) that as the voltage increased, the generation of CO2 and CO gases increased, for both shielding gases. The other welding parameters were kept constant in order to evaluate only the influence of the welding voltage on the generation of gases. This phenomenon is due to the fact that the increase in voltage causes an increase in the temperature of the welding arc, which implies greater fusion of the electrode and evaporation of metallic drops (MENDEZ; JENKINS; EAGAR, 2000). It is known that the generation of CO2 and CO gases during the welding process comes either from the burning of the electrode and evaporation of metallic droplets, or from the electrochemical reaction of reduction of the CO2 present in the shielding gases to CO (WHIPPLE; KENIS, 2010). (LACKNER; WINTER; AGARWAL, 2010).

It is also possible to observe through Figure 7 that the percentages of CO2 generated with the 100%CO2 shielding gas exceeded the limits allowed by the NR-15 and OSHA standards. As for the generation of CO2 in the welding process with Ar+25%CO2 shielding gas, the permissible limits of both standards were not exceeded.

With regard to CO generation, for both shielding gases, the limits of NR-15 and OSHA standards were exceeded only in experiments with 21V and 23V welding voltage.

Figure 8 shows the behavior of CO2 and CO generation using 100%CO2 as a shielding gas. Figure 9 shows the behavior of CO2 and CO generation using Ar+25%CO2 as a shielding gas.

In figure 10, the ANOVA table is presented together with the Tukey test, for the CO2 and CO generation data, respectively, in the welding with 100%CO2 shielding gas. In figure 11, ANOVA and Tukey test for CO2 and CO gases, respectively, for welding with Ar+25%CO2.

Through ANOVA, it was possible to observe that there was a significant difference in the percentages of CO2 generation as a function of welding voltages 19V, 21V and 23V, for both shielding gases 100%CO2 and Ar+25%CO2. Through the Tukey average comparison test, it was verified that the significant difference between the CO2 generation averages occurs between the voltages of 19V and 23V, for both shielding gases.

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Shielding Gas	Voltage (V)	Generated Gas	Analysis	Mean Comparison
100%CO2	19V	CO2		
100%CO2	21V	CO2	ANOVA	Tukey
100%CO2	23V	CO2		
100%CO2	19V	CO		
100%CO2	21V	CO	ANOVA	Tukey
100%CO2	23V	CO		
Ar+25%CO2	19V	CO2		
Ar+25%CO2	21V	CO2	ANOVA	Tukey
Ar+25%CO2	23V	CO2		
Ar+25%CO2	19V	CO		
Ar+25%CO2	21V	CO	ANOVA	Tukey
Ar+25%CO2	23V	CO		

Table 3. Statistical Planning.

Source: authors (2022).

Shielding Gas	Experiment	Regulated Voltage(V)	Average Voltage(V)	Average Current(A)	Wire Feed Speed (m/min)	Welding Speed (mm/min)	Stick Out (mm)	Gas Flow Rate (L/min)	Welding Time	Pre-Welding Mass (g)	Post Welding Mass (g)	Deposited Mass (g)
100%CO2	1	19	19,4	152	3,3	200	11	12	01:01	491,8	518,8	27
100%CO2	2	19	19,3	149	3,3	200	11	12	01:02	488,7	516,6	27,9
100%CO2	3	19	19,3	149	3,3	200	11	12	01:00	491,7	519	27,3
100%CO2	4	21	21,1	148	3,3	200	10	12	00:58	492,5	520,9	28,4
100%CO2	5	21	21	145	3,3	200	10	12	00:58	494,1	523,7	29,6
100%CO2	6	21	21,2	149	3,3	200	10	12	00:57	494,1	524	29,9
100%CO2	7	23	23	145	3,3	200	9	12	00:59	487	514,7	27,7
100%CO2	8	23	23,1	148	3,3	200	9	12	00:58	482,8	510,3	27,5
100%CO2	9	23	23,1	146	3,3	200	9	12	00:59	482	509,6	27,6
Ar+25%CO2	10	19	19	152	3,3	200	11	12	00:58	486,7	515,3	28,6
Ar+25%CO2	11	19	19,1	150	3,3	200	11	12	00:59	486,2	514,5	28,3
Ar+25%CO2	12	19	19	147	3,3	200	11	12	01:00	483,2	511,1	27,9
Ar+25%CO2	13	21	21,1	155	3,3	200	10	12	00:58	492,8	520,9	28,1
Ar+25%CO2	14	21	21	153	3,3	200	10	12	00:58	487,1	514	26,9
Ar+25%CO2	15	21	21	151	3,3	200	10	12	00:59	487,6	515,8	28,2
Ar+25%CO2	16	23	23	155	3,3	200	9	12	00:59	487,4	515,4	28
Ar+25%CO2	17	23	23	150	3,3	200	9	12	01:00	492,4	519,7	27,3
Ar+25%CO2	18	23	23,1	153	3,3	200	9	12	01:00	484	514,1	30,1

Table 4. Parameters Resulting from the Welding Process.

Source: authors (2022).

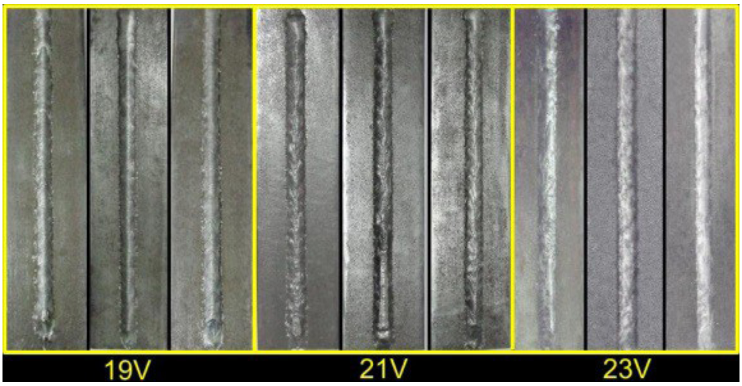

Figure 5. Weld beads resulting from the process with 100%CO2 shielding gas.

Source: authors (2022).

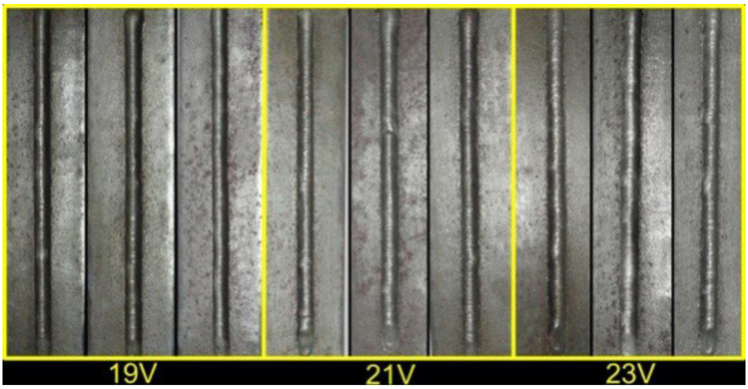

Figure 6. Weld beads resulting from the process with Ar+25%CO2 shielding gas.

Source: authors (2022).

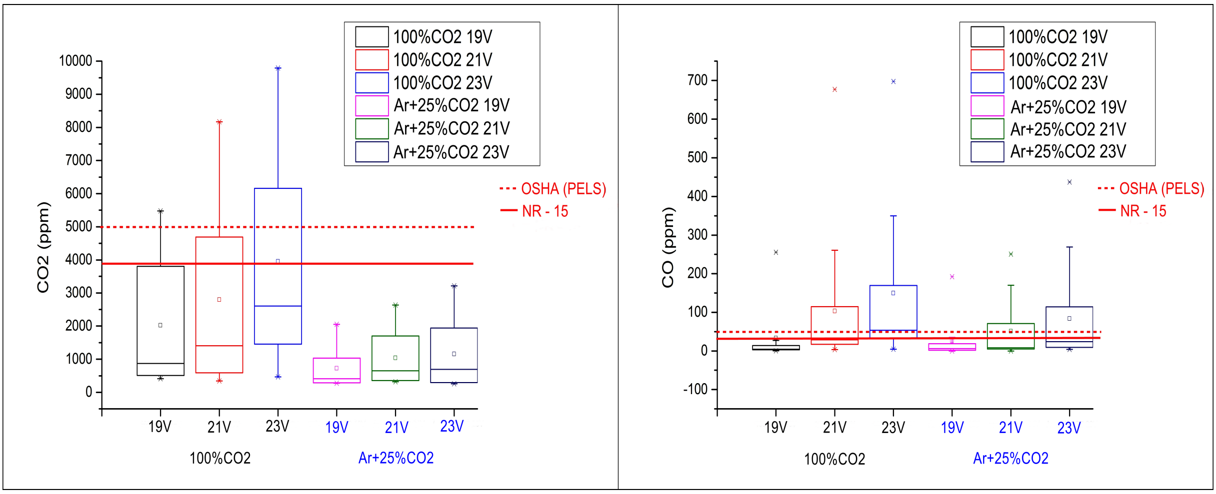

Figure 7. Boxplot of CO2 and CO generation data during welding with shielding gases 100%CO2 and Ar+25%CO2.

Source: authors (2022).

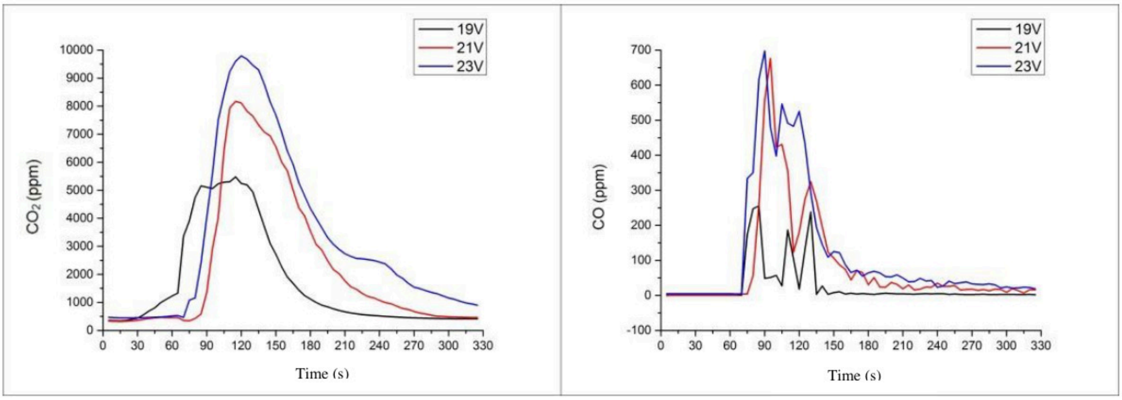

Figure 8. Generation of CO2 and CO during process without arc, with arc and after welding with shielding gas 100%CO2.

Source: authors (2022).

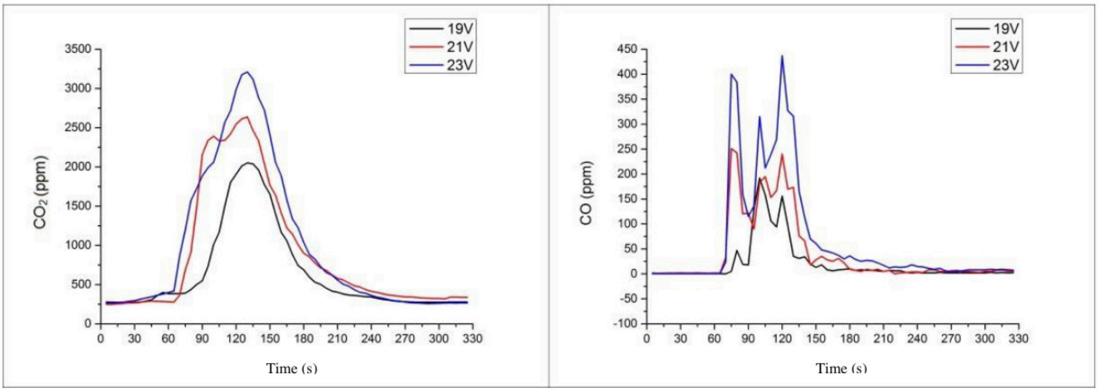

Figure 9.: Generation of CO2 and CO during process without arc, with arc and after welding with shielding gas Ar+25%CO2.

Source: authors (2022).

(a)

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	9,85741E7	4,9287E7	7,49729	7,83084E-4
Error	153	1,00582E9	6,57398E6		
Total	155	1,10439E9			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At a level of 0.05 the population means are significantly different.

Tukey Test

	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
21V 19V	777,79487	502,83751	2,18752	0,27211	0,05	0	-412,29556	1967,8853
23V 19V	1934,78205	502,83751	5,44151	5,10042E-4	0,05	1	744,69162	3124,87248
23V 21V	1156,98718	502,83751	3,25399	0,05867	0,05	0	-33,10325	2347,07761

Sig 1 indicates that the difference in means is significant at a level of 0.05.
Sig 0 indicates that the difference in means is not significant at a level of 0.05.

(b)

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	356457,89744	178228,94872	8,41321	3,4158E-4
Error	153	3,24122E6	21184,41914		
Total	155	3,59767E6			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At a level of 0.05 the population means are significantly different.

Tukey Test

	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
21V 19V	70,11538	28,54445	3,47382	0,03996	0,05	1	2,55783	137,67294
23V 19V	116,26923	28,54445	5,76047	2,18043E-4	0,05	1	48,71168	183,82678
23V 21V	46,15385	28,54445	2,28666	0,2416	0,05	0	-21,40371	113,7114

Sig 1 indicates that the difference in means is significant at a level of 0.05.
Sig 0 indicates that the difference in means is not significant at a level of 0.05.

Figure 10. (a) ANOVA and Tukey test for CO2 generation using 100%CO2 shielding gas. (b) ANOVA and Tukey test for CO generation using 100%CO2 shielding gas.

Source: authors (2022).

(a)

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	5,15261E6	2,5763E6	3,84744	0,02343
Error	153	1,02451E8	669615,53		
Total	155	1,07604E8			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At a level of 0.05 the population means are significantly different.

Tukey Test

	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
21V 19V	315,41667	160,48191	2,77954	0,12433	0,05	0	-64,40381	695,23715
23V 19V	429,76923	160,48191	3,78725	0,02226	0,05	1	49,94875	809,58971
23V 21V	114,35256	160,48191	1,00771	0,75645	0,05	0	-265,46792	494,17305

Sig 1 indicates that the difference in means is significant at a level of 0.05.
Sig 0 indicates that the difference in means is not significant at a level of 0.05.

(b)

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	88892,33013	44446,16506	6,03461	0,003
Error	153	1,12688E6	7365,20546		
Total	155	1,21577E6			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At a level of 0.05 the population means are significantly different.

Tukey Test

	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
21V 19V	25,25	16,83084	2,12163	0,29368	0,05	0	-14,58438	65,08438
23V 19V	58,29808	16,83084	4,8985	0,00199	0,05	1	18,4637	98,13246
23V 21V	33,04808	16,83084	2,77687	0,12482	0,05	0	-6,7863	72,88246

Sig 1 indicates that the difference in means is significant at a level of 0.05.
Sig 0 indicates that the difference in means is not significant at a level of 0.05.

Figure 11. (a) ANOVA and Tukey test for CO2 generation using Ar+25%CO2 shielding gas. (b) ANOVA and Tukey test for CO generation using Ar+25%CO2 shielding gas.

Source: authors (2022).

Concerning the generation of CO, it was observed that there was also a significant difference in the percentages of generation of this gas as a function of the welding voltages 19V, 21V and 23V, for both shielding gases. Through the Tukey test, it was verified that the significant difference between the averages of CO generation also occurs between the voltages of 19V and 23V, for both shielding gases.

CONCLUSION

It was observed that for the CO2 generation values, the data acquired during the tests carried out with 100%CO2 shielding gas varied with limits above the values stipulated by NR-15 (3900ppm) and by the permissible exposure limits of OSHA (5000 ppm). The data referring to the generation of CO2 during the tests with shielding gas Ar+25%CO2 did not exceed the limits stipulated by NR-15 and the permissible exposure limits of OSHA. With regard to CO generation, tests with voltage of 19V did not exceed the limits stipulated by NR-15 (39ppm) and OSHA (50ppm), for both shielding gases, exceeding only in tests with voltages of 21V and 23V.

Regarding the statistical analysis (ANOVA), evidence was observed that there is a significant difference in the average generation of CO2 and CO due to the increase in welding voltage, with the use of shielding gases 100%CO2 and Ar+25%CO2. Through the Tukey test, evidence was identified that the difference in the average generation of CO2 and CO was significant between the voltages of 19V and 23V, for both shielding gases.

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