Weld World (2015) 59:217–224
DOI 10.1007/s40194-014-0196-x

RESEARCH PAPER

Influence of the CO_2 content on operational performance of short-circuit GMAW

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Received: 22 May 2014 / Accepted: 29 September 2014 / Published online: 18 October 2014

Abstract CO_2 blended with Ar is the most common shielding gas used for short-circuit gas metal arc welding (GMAW). There has been some technical knowledge devised from the process application over the years (personal opinion and results from practice) on the selection of the gas blend composition. However, there is still a lack of more scientific data to explain the performance of the mixtures. This paper presents a systematic study of the influence that CO_2 content in mixture with Argon has on the operational performance of the short-circuit GMAW. The objectives of this study were to describe, to quantify and to explain the alterations in the metal transfer behavior, spatter generation, weld bead geometry and bead finish due to the different CO_2 contents in the shielding gas. Carbon steel plates were welded in adequate parametric conditions for each CO_2 + Ar shielding gas composition (CO_2 ranging from 2 to 100 %). These parametric conditions were found by applying a metal transfer regularity index over welds carried out at different voltage settings for each gas blend. A target of 130 A was applied as base for comparison. Laser shadowgraphy with high-speed filming and current and voltage oscillograms were used as analysis tools. The results showed (and confirmed) that the increase of the CO_2 content deteriorates metal transfer regularity, leading to excessive spatter generation and uneven bead appearance, but increases the penetration and the fusion area of the weld beads and improves bead convexity. In general, the CO_2 content should neither be lower than 10 % (unless for thin plates) nor higher than 30 %.

Keywords GMA welding · Shielding gases · CO2 · Metal transfer · Weld shape

Doc. IIW-2508, recommended for publication by Commission XII "Arc Welding Processes and Production Systems."

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1 Introduction

Shielding atmosphere plays a fundamental role in the operational behavior of the gas metal arc welding (GMAW) process, since the shielding gas composition controls arc stability, metal transfer mode, fume emission, spatter generation and weld bead geometry. The most common shielding used in GMAW for carbon steel applications is a blend of Ar and CO_2. The CO_2 content in these blends varies from a very low amount of CO_2 up to a 100 %; yet commercially, the applicable blend composition lay on a range from 8 to 25 % of CO_2, having the pure CO_2 as an alternative for the blend. In general, it is considered that the higher the CO_2 content, the "hotter" the shielding becomes and the deeper penetration is reached by the arc.

However, the limits for the best percentages of CO_2 in a blend are questionable. Zielinska et al. [1] demonstrated that the arc stability becomes poor with CO_2 content over 9 %. Stenbacka and Persson [2] pointed out that adding more than 15 % of CO_2 in the shielding gas mixture makes the metal transfer unstable and increases fume and spatter generation. It may be correlated with the conclusion of Soderstrom and Mendez [3], for whom higher percentages of CO_2 in the mixture with Argon increase the current density and decrease the anode spot on the droplet surface. Plasma pressure is concentrated in a smaller area, resulting in sufficient force to lift the droplet, leading to its displacement on the electrode tip, which, in turn, disturbs the "soft" transfer of the metal droplet to the welding pool and leads to increased spatter generation.

Hermans and den Ouden [4], in agreement with Kim and Eagar's results [5], observed that metal transfer occurs with the droplet lifting when the CO_2 content exceeds 10 %. Rhee and Kannatey-Asibu [6] correlated this phenomenon with oxidation of the electrode surface, leading to an increased amount of alloying element vapors that decrease the rate of the droplets formation and disturb their detachment by giving rise to a vapor-recoil force. An influence of a repulsive electromagnetic force was also reported by Jacobsen [7], as the result of higher dissociation energy needed for molecular gases, such as CO_2.

As regards the bead geometry, from key literature produced by the American Welding Society [8], it is known that additions of CO_2 improve wettability, also resulting in an increase of penetration and fusion area of the bead. Stappon and Lyttle [9] believe that a higher amount of carbon dioxide in the shielding gas achieves higher penetrations because of its higher heat capacity rate. However, according to Scotti and Ponomarev [10], heat transfer to the base metal is only one of the factors that influence the bead geometry. The mechanical action of the droplets in transfer, as demonstrated by Scotti and Rodrigues [11], also governs the formation of the weld bead profile (in the GTAW process, for example, even with pure Ar, there is no finger-like bead profile because there are no droplets in transfer). And the mechanical action, in turn, is also dependent on shielding gas composition.

However, despite of numerous investigations in this area, there is no systematic and comprehensive data as to the role of CO_2 content on GMAW performance. Moreover, it is not always that the appropriate arc length for each condition is used in comparative studies. For example, Jeffus [12], aiming to study the effect of the shielding gas on GMAW performance, used the same voltage of 25 V for all mixtures. This approach may not guarantee the same stable arc for all conditions. Klaric et al. [13], studying the influence of welding parameters on the bead geometric profile, used the welding voltage recommended by the electrode wire manufacturer. Although these parameters are appropriate for some given welding conditions, there is no certainty that this voltage will result in ideal arc lengths and the best operational process performances for the adequate comparison of results. In addition, despite the fact that the advantages and disadvantages of the GMAW with pure CO_2 are fully presented in technical literature, there is still a lack of information regarding the Ar + CO_2 mixtures with CO_2 content higher than 25 % and less than 100 %.

Thus, the aim of this work was to systematically investigate the influence of the CO_2 content in the shielding blend with Ar, using a broader range (from 2 to 100 %), on the operational performance of the GMAW process with short-circuiting transfer mode.

2 Methodology

2.1 Experimental procedure

Blends of Ar with different nominal contents of CO_2 (2, 5, 10, 15, 20, 30, 50, 90 and 100 %) were used to shield short-circuiting GMA welds. The weldments were carried out on carbon steel plates (3-mm-thick, butt joint with 1-mm gap) in a flat position, with an AWS ER70S-6 wire (Ø=1.2 mm), using a commercial power source (inverter) operating in conventional mode (constant voltage). The use of a joint configuration rather than the conventional bead-on-plate welds aimed to imitate a more practical condition. A laboratory mixer was used to prepare the gas blends. The corresponding shielding gas compositions were verified by a commercial gas analyzer, taking into account that only a maximum of ± 0.2 % of the CO_2 content tolerance in relation to the nominal values was accepted. The main welding parameters (current, voltage and wire feed rate) were monitored by a data acquisition system, at a frequency of 5000 Hz and 14 bit of resolution.

From a methodology point of view, the short-circuit metal transfer mode was chosen for comparative experiments since the momentum of the droplets is negligible (contact metal transfer), enabling the effect of the gas to be more evident (heat transfer from the arc, consequently from the shielding gas, is strongly correlated with the penetration depth, as stated by Murray and Scotti [14]). Welding current, which has strong influence on metal transfer and weld bead formation, was maintained constant for all gas compositions, at around 130 A. This value is consistent with the plate thickness and attends the established mode of metal transfer. This low current target value was also chosen to avoid a high-energy welding to disguise the gas effect. To keep the same current, adjustment in the wire feed rate was implemented when a gas composition is demanded. To keep the same pool volume for all welds, the ratio wire feed rate and travel speed was kept constant. The contact tip to work distance was arbitrarily chosen as 12 mm.

As widely known, weld bead formation is directly influenced by arc length. And so is arc stability in short-circuiting transfer. Arc length, in turn, is defined by the voltage setting for a given welding condition (wire feed rate, contact tip work distance, etc.). And there is a very narrow range of arc length within the arc that is stable for this mode of transfer. However, for different shielding gases, the same set voltage will result in different arc lengths. And a comparison of the effect of the shielding gas would have no meaning if each gas composition were used to a proper arc length (the inductance setting, a secondary stability factor setting, was not changed because the goal was to study the influence of the gas and not the best parameter condition for each shielding mixture). To search for the ideal arc length for each gas composition, preliminary tests were carried out by scanning voltage settings for each gas composition, maintaining a constant wire feed rate. Therefore, three voltage settings (determined experimentally) were selected, which supposedly offered appropriate arc lengths for each type of shielding gas. Within these voltage conditions, only the one that provided the best operational performance was chosen to be compared to the other gas combinations.

The ideal arc length selection was determined on the ground of metal transfer stability, established through a criterion based on statistical analysis of welding oscillograms (described in detail elsewhere by Rezende et al. [15] and Scotti et al. [16]). According to these authors, the criterion is based on the premise that metal transfer stability is connected to a constancy of arcing and short-circuiting times, as much as to proper volume of the droplet at the moment of detachment by the force due to surface tension. Thus, two parameters must be satisfied to have the criterion accomplished, namely:

1. A minimum Vilarinho regularity index for short-circuit transfer, for which the symbol is IV_{sc} (Eq. 1):

$$IV_{sc} = \frac{\sigma_{tsc}}{t_{sc}} + \frac{\sigma_{tarcing}}{t_{arcing}} \quad (1)$$

   Where σ_{tsc} = standard deviation of mean short-circuit time, $\sigma_{tarcing}$ = standard deviation of mean arc burning time, t_{sc} = short-circuit mean time and t_{arcing} = arc burning mean time (in the present work, these parameters were calculated from data logged at 2000 Hz for an average acquisition time of 15 s). For IV_{sc} calculations (a computer routine), all short-circuits are considered, even the incipient, that are characterized just by droplet touch on the weld pool, without its transfer. The less the IV_{sc} value, the more regular the transfer.

2. Droplets inside an acceptable droplet size range (it can be assumed that a droplet should not become too big before detachment, but, on the other hand, it must have a minimum volume to provide a stable surface tension metal transfer). The droplet volume is estimated (assuming it as a sphere) from droplet transfer frequency (F_{sc}), by taking only greater than 2-ms-longer short-circuits (average time needed to short-circuit transfer to happen), and wire feed rate.

2.2 Analysis of results

Operational performance of the GMAW process was evaluated according to metal transfer regularity (IV_{sc} index and droplet volume), relative amount of welding spatter (spattering), weld bead appearance and geometry. The amount of spatter was found by measuring the weight of the test plates before and after the welding and estimating the feeding wire mass consumed during the welding (from the wire feed rates and welding times). The relative relationship between the increase in weight of the test plate and the mass of consumed wire provides the spattering level (percent), not taking into account fumes and slags. Bead geometry was analyzed from test plate cross-sections prepared for macrographs. These sections had been properly prepared metallographically (sanded, polished and etched with Nital 10 %) to highlight the fusion area and heat affected zone. For each weld bead macrography, average fusion area and depth of penetration were measured. In addition, the height of the reinforcement and the width of the weld bead were also measured. Finally, to visualize the metal transfer as a means of verifying the influence of the gas on the critical diameter of the droplet before detachment from the electrode tip, high-speed filming synchronized with current and voltage was applied.

3 Results and discussions

Table 1 presents the setting and monitored data and indexes calculated/measured from the welding experiments for the conditions that showed the best regularity of metal transfer within the three conditions tested (three setting voltages) for each shielding gas. It can be observed that the increasing of CO_2 content requires, as a rule, higher setting voltages. It should be also noticed that for the highest percentages of CO_2 in the shielding blend (90 % CO_2 + 10 % Ar and pure CO_2), wire feed rate demanded a minor increase in its values to maintain the target current at around 130 A for all comparable welds. But as pool volume influences the effect of other factors on bead geometry, a correction to the travel speed was correspondingly imposed to compensate for this slightly higher wire feed rate (pool volume was the same regardless of wire feed rate). One could argue that the welding energy would also change with this approach, but as the objective of this work was to investigate the shielding gas influence and not the welding current influence, this seemed to be the best option (an adjustment in the contact tip to work distance would also obtain the same current correction effect, with no need of travel speed adjustment, but other bead geometry governing parameter would take place anyway). From Table 1, it can also be noticed that the predicted droplet size before the detachment from the electrode tip is increased as CO_2 content is greater (assuming a spherical shape). Considering that the melting rate (wire feed rate) was kept the same for most welds and only marginally increased for the CO_2 richest blends, the droplet size increase was a consequence of the detachment frequency reduction.

Figure 1 illustrates the behavior of the metal transfer regularity (evaluated by the IV_{sc} index) and the spatter generation rate as a function of CO_2 content in the shielding gas. Similar tendencies are observed between IV_{sc} and spattering for

Table 1 Setting, monitored and calculated parameters for the welding tests performed using different CO_2 contents

Parameter	CO_2 content in the shielding gas (%)								
	2	5	10	15	20	30	50	90	100
Setting voltage (V)	17.5	18.5	19.0	19.5	19.5	20.5	21.0	22.5	23.0
Wire feed rate (m/min)	2.45							2.48	
Travel speed (cm/min)	32.0							32.4	
Mean voltage (V)	16.5	17.6	18.1	18.5	18.7	19.5	20.5	21.5	22.0
RMS voltage (V)	16.7	17.8	18.4	18.7	18.9	19.6	20.7	21.8	22.2
Mean current (A)	127	128	129	128	129	129	130	131	130
RMS current (A)	139	141	137	140	140	139	137	142	140
IV_{sc} index	0.51	0.52	0.40	0.52	0.62	0.83	1.01	1.02	1.16
Droplet detachment frequency (Hz)	35	36	32	30	25	23	20	18	18
Estimated droplet diameters under transfer (mm)	1.7	1.7	1.7	1.8	1.9	2.6	2.6	2.6	2.7
Spattering (%)	1.9	2.7	4.1	4.9	5.4	6.2	7.1	9.4	11.3

Notes: the lower the IV_{sc}, the more stable the metal transfer regularity of the process

different shielding gases; in general, metal transfer regularity and deposition efficiency are getting worse with increasing of CO_2 in the blend, although not presenting the same gradients. These tendencies are supported by the analysis of variance applied on the data (for a 0.05 significance level), finding a F ratio of 8.2 for a critical F of 4.5 and a P value of 0.01. The highest spatter generation rate was obtained for pure CO_2 welding, which has already been observed in previous studies [17–19].

Figure 2 illustrates the weld beads obtained during the welding tests with different contents of CO_2. As mentioned, the appearance of the beads was evaluated subjectively by visual aspect and uniformity. It can be observed that, with CO_2 content increasing in the blend, the visual appearance and uniformity of welds get worse (starting with smooth weld beads made with 2 % CO_2 + 98 % Ar and 5 % CO_2 + 95 % Ar and ending with uneven and rough beads, in the case of 90 % CO_2 + 10 % Ar and pure CO_2), which is in agreement with the IV_{sc} index and spatter generation tendencies.

The similar tendencies observed in metal transfer regularity, spatter generation and weld appearances can be justified with images obtained by shadowgraphy with high-speed filming for the welding conditions using low (Figs. 3 and 4), medium (Figs. 5, 6 and 7) and high (Fig. 8) CO_2 contents in the shielding blend. As seen in Fig. 3 (which illustrates 5 % CO_2 + 95 % Ar welding condition), the droplet transfer occurs softly, without any evident obstacle or spatter generation. It can be observed how a droplet is formed on the wire tip, how it grows until the welding pool is reached (frames a–d), how the liquid meniscus between the droplet and the pool is formed

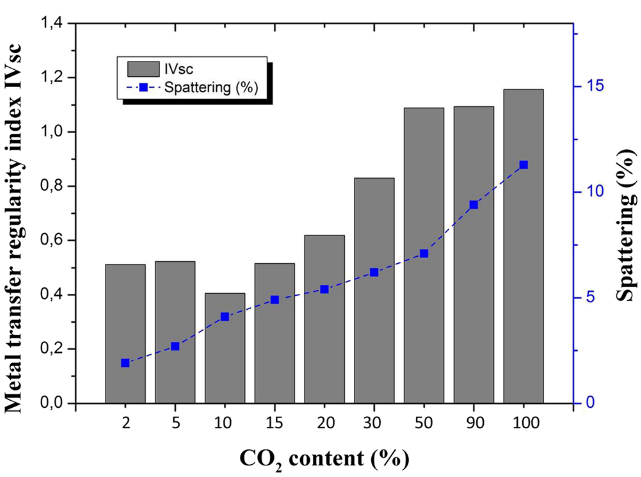

Fig. 1 Influence of the CO_2 content in the Ar-based shielding gas on the metal transfer regularity (evaluated by IV_{sc}, the less the better) and spatter generation rate (GMAW operating in short-circuiting transfer mode at 130 A)

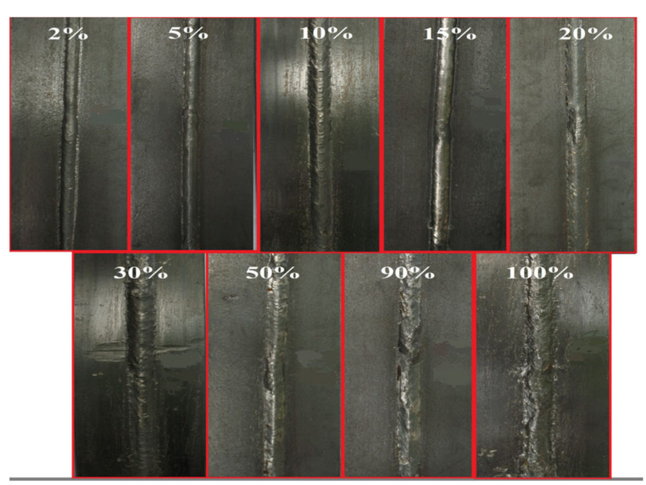

Fig. 2 Weld beads obtained by using different contents of CO_2 in Ar-based shielding gas (GMAW operating in short-circuiting transfer mode at approximately 130 A)

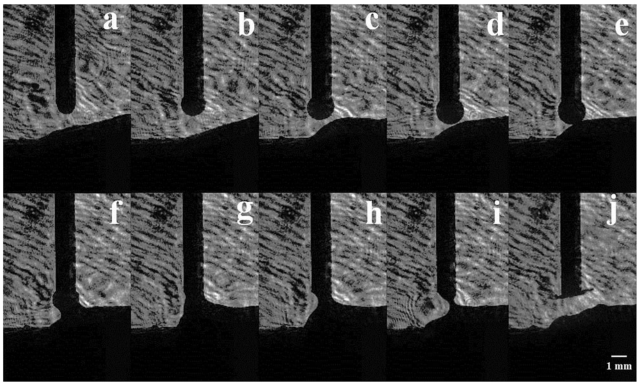

Fig. 3 Sample of the image sequences that illustrates a typical metal transfer for the 5 % CO_2 content Ar-based shielding gas (128 A and 17.6 V, mean values)

(frame e) and how the liquid metal is transferred to the pool (frames f–i). The transfer is even smoother for the 2 % CO_2 + 98 % Ar shielding blend. In the case of 10 % CO_2 + 90 % Ar (Fig. 4), it is possible to perceive some evidences of transfer disturbances, such as a droplet lifting (frames b, c) before touching the pool and some spatter generation mechanism (frame i) just after the detachment.

When the CO_2 content encloses an intermediate range (20 % CO_2 + 80 % Ar, 30 % CO_2 + 70 % Ar and 50 % CO_2 + 50 % Ar), some disturbing phenomena in the metal transfer can be observed. For example, incipient short-circuits are evidently occurring in Fig. 5 (frames f–g), when the droplet touches the weld pool for a very short time, but the contact area is not enough for the droplet to be transferred by surface tension force, so the droplet is repelled. Also, the metal transfer is deteriorated by droplet deviation from the electrode tip, as seen in Fig. 6 (frames c–e). This phenomenon already has been observed for high CO_2 contents [4, 5]. Moreover, liquid meniscus rupture and consequent weld pool oscillations are more pronounced for this CO_2 range, leading to spatter generation (frames n–o, Fig. 6). For higher CO_2 contents

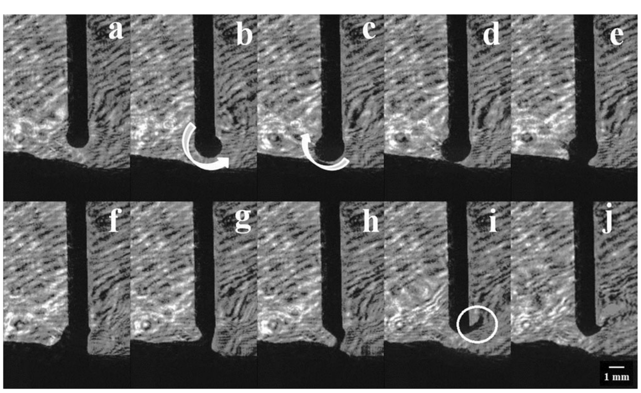

Fig. 4 Sample of the image sequences that illustrates a typical metal transfer (*the white circle/arrows* emphasize the phenomena described in the text) for a reasonably low CO_2 content (10 %) Ar-based shielding gas (129 A and 18.1 V, mean values)

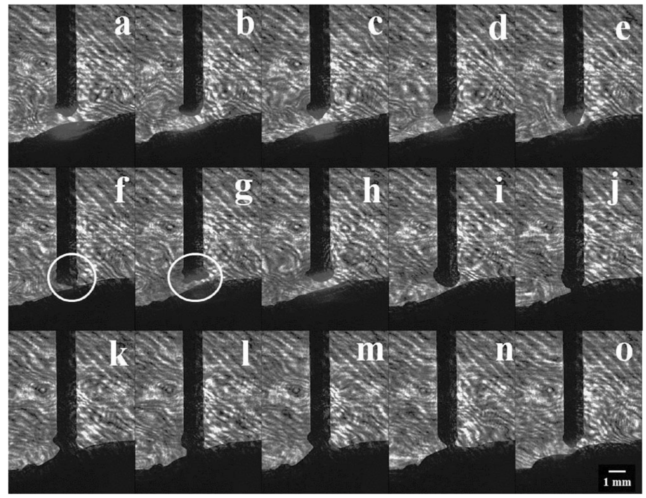

Fig. 5 Sample of the image sequences that illustrates a typical metal transfer (*the white circles* emphasize the phenomenon described in the text) for the 20 % CO_2 content Ar-based shielding gas (129 A and 18.7 V, mean values)

(50 %), the phenomena mentioned above become more pronounced (Fig. 7).

And, finally, an obviously irregular and instable metal transfer can be observed in Fig. 8, related to pure CO_2 welding. It is important to mention that this condition refers to the highest metal transfer stability reached for this shielding gas. All phenomena occurred when welding with medium CO_2 content (Figs. 5, 6 and 7) were intensified, such as multiple incipient short-circuits (frames g, l), droplet form changes (frames j, m), weld pool oscillations-droplet deviation (frames b–c, o) and spatter generation (frame t). Besides, one

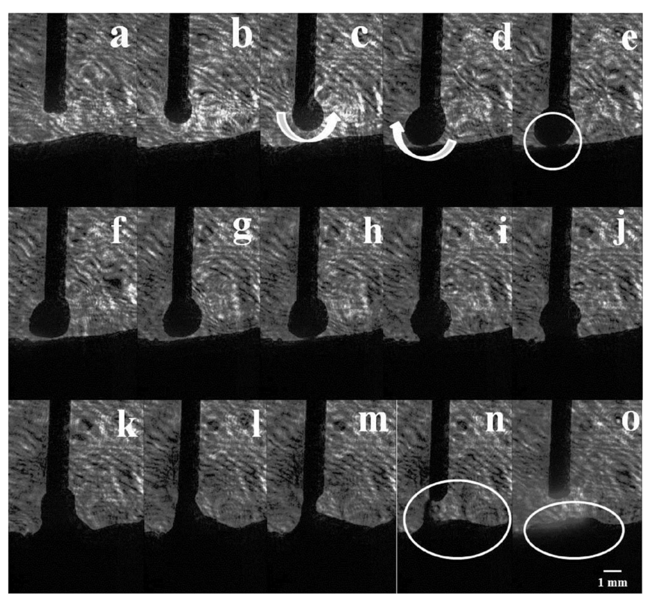

Fig. 6 Sample of the image sequences that illustrates a typical metal transfer (*the white circles* emphasize the phenomena described in the text) for the 30 % CO_2 content Ar-based shielding gas (129 A and 19.5 V, mean values)

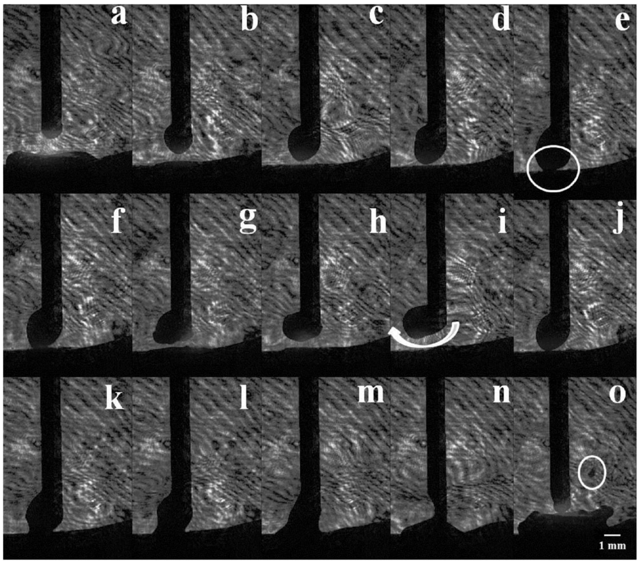

Fig. 7 Sample of the image sequences that illustrates a typical metal transfer (*the white circles/arrow* emphasize the phenomena described in the text) for the medium CO_2 content (50 %) Ar-based shielding gas (130 A and 20.5 V, mean values)

interesting phenomenon was observed many times during pure CO_2 welding, i.e., droplet deviation from the electrode tip was so strong that the droplet "climbed" the electrode extension (Fig. 9).

Thus, metal transfer visualization allowed one to correlate the data obtained in the experiments and justify all the alterations described above:

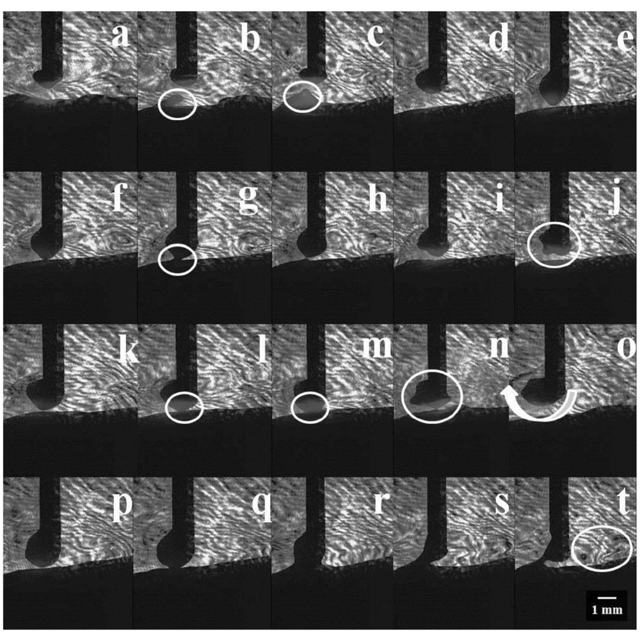

Fig. 8 Sample of the image sequences that illustrates a typical metal transfer (*the white circles/arrow* emphasize the phenomena described in the text) for the highest CO_2 content (pure CO_2) shielding gas (130 A and 22.0 V, mean values)

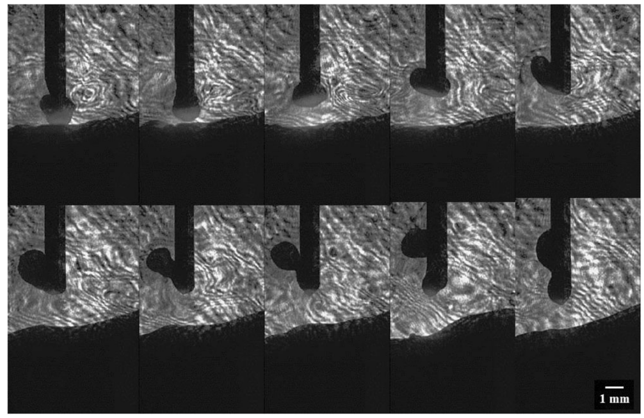

Fig. 9 Another sample of the image sequences that illustrates the droplet "climbing" the electrode when welding with pure CO_2 (130 A and 22.0 V, mean values)

- Higher percentages of CO_2 in the shielding blend cause deterioration of the metal transfer regularity (IV_{sc} increasing—Fig. 1) because of incipient short-circuits and droplet deviation.
- Liquid meniscus rupture and consequent weld pool oscillation are more pronounced for increasing CO_2 content, resulting in higher spatter generation rates, as observed in Fig. 1.
- Spattering along with instable arc (provoked also by incipient short-circuits) and irregular droplets transfer lead to uneven formation of the weld beads and to the deterioration of its visual aspect (Fig. 2).
- The droplet size before the detachment from the electrode tip is larger for higher CO_2 contents, as predicted in Table 1.

Cross sections of the welds obtained with different contents of CO_2 in the shielding atmosphere can be observed in Fig. 10.

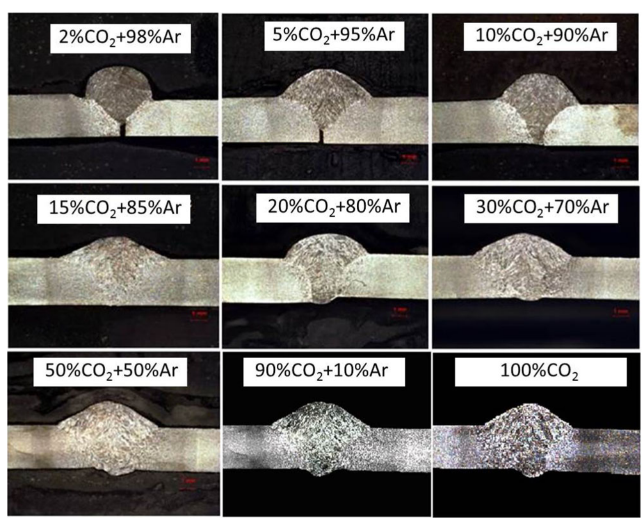

Fig. 10 Cross-sectional areas of the weld beads obtained using different contents of CO_2 in the shielding gas

Table 2 Geometrical values of the weld bead and their standard deviations for different contents of CO_2 (two cross sections from each test plate—one test plate per gas content)

CO_2 content (%)	Fusion area (mm^2)	σ	Penetration (mm)	σ	Width (mm)	σ	Reinforcement (mm)	σ	Convexity index
2	3.12	0.10	1.47	0.18	4.3	0.17	2.1	0.08	0.49
5	5.18	0.12	2.08	0.12	5.6	0.10	1.8	0.07	0.32
10	5.13	0.07	2.65	0.09	5.5	0.23	1.8	0.05	0.33
15	7.09	0.15	2.97	0.20	6.2	0.15	1.6	0.04	0.26
20	7.18	0.09	3.12	0.05	6.5	0.08	1.6	0.02	0.25
30	8.52	0.10	3.14	0.04	7.0	0.12	1.5	0.02	0.21
50	9.09	0.19	3.22	0.10	7.2	0.05	1.4	0.04	0.19
90	9.18	0.13	3.22	0.06	7.1	0.11	1.2	0.05	0.17
100	9.23	0.09	3.24	0.05	7.3	0.09	1.2	0.02	0.16

Notes: σ = standard deviation of quantities; *Convexity Index* = reinforcement/width

Table 2 presents the dimensional mean values and respective standard deviations of the referred weld beads. The behavior of the fusion area and penetration as a function of the CO_2 content is illustrated in Fig. 11. It must be pointed out that the penetration was considered from the top of the plate surface to the bottom of the bead (and not to the bottom of the plate, as usual). The reason for this measuring approach is that in some welds, the penetration exceeded the bottom surface of the plate. The same approach was applied to the fusion calculation area. As can be seen, increasing CO_2 content in the shielding gas makes both penetration and fusion area larger, especially up to 30 % of CO_2 content. This is a well-known phenomenon, attributed in current literature [8, 9] to a higher heat conductivity of CO_2 in comparison with Ar. One must remember that the effect of arc plasma jet and droplet momentum on penetration is minor when welding with short-circuit mode.

The influence of the CO_2 additions to the gas mixture on the width and reinforcement is more meaningful if representing the bead convexity. Thus, the effect of these parameters on these responses was evaluated by a convexity index (a ratio of bead reinforcement and width), as seen in Fig. 12. Convexity declines with CO_2 content increments. This happens due to the increased wettability of the liquid metal accompanying the CO_2 additions (as a consequence of a higher heat transfer of CO_2), making the weld bead even wider and flatter. Zielinska et al. [1] found that higher percentages of CO_2 also produce wider arcs.

Thus, from the technical point of view (neither concerning costs nor mechanical properties), one can say that the most appropriate weld bead geometries were achieved by welding within the range of 10 to 30 % CO_2. With smaller amounts of CO_2 in the shielding gas, reduced penetration and high convexity were observed. Over 30 %, despite the continuous improvement to the convexity, the gain of penetration is marginal. On the other hand, spattering increases (waste of material and cost–time consumed by removal from the plate and cleaning torches and ground) and bead finish (cosmetic aspects) gets worse. However, this analysis must be done carefully. If a thicker plate (>3 mm) is to be welded, no difference is expected. On the contrary, a thinner plate demands other considerations. One could say that the only

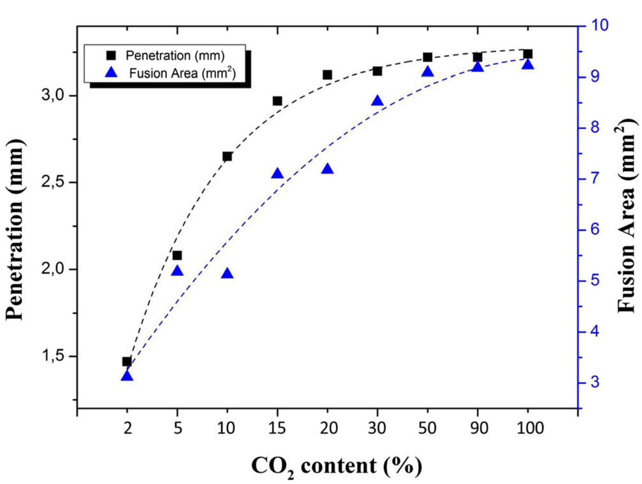

Fig. 11 Fusion area and penetration of weld beads as a function of CO_2 content in shielding gas

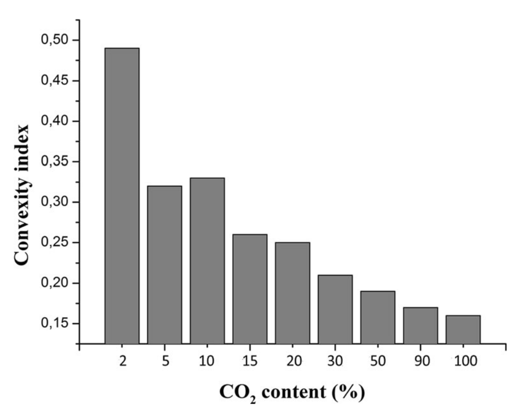

Fig. 12 Bead convexity index as a function of CO_2 content in shielding gas

change demanded would be a reduction of the mean target current. But short-circuit becomes less stable with current much lower than 100–120 A, unless the electronic power sources, with control over the transfer, are used. In these cases, a lower percentage of CO_2 in the shielding gas could be a better option, since fine bead appearance (a lower heat diffusion of a thinner plate would reduce the bead convexity) and less spattering would result. Costs are also a matter to be considered. Ar is usually more expensive to produce than CO_2. But, one must remember that as expensive as the gas production is, the gas mixture and transportation when provided in bottles is more expensive. Finally, but not least, the user must consider that more fume is generated in GMAW with higher CO_2 contents, as shown by Meneses et al. [18, 19].

4 Conclusions

This systematic study showed the influence that CO_2 content in Argon-based shielding gas has on the operational performance of the GMAW process with short-circuiting metal transfer. The effect of each gas composition was not taken from the same welding parameterization, which would be biased toward a certain condition, but, at the same mean current, under the voltage setting which provided the higher metal transfer stability in each case. According to the applied method, it can be concluded (or confirmed) that the increase of CO_2 content deteriorates metal transfer regularity, leading to excessive spatter generation and uneven bead appearance. But at the same time, it increases the penetration and fusion area of weld bead (remarkably up to 30 % CO_2 and marginally over this content). Moreover, with the increasing of CO_2 in the shielding gas, the width of the weld bead increased and reinforcement decreased, resulting in lower bead convexity. Thus, it is confirmed that the 10 to 30 % range of CO_2 in the mixture with Ar leads to the most appropriate geometric parameters and appearance of weld bead, which still has an acceptable spatter rate generation. A higher percentage of CO_2 (100 %) would be justified only due to the lower costs, at the expense of a poorer finish, more spattering and more fume emission (not considering potential effect on mechanical properties). A lower content of CO_2 would apply for thinner plates, as a means of reducing penetration without the trouble of process stability working with very low mean current.

Acknowledgments The authors wish to thank all team members of the welding group Laprosolda (Center for Research and Development of Welding Processes) of the Federal University of Uberlandia, Brazil, for infrastructure, support and advice. They also give thanks to the Brazilian organizations for Research and Development, Fapemig (through project TEC 604/2005), CNPq (for the scholarships) and Capes (through the program PROEX)

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