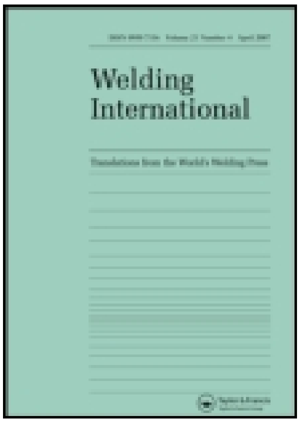

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Effect of shielding gas and transfer mode on the application of 625 alloy in carbon steel

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In this study, the effect of shielding gas (Ar, Ar/CO_2, Ar/O_2 and Ar/He/O_2) and transfer mode (short circuit and pulsed current) in MIG/MAG welding with ER-NiCrMo-3 wire to produce bead-on-plate deposits and root passes in 'V' joints of ABNT 1020 steel were analysed. The most favourable results in root pass welding were obtained with pulsed current, employing a 'V' joint with a 90″ aperture and Ar + 25% CO_2 atmosphere. The use of shielding atmospheres with 20% helium and a low percentage of active gas did not produce the expected results, being effective only in bead-on-plate weld deposition. However, it was not very effective to produce satisfactory results in root pass welding. Poor results were obtained in welding with short-circuit transfer regardless of the shielding gas used and when an atmosphere of pure argon was used, regardless of the mode of transfer.

Keywords: nickel alloys; 625 alloys; ER NiCrMo-3; GMAW; root welding; recovery

1. Introduction

In recent decades, the use of coated steel to increase corrosion resistance has grown maintaining production costs at lower levels than those required when employing more noble material such as stainless steel. Hence, a number of techniques have been employed, using both polymeric coatings and metallic coatings, these produced via processes such as double hot-rolling, sheet coating or deposited by processes such as thermal aspersion or arc welding. In addition to stainless steels, the use of Nickel alloys has been increasingly considered, in particular 625 alloy due to its high resistance to fatigue corrosion.

Hence, as with other coatings applied using arc welding processes, such as cavitation resistant coatings, achieving success in the application of 625 alloy involves the choice of deposition processes and techniques which enable the deposition rate to be reconciled with the production of low dilution and flaw-free welds. The high cost involved in these operations, in particular due to the commercial price of the coating, has led to the option for processes with the capacity to produce high-quality welds with an aspect such as deposition rate of secondary importance. As they fully meet these requirements, 625 alloys arose as the frequent choice for processes such as TIG with wire feed[1] and Plasma with the addition of metal, both in the wire form[2] and particle form[3,4].

In the light of the growing rise in demand for sheets and equipment coated with 625 alloy, a space opened up for the identification of new welding processes and procedures which enable already existing options to be amplified, adding new techniques which enable the level of production to be increased or easy to use processes within an industrial setting. Inserted into this context, the MIG/MAG process, in particular the pulsed current mode, presents proven advantages in the application of special cavitation resistant coatings, such as operation simplicity, the production capacity of welds free of flaws and low dilution[5]. Despite its potential, use of the process in the application of 625 alloy coatings has been limited as with rare exceptions[1,6], the process has been presented as applicable almost exclusively by catalogues of manufacturer's of alloys resistant to corrosion or gas shielded.

This paper forms part of a research developed with the aim of formulating welding procedures for the application of 625 alloy in the coating of the inner surface of petroleum pipes for subsequent machining of the bezel and welding of root passes and hot joint welding, also using AWS SFA-5.14 ER NiCrMo-3, consumable appropriate to the welding of 625 alloys via the MIG/MAG process. In initial tests, use of the electrode coated and TIG processes did not add further difficulty to the obtaining of good results. However, the first tests carried out with the MIG/MAG process with short-circuit transfer in Argon-rich atmosphere ($CO_2 < 5\%$) demonstrated that low wettability would be a problem to be faced. In the light of the need to increase wettability, the transfer mode and composition of the shielding gas became important analysis elements. With regard to transfer mode, the main aim was to verify the possibility of using pulsed current instead of the short circuit, given the tendency of the latter to present lower heat support when compared with the other transfer modes at the same average current value. As far as shielding atmosphere, research sought to identify the effect produced by use of ternary mixtures (Ar/He/O_2), frequently recommended for applications with 625 alloys as well as binary mixtures (Ar/O_2 and Ar/CO_2) extending research to the application of active gases with contents even higher than those frequently used in welding with Inconel 625.

2. Materials and methods

To perform the tests, a MIG/MAG welding source was used with the capacity to operate in short circuit and

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Table 1. Table with domain of experiments performed.

Gas/transfer mode	SC (1)	Spray	Pulsed	DOP (2)	DJ (2)
100% Ar	X	X	X	X	
Ar + (5, 15, 25) % CO_2	X		X	X	X
Ar + (5, 15, 25) % O_2	X		X	X	X
Ar + 20% He +1% O_2	X		X	X	X

Note: 1 – SC, short circuit; 2 – DOP, deposit on plate; DJ, deposit at joint.

pulsed current in transfer modes, and to a lesser extent in spray transfer. In terms of gases, shielding composed exclusively of an inert gas (pure Argon), binary mixtures (Ar/CO_2 and Ar/O_2) and ternary mixtures (Ar/He/O_2) was used. Binary mixtures based on argon were chosen for their effect on the wettability of those deposited. The presence of oxygen in the mixture either in its pure (O_2) or combined (CO_2) form may reduce the surface tension of the cast metal, granting greater wettability to the metallic bath.

A different proposal for the composition of the shielding atmosphere comes from ternary mixtures, in which oxygen is added at percentages of the order of 1–3% to minimize the effects of oxidation and the presence of He is increased to equal percentages or those in excess of 20% in detriment of the argon gas to modify the geometry of the fusion well. In this respect, Glickstein[7] identified that the presence of helium in the mixture increases the intensity of the electric field and raises the thermal conductivity of the discharge which results in wider arcs and higher temperature distributions in relation to discharges produced in pure argon.

To produce the binary mixtures used in the tests, Witt gas mixtures were employed for Ar/CO_2 and Ar/O_2, while for the ternary mixture a commercial mixture was used (79% air + 20% He + 1% O_2). In Table 1, the domain of the experiments carried out is presented, involving the composition of the gas, the modes of transfer and type of position (deposit on plate and deposit at joint).

Tests involved deposition on steel plates and root pass welding in chamfer without the use of copper joints, carried out in a flat position and the welding pistol handled by a trained welder. Test samples were conducted on deposits on plates measuring 150 × 200 mm (L × W), thicknesses of 8.0 and 10.0 mm of ABNT 1020 steel plates. For root welds, test samples were assembled with a 'V' joint based on ABNT 1020 steel plates, measuring 150 × 100 mm (L × W), thicknesses of 8.0 and 10.0 mm, bezel angles of 30°and 45°, root face (frequently referred to as nose) of 1.0 mm and different play values (1.0–2.0 mm). All tests were carried out using AWS SFA-5.14 ER NiCrMo-3 wire of 1.2 mm in diameter (Tables 2 and 3).

With the exception of the spray transfer mode, tests were carried out with parameters adjusted to produce an average current of 100 A. This current value was sufficient to perform welding of the root pass in all the welding positions. Though bead variations exist, in virtue of the manual handling of welding, welding speed was maintained at values of the order of 3.3 mm/s. Regardless of whether a deposit on the plate or at the joint, welds were conducted in the direction the material was pushed with a drag angle of approximately 30° and an incidence angle of 90° in relation to the surface of the plate.

2.1 Deposits on plate

With the exception of spray transfer welding, use of pure argon in MIG/MAG welding with ER-NiCrMo-3 wire has been shown to be impractical. In the short-circuit mode, despite a stable transfer and a low incidence of spatter, use of pure argon resulted in deposits with no wettability regardless of the adjusted current. Attempts to reduce welding speed for values lower than 3.3 mm/s to increase the dimensions of the fusion well or the application of weaving techniques to increase the width of deposits did not produce an effect on the angle of wettability. The same problem was not observed in welding with pulsed current. In this situation, even using totally distinct pulse parameters such as 300 A/4.0 ms or 400 A/2.8 ms, the deposits produced in pure argon atmosphere presented low wettability (Figure 1). As with short-circuit transfer, use of weaving techniques resulted in the appearance of beads of a wider width, however, without altering the wettability angle on the edge of the deposits. More favourable results were obtained in spray transfer welding in which due to the high value of the current, beads presented an acceptable angle of wettability. However, the levels of current applied in the range of 200 A limit its use in flat position welding and thick workpieces, if it is proven that the high level of energy does not produce deposits of a high dilution.

In tests with binary mixtures, it was verified that the addition of 5 and 15% CO_2 to argon despite not producing any alteration in the stability of drop detachment, did also not modify the geometry of the weld, which maintained the profile of low wettability (Figure 2). Favourable results were obtained with the addition of 25% CO_2 in particular in pulsed current welding, given the improvement produced in the weld geometry (Figure 3) without, however, producing alterations in the stability of the metallic transfer. While in welding via short-circuit transfer, the results were not favourable given the tendency of the low wettability of the deposits.

Tests conducted with a binary atmosphere of Ar + O_2 demonstrated that the addition of 25% oxygen to argon

Table 2. Chemical composition of 625 alloy[8].

Ni (%)	Cr (%)	Mo (%)	Nb (%)	C (%)	Fe (≤%)	Si (≤%)	Al (≤%)	Ti (≤%)	Mn (≤%)	Cu (≤%)	S (≤%)	P (≤%)
Bal.	20.0–23.0	8.0–10.0	3.15–4.15	0.03–0.10	5.0	0.5	0.4	0.4	0.5	0.5	0.015	0.015

Table 3. Values for chemical composition of ER NiCrMo-3 wire[9].

Ni (%)	Cr (%)	Mo (%)	Nb (%)	C (≤%)	Fe (≤%)	Si (≤%)	Al (≤%)	Ti (≤%)	Mn (≤%)	Cu (≤%)	S (≤%)	P (≤%)
58.0	20.0–23.0	8.0–10.0	3.15–4.15	0.10	5.0	0.50	0.40	0.40	0.50	0.50	0.015	0.020

makes the mixture effective in increasing the wettability of deposits, but presents as a disadvantage the tendency to produce a more unstable metallic transfer. In particular, for pulsed current welding, the addition of 25% oxygen produced a transfer characterized by the appearance of more than one drop per pulse and/or the excessive growth of the globule before detachment. In both situations, metallic drops ended up being ejected outside the arc environment, characterizing the formation of splashes. Attempts to alter the parameters of current pulsation were incapable of eliminating the occurrence of these undesirable globules. In addition to the problems associated with the instability of the transfer, the deposits obtained under gaseous shielding of $Ar + O_2$ presented a darker colouring in addition to producing deposits with a dry appearance. In a similar manner to the mixture of Ar and CO_2, the addition of percentages of oxygen of 5 and 15% to argon did not produce any significant changes in the geometry of the weld, regardless of the mode of transfer employed for welding.

In deposits on plates with short-circuit transfer protected by a ternary mixture (Figure 4), despite the presence of helium and oxygen in the composition, there was no significant alteration in the results in relation to welds produced in a pure argon atmosphere or with the addition of CO_2 and O_2. More favourable results were obtained in pulsed current transfer in which the use of the ternary mixture of $Ar/He/O_2$ produced deposits with a lot of wettability superior to that resulting from welding with short-circuit transfer, despite the value of the average current in both cases being of the same magnitude (Figure 5).

Bearing in mind that spray transfer welding produced good wettability even when pure argon gas was used, the energy input is seen to be important when obtaining wettability in deposits on plates. For deposits produced with short-circuit transfer in low input (0.5 kJ/mm), both the binary mixtures (Ar/O_2 and Ar/CO_2) and ternaries ($Ar/He/O_2$) demonstrated themselves to be ineffective in altering wettability. While in pulsed current welding in which the average heat input was of the order of 0.8 kJ/mm, regardless of the mixture being binary or ternary, there was the formation of deposit with a favourable geometry. In line with the trend, the best results obtained correspond to deposits on plates with a heat input of approximately 1.3 kJ/mm (202 A; 29.5 V/4.5 mm/s) obtained during spray transfer welding even with pure argon.

2.2 *Deposits at joint (root pass)*

In relation to root pass welding in 60° and 90° joints, the metallic transfer via short circuit produced a stable transfer yet difficult to apply as a result of the low reproduction capacity of the deposits. During tests, combinations of parameters which resulted in acceptable geometries on a first test, at a second attempt produced deposits with a lack of total penetration or poor geometric formation, characterized by the lack of symmetry in the deposit (Figure 6). Attempts to increase the play of the joint, reduce the opening angle or reduce the size of the nose did not produce satisfactory results, in particular due to the low fluidity of the fusion well, which limited the increase in shift speed of the welding gun. With short-circuit transfer,

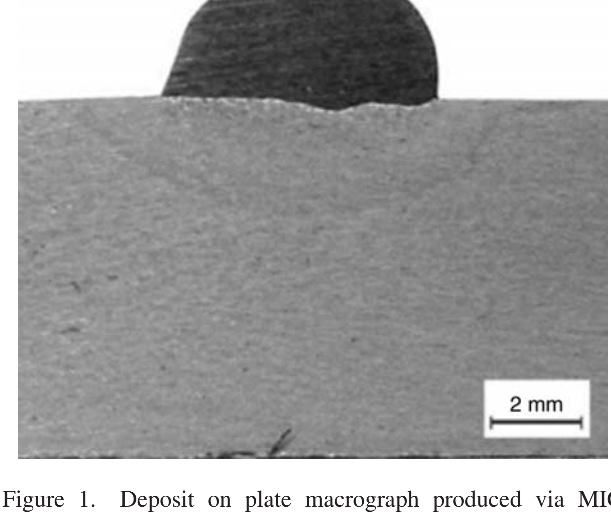

Figure 1. Deposit on plate macrograph produced via MIG process with pulsed current. Data: I_p, 300 A; t_p, 4.0 ms; I_b, 45; t_b, 14.6 ms; V_a, 0.052 m/s; I_m, 104 A; U_m, 20.4 V; V_s, 3.0 mm/s; input: 0.7 kJ/mm; gas: 100% Ar.

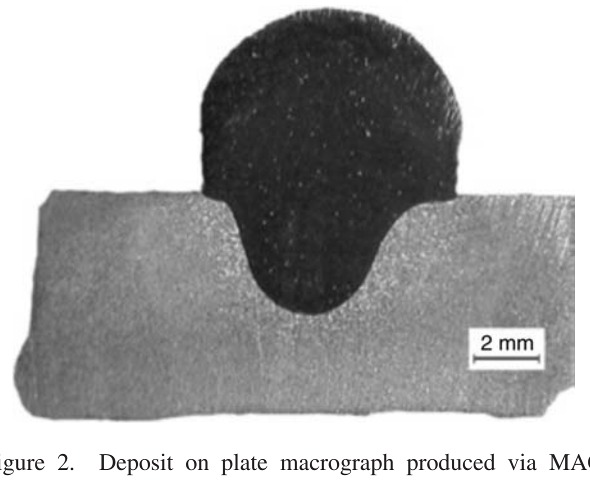

Figure 2. Deposit on plate macrograph produced via MAG process with pulsed current. Data: I_p, 300 A; t_p, 4.0 ms; I_b, 45; t_b, 14.6 ms; V_a, 0.052 m/s; I_m, 102 A; U_m, 20.3 V; V_s, 3.0 mm/s; input: 0.7 kJ/mm; gas: Ar + 15% CO_2.

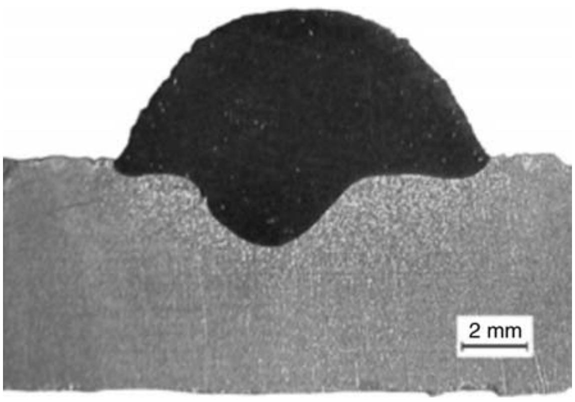

Figure 3. Deposit on plate macrograph produced via MAG process with pulsed current. Data: I_p, 300 A; t_p, 4.0 ms; I_b, 45; t_b, 14.6 ms; V_a, 0.055 m/s; I_m, 102 A; U_m, 23.3 V; V_s, 3.0 mm/s; input: 0.8 kJ/mm; gas: Ar + 25% CO_2.

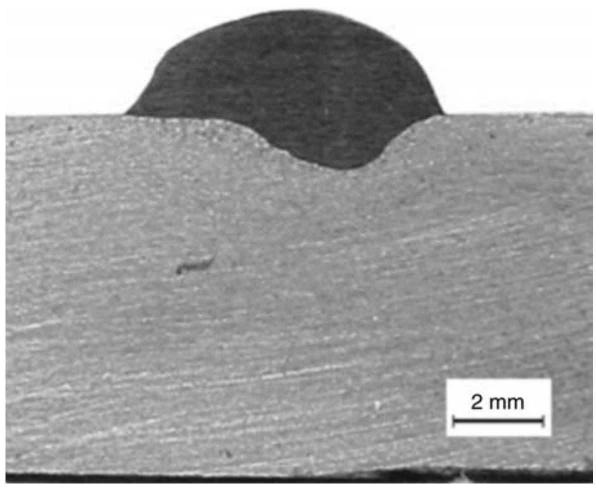

Figure 5. Macrograph of deposit on sheet with pulsed current transfer and ternary atmosphere. Data: I_p, 300 A; t_p, 4.0 ms; I_b, 45; t_b, 14.6 ms; V_a, 0.055 m/s; I_m, 102 A; U_m, 23.3 V; V_s, 3.0 mm/s; input: 0.8 kJ/mm; gas: Ar + 20% He + 1% O_2.

the formation of deposits was shown to be frequent with excess penetration (Figure 7), a problem which persisted regardless of the shielding gas used during welding. The addition of CO_2 or O_2 to argon produced an improvement in the wettability of the deposits produced with short-circuit transfer, though it was incapable of improving the short repetitiveness of the process. Even the use of the ternary mixture did not produce satisfactory results also as a result of the low repetitiveness of the deposits produced with short-circuit transfer. After computing the results obtained, the low rate of success correctly represents the difficulty in using the MIG/MAG process with short-circuit transfer in root pass welding, not only because of low wettability, but also due to the increased difficulty of ensuring the repetitiveness in the dimensions of the nose reinforcement.

More favourable results in root pass welding with the MIG/MAG process were obtained operating with pulsed current in which deposits with appropriate geometry for welding with multiple passes were obtained using a V-joint with an opening of 90° and an atmosphere of Ar + 25% CO_2 (Figure 8). In addition to the more favourable geometry, less problems were observed associated with repetitiveness both in relation to excess and a lack of penetration. However, despite the pulsed current/Ar + 25% CO_2 combination being the one which produced less problems associated with root pass geometry, obtaining root uniformity imposed a high degree of difficulty in particular when compared with the TIG and coated electrode processes, as these have a greater facility to produce a satisfactory root. However, welding employing pulsed current and a ternary mixture with Ar, He and O_2 did not produce good results in welding in chamfer, due to the irregularity of the deposits produced. Attempts to act on the pulsation parameters or joint geometry did not enable the problem to be resolved and with this, obtain acceptable quality welds. For this combination of the transfer mode and shielding gas, welds with favourable geometry were limited to tests involving deposition on plates.

In relation to the use of MIG/MAG welding for the application of coating, despite the good results obtained with pulsed MAG/Ar + 25% CO_2 combination in deposits on plates, the literature is emphatic in limiting

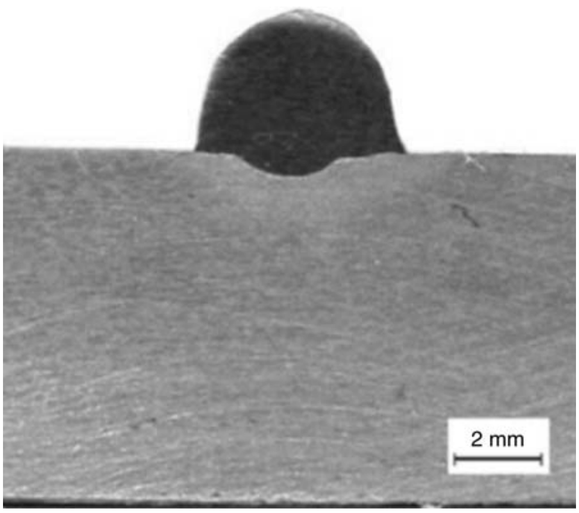

Figure 4. Deposit on plate macrograph with short-circuit transfer and ternary atmosphere. Data: V_a, 3.6 m/min; I_m, 102 A; U_m, 17 V; V_s, 3.0 mm/s; input: 0.58 kJ/mm; gas: Ar + 20% He + 1% O_2.

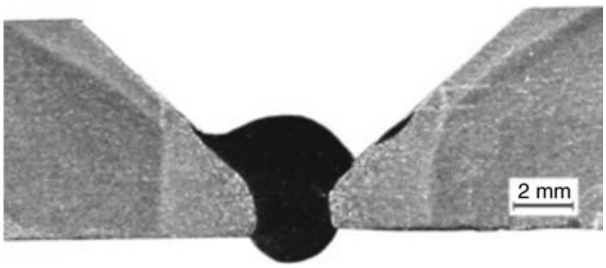

Figure 6. Geometric formation with the lack of symmetry of root pass in MAG welding with short-circuit transfer. Data: V_a, 3.6 m/min; I_m, 102 A; U_m, 17 V; V_s, 3.2 mm/s; input: 0.5 kJ/mm; gas: Ar + 25% CO_2. 90° Chamfer.

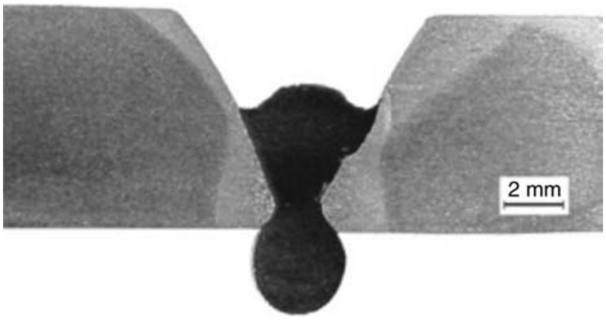

Figure 7. Formation of an excessive reinforcement in root pass weld in MAG welding with short-circuit transfer. Data: V_a, 3.6 m/min; I_m, 102 A; U_m, 17 V; V_s, 3.2 mm/s; input: 0.5 kJ/mm; gas: Ar + 25% CO_2. 60° Chamfer.

Figure 8. Macrograph of root pass in MAG welding with pulsed current transfer. Data: I_p, 300 A; t_p, 4.0 ms; I_b, 45; t_b, 14.6 ms; V_a, 0.055 m/s; I_m, 102 A; U_m, 23.3 V; V_s, 3.2 mm/s; input: 0.8 kJ/mm; gas: Ar + 25% CO_2.

the percentage of active gas capable of being used in the welding of Nickel alloys. For NDI[10], MIG/MAG welding of Nickel alloys must be carried out in atmospheres in which the presence of inert gases (Ar or Ar/He) is equal to or higher than 97.5% to avoid the appearance of surface deposits of high hardness formed from the oxidation reactions of Al and Ti, whose presence in relatively low levels seeks to minimize the effect of hardening due to ageing[11]. However, as these are refractory compounds and with a high adhesion power, the presence of oxides of Al and Ti require the mechanical removal from the surface of the deposited metal, if welding involves multiple passes. Avesta welding[12] also recommends the addition of 1–3% CO_2 to the Ar + 30% He mixture to stabilize the arc during welding, suggesting that higher percentages of CO_2 may lead to the oxidation of the surface and the inclusion of carbon in the metal via the cast well. Along the same line of recommendation, yet without presenting any justification, Kobelco[13] and Praxair[14] suggest atmospheres formed by the gases Ar/He or Ar/He/CO_2, in this the latter always limiting the percentage of active gas in the mixture to values of the order of 1–3%. A very different situation is found in the use of additional metal to 625 alloys in the form of fluxed core wire, in which the presence of 25% CO_2 in the gaseous atmosphere is considered fundamental to obtain acceptable deposits[10,13,15]. Confronting the justifications presented for the limitation of the CO_2 percentage for welding with ER NiCrMo-3 wire, it is possible to verify that the fluxed core wire manufacturers for 625 alloys do not indicate the presence of Ti or Al (Table 4) in the composition of the deposited metal[15,16], which contributes to the explication about the harmful effect of the presence of refractory oxides originated by the addition of CO_2 to the shielding gas. Nevertheless, it is necessary to point out the existence of manufacturers of fluxed core wire for 625 alloys which suggests welding being carried out with an atmosphere containing 25% CO_2 despite the existence, even at a low percentage, of Ti and Al in the composition of the deposited metal (Table 5).

On the other hand, if the use of Ar/CO_2 may be avoided for welds with multiple passes due to the appearance of hard microstructures, potentially the mixture might be used for single pass welds, since in this situation, the presence of oxides on the surface would not result in greater consequences for deposits. It is important to emphasize that the appearance of regions of hard microstructures in the welding of 625 alloys may occur regardless of the shielding gas, the transfer mode or even the welding process used. When investigating the tenacity of the fracture of the zone affected by the heat/connection zone (ZAC-ZL) of X60 steel joints welded with ER NiCrMo-3 electrodes, Pope et al.[18] demonstrated that these joints are susceptible to presenting localized fragile zones characterized by the presence of martensitic microstructures with a hardness of approximately 360 VH.

In general, use of shielding atmospheres with a low percentage of active gas did not produce the expected results in joint welding. Despite the literature indicating that the presence of He is effective when obtaining deposits with good wettability, the results encountered suggest that additions in the range of 20% are only effective in deposition on plates, but that the percentage is limited when producing satisfactory results at the root. Potentially, percentages in the range of 30% or more improve wettability to the point of enabling a satisfactory root pass to be produced with the MIG/MAG process. However, in the light of the difficulty encountered even when the

Table 4. Values for the chemical composition[a] of fluxed core wire compatible with 625 alloy welding.

Ref.	Cr (%)	Mo (%)	Nb (%)	C (%)	Fe (≤%)	Si (≤%)	Al (≤%)	Ti (≤%)	Mn (≤%)	Cu (≤%)	S (≤%)	P (≤%)
13	22.0	9.2	3.8	0.03	3.0	0.3	NE	NE	0.4	NE	NE	NE
11	21.43	9.21	3.42	0.028	4.84	0.31	NE	NE	0.88	0.01	0.004	0.004
14	21	9.0	3.4	0.02	0.40	0.3	NE	NE	0.4	NE	NE	NE

[a]Nickel content: balance.

Table 5. Values for the chemical composition of ER NiCrMo-3 wire[17].

Ni (≥%)	Cr (%)	Mo (%)	Nb + Ta (%)	C (≤%)	Fe (≤%)	Si (≤%)	Al (≤%)	Ti (≤%)	Mn (≤%)	Cu (≤%)	S (≤%)	P (≤%)
64	20	9	3.4	0.04	0.50	0.30	0.05	0.10	0.30	0.05	0.015	0.020

Ar + 25% CO_2 mixture is used, the use of the process for welding in joints merits further investigation.

Due to the potential reduction in costs, not only due to the price of a cubic metre of gas but also due to the logistics of supply, it is important that analysis be carried out on the true effect generated by the use of Ar/CO_2 on the formation of hard microstructures and their risk potential in the fragilization of the welded joint, envisaging the application of the process for the filling/finishing of joints or coating of surfaces by overlaying. The suggestion for these applications results from the difficulty encountered in this paper for the application of ER NiCrMo-3 when performing the root pass in joints produced in ABNT 1020 steel plates, regardless of the gas or mode of transfer. It is equally important to mention the need to verify whether the presence of active gases in the atmosphere may result in a drop in corrosion resistance.

3. Conclusions

In this paper, the effects of shielding gas and the MIG/MAG mode of transfer on welding with ER NiCrMo-3 wire of 1.2 mm in diameter were analysed both on plates and joints produced in ABNT 1020 steel.

In relation to deposits on plates, the results obtained indicate that

- Use of shielding atmospheres with 20% helium and low active gas percentage was shown to be effective only in welding with deposition on plates, producing deposits of good wettability.
- Poor results were obtained in short-circuit transfer welding, regardless of the shielding gas.
- Use of an atmosphere composed of pure argon was only shown to be feasible for spray transfer welding when deposits present good wettability. In other transfer modes (short circuit and pulsed current), the low wettability of weld beads made use of pure argon unfeasible even for deposit on plate welding.

In relation to deposits at joints, it was observed that

- The most favourable results in root pass welding were obtained in pulsed current welding, employing a V-joint with an opening of 90°and Ar + 25% CO_2 atmosphere. However, despite the gaseous mixture employed having caused an improvement in the appearance of the weld, a difficulty in maintaining the uniformity of the reinforcement on the reverse side of the root along the joint was still observed.
- Use of shielding atmospheres with 20% helium and low percentages of active gas did not produce the results expected and have a limited effect on improving the wettability of the root pass.

Notes

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