PEER REVIEW, Vol. 6, Nº 8, 2024
DOI: 10.53660/PRW-1989-3705
ISSN: 1541-1389

Influence of different shielding gas ratios on the microstructure and mechanical properties of MIG/MAG robot welded JSC270C steel.

Influência de diferentes proporções de gases de proteção na microestrutura e propriedades mecânicas do aço JSC270C soldado por robores MIG

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ABSTRACT

Welding is a manufacturing process that aims to create a permanent joint between two components using parameters such as heat, pressure, or energy. It is currently one of the most widely used processes in industry and there are no concerns about the safety of the products produced. Welding gases are responsible for the protection of the weld pool and the stability of the electric arc, which directly affects the quality and final properties of the weld. The aim of this study was to evaluate the current conditions of the welding process in a large company in the Manaus Industrial Pole (PIM), Amazonas-Brazil, in order to find the best ratio of shielding gases for MIG/MAG welding, with the aim of and optimizing the processes. Mechanical tensile and microhardness tests were carried out, based on JIS, ASTM and internal company standards, to evaluate the conditions and properties of the samples with the current shielding gas ratios used in the company, in order to find those that best match the reality of the processes.

Keywords: Shielding gases; MIG/MAG welding; Mechanical properties of the weld.

Recebido: 08/03/2024 | Aceito: 10/04/2024 | Publicado: 12/04/2024

RESUMO

A soldagem é um processo de fabricação que tem como objetivo criar uma junção permanente entre dois componentes, utilizando parâmetros como o calor, a pressão ou a energia. É atualmente um dos processos mais utilizados na indústria e não existem preocupações quanto à segurança dos produtos produzidos. Os gases de soldagem são responsáveis pela proteção da poça de fusão e pela estabilidade do arco elétrico, o que afecta diretamente a qualidade e as propriedades finais da soldadura. O objetivo deste estudo foi avaliar as condições atuais do processo de soldagem em uma empresa de grande porte do Pólo Industrial de Manaus (PIM), Amazonas-Brasil, a fim de encontrar a melhor relação de gases de proteção para a soldagem MIG/MAG, com o intuito de padronizar e otimizar os processos. Foram realizados ensaios mecânicos de tração e microdureza, baseados em normas JIS, ASTM e normas internas da empresa, para avaliar as condições e propriedades das amostras com as atuais proporções de gases de proteção utilizadas na empresa, com o objetivo de encontrar as que melhor se adequam à realidade dos processos.

Palavras-chave: Gases de proteção; Soldagem MIG/MAG; Propriedades mecânicas da solda.

INTRODUCTION

Welding is a manufacturing process that seeks to create a permanent bond between two components, using parameters such as heat, pressure or energy. It is currently one of the most widely used processes in industry and there are no concerns about the safety of the products produced.

Gas shielded welding, with an emphasis on the MIG/MAG process, is currently used in countless industrial applications. The ease of automation and the various types of materials that can be welded using this method further expand its applications (BERNARDES, J. L. et al, 2007). The arc and the welding area are protected by a gas or mixture of gases, which can be inert or active, whose function is to prevent contamination of the molten metal droplets that are transferred to the weld pool by the gases present in the atmosphere. The process is known as MIG when the shielding used is inert or rich in inert gases or MAG when the gas used is active or has mixtures rich in active gases (MARQUES, P. V, et al, 2005). The process is used on a large scale to join steels in industry. The motorcycle sector, for example, uses the MIG method with different proportions of gases to manufacture different components, such as the tank, chassis and fairing.

As there are various gas ratios with varying effects, time is often wasted setting up and adjusting machines when changing gases and parts, which leads to a loss of productivity. Another factor to consider is the gas flow rate, which directly affects the final cost of the operation, depending on the gas used. However, the exclusive use of a more expensive or cheaper gas does not necessarily guarantee the needed quality.

Therefore, the standardization of a single shared process is necessary for better control of quality and process costs. In MIG/MAG welding, it is necessary to protect the joint area from external contamination that could weaken the joint. To do this, a protective atmosphere is created which is pumped in a constant flow during welding.

The shielding gases widely used in carbon steel welding in recent decades are argon (Ar), carbon dioxide (CO2) and helium (He), which are used pure or mixed. The use of the right protective gas guarantees the efficiency of the weld deposition and the cost, with helium (He) being the most expensive gas, Ar being of intermediate price and CO2 the cheapest (IRVING, B. 1999, p. 37-41). The main purpose of this protective atmosphere, created by gases such as oxygen (O2), carbon dioxide (CO2), helium (He) and argon (Ar), is to protect the weld pool from harmful impurities that cause defects. But in addition to this primary function, the shielding gas has a significant effect on the geometry of the weld, the appearance of the weld bead, metallurgical and mechanical properties, welding speed, metal transfer, arc or laser stability and fume emission. The shielding gas is therefore a decisive factor in the properties of the welded joint and the efficiency of the welding process.

These gases are divided into inert MIG and active MAG and have a direct effect on the quality and mechanical properties of the joint. When welding steel with MIG/MAG, as the oxide layer near the weld pool is consumed, the arc tends to deviate and search for new areas with oxide layers to emit electrons. This effect can reduce arc stability and result in poor weld penetration. An oxidizing gas (O2 or CO2) is added to the shielding mixture to regenerate the oxide layer and suppress this effect (TATAGIBA, L. C. S. et al, 2012, pp. 218-228).

Some studies have already demonstrated the relationship between welding parameters, such as the percentage of gases, and the mechanical properties of joints in aluminum alloys, stainless steel and carbon steel welded by processes using gases, such as MIG, cored wire and hybrid LASER-MIG (MVOLA, B. et al, 2017, pp. 2369-2387); (DE ALMEIDA, D. T. et al, 2018, pp. 333-340); (DE LIMA, R. B. E. 2019).

This work aims to evaluate the effect of the proportions of gases used in the MIG/MAG process on the mechanical properties and microstructures of welded joints of JSC270C cold-rolled steel, used for the manufacture of motorcycle tanks. The proportions used were: (proportion 1: 100% argon), (proportion 2: 92% air and 8% CO2), (proportion

3: 75% air and 25% CO_2), (proportion 4: 100% CO_2). The joints were subjected to tensile, flexural, Vickers, and microhardness tests and analyzed by light microscopy.

MATERIALS AND METHODS

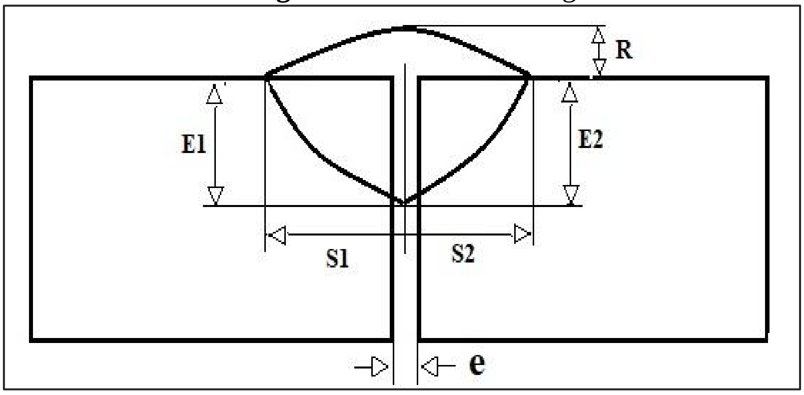
Materials

The specimens were supplied by CHINA STEEL CORPORATION in the form of rolled sheets with the dimensions 250x10x0.26 cm (chemical composition: C 0.100%, Mn 0.500%, P 0.035%, S 0.025% and Al 0.020%). Welding of the plates was performed using solid wire of diameter 1.0 mm, class AWS A5.18 ER70S-6 EM 440 G3Sil, supplied by ESAB company (chemical composition: C 0.080%, Mn 1.500%, Si 0.900%). The following gases were used for arc protection: Argon (Ar) with a purity of 99.998% and carbon dioxide (CO_2) with a purity of 99.998%, both supplied by White Martins company.

Methods

Preparation of the sample: The sheets (base metal) were cut to 250x100x2.6 mm. A steel brush and degreaser were used to clean the plates. The plates were joined with a butt joint, square groove and root opening with e = 0.5 mm as shown in Figure 1. The dimensions E1 and E2 are the penetration depths of the joint, while S1 and S2 are the widths of the weld. R refers to the reinforcement and "e" indicates the weld root opening. These parameters were measured on all specimens using a macrograph and an optical stereoscope.

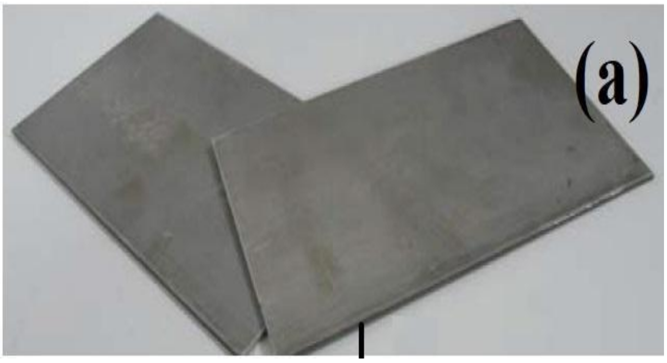
Figure 1: Elements of the groove.



Source: Costa et al (2024).

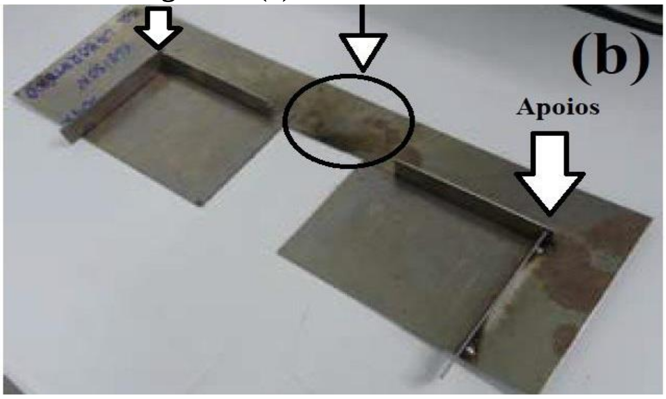
Welding process and variables: A support was used to stabilize the plates during the welding process, reducing warping and preventing movement, as illustrated in Figure 3.

Figure 2: (a) Sheets used in the study.



Source: Costa et al (2024).

Figure 3: (b) Assembled device.



Source: Costa et al (2024).

Welding was carried out using the Metal Inert Gas and Metal Active Gas (MIG/MAG) process. The gases used were Argon (99.998%) and CO_2 (99.500%), supplied by WHITE MARTINS company, with a gas flow rate of between 10 and 15 ℓ/minute. The displacement angle was 15°, the stick-out 15mm, with pulsed transfer, single pass welding and a welding speed of 100 mm/min. The continuous current (CCEP) and voltage applied are detailed in Table 1.

Table 1. Welding parameter values used.

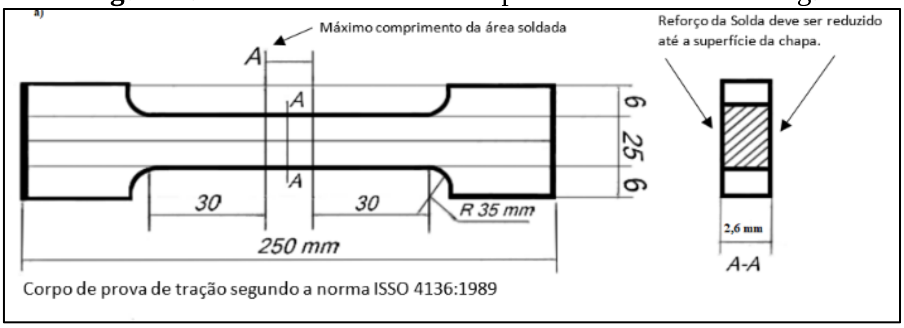
Shielding gas	Current (A)	Voltage (V)
100% Argon	156	19,3
92% Ar e 8% CO_2	162	19,6
75% Ar e 25% CO_2	155	19,7
100% CO_2	155	20

Source: Costa et al (2024).

Welding was automated, carried out by two specialized robots: a MOTOMAN model SSA 2000 and an OSAKA TRANSFORMER COMPANY-OTC model DM 350 welding source. Using this system, the process parameters were controlled, using pure gas (100% Ar) and its mixtures (92% Ar and 8% CO2) and (75% Ar and 25% CO2). The second welding robot, YASKAWA MOTOMAN model AR1440, operated with an OSAKA TRANSFORMER COMPANY-OTC welding source, model WELBEE M350L, using only gas (100% CO2) for welding.

Tensile test: The evaluation was carried out using a universal testing machine (EMIC, DL10000), equipped with a 10-ton load cell. The procedure followed the guidelines of the Japanese Industrial Standards (JIS) Z 3121 (2013). Ten samples were tested for each gas ratio in order to evaluate the methods established by this test.

Figure 4: Main dimensions of the specimen for tensile testing.

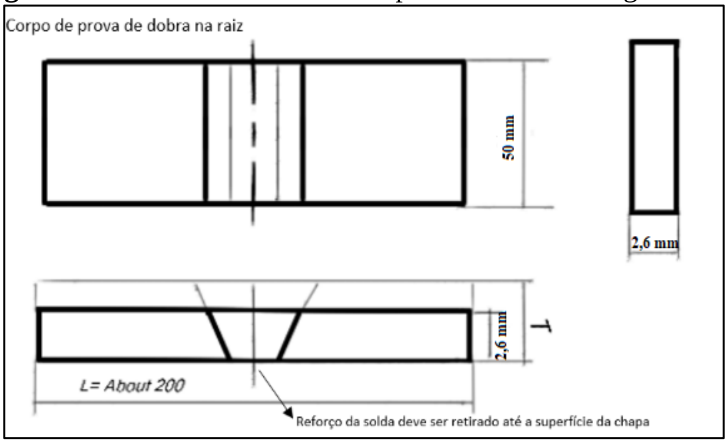


Source: Costa et al (2024).

Bending test: For this test, a universal machine (SHIMADZU, UH 30000) was used, where 10 specimens were tested, respecting the dimensional parameters of standard JIS Z 3122 (2013) - Methods for Evaluating Bending Tests on Top Welds, Figure 5. The bending test applied force perpendicular to the weld, at its base opposite the welded face.

Tests were carried out on 10 samples for each gas ratio, following the evaluation methods specific to this test.

Figure 5: Main dimensions of the specimen for bending tests.



Source: Costa et al (2024).

Víckers microhardness: The microhardness test was carried out using a microdurometer (SHIMADZU, DL200) following the procedures set out in the ABNT NBR 6672 standard.

Metallography: The macro and microstructural assessment was carried out in accordance with the metallographic procedures set out in ABNT NBR 13284. The chemical attack was carried out using 10% Nital acid for a period of 5 seconds. Macrostructure images were captured using an optical stereoscope (LEICA, DM5500), while microstructure images were obtained using an optical microscope (WILSON, TUKON 2100).

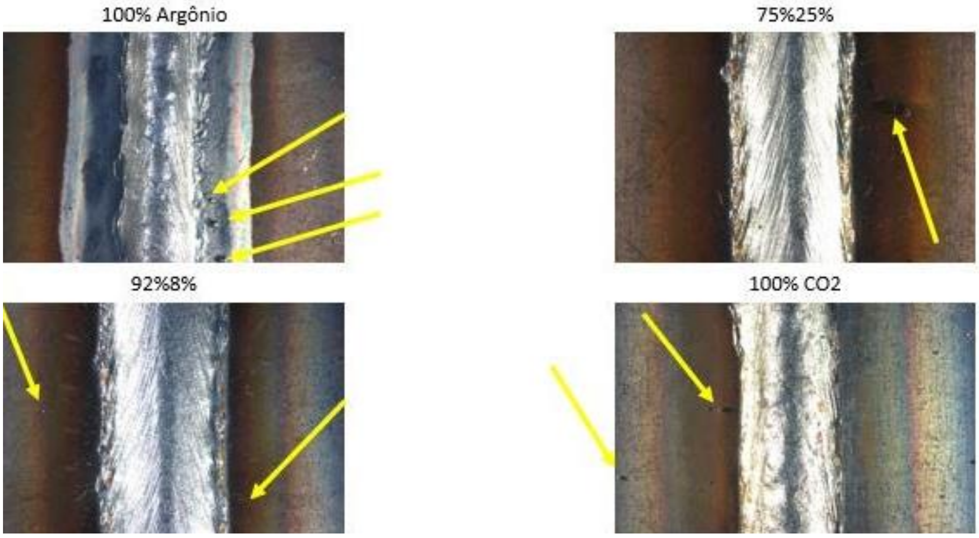
RESULTS AND DISCUSSION

Visual inspection of the joints obtained

First, a visual inspection of the weld beads was performed to check for any discontinuities that could affect the integrity of the weld.

According to the study consulted (MVOLA, B. et al, 2017, pp. 2369-2387), the addition of CO2 results in deeper, wider welds with more spatter. The same effect can be seen in the surface analysis of the weld in Figure 6. Notice the difference in the weld beads: the 100% Ar and 100% CO2 weld beads were higher, while the other two were more distributed over the base metal.

Figure 6: Surface analysis of the weld bead. Highlighted arrows indicate the presence of spatter. (a) 100% Ar, (b) 92%8% Ar, (c) 75%25% Ar, (d) 100% Ar. Magnification 20X.

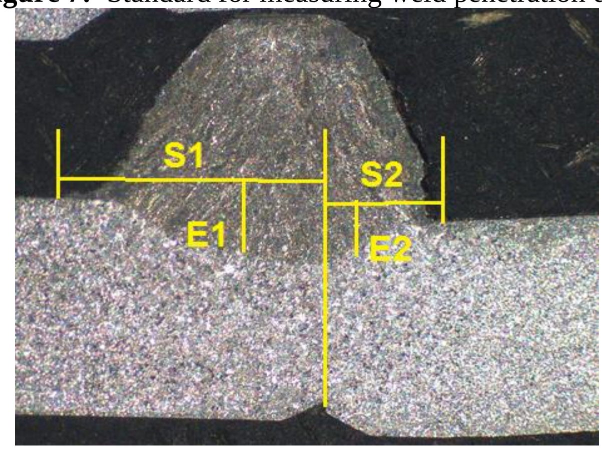


Source: Costa et al (2024).

Chamfer Elements

Another important characteristic evaluated was the depth of fusion measured from the original surface of the base metal (penetration), which directly influences the mechanical properties of the joint. Figure 7, shows that the abbreviations S (S1 and S2) correspond to the length of the weld measured in each base metal and the abbreviations E (E1 and E2) correspond to the penetration of the weld in each base metal, the letters having been chosen purely for nomenclature.

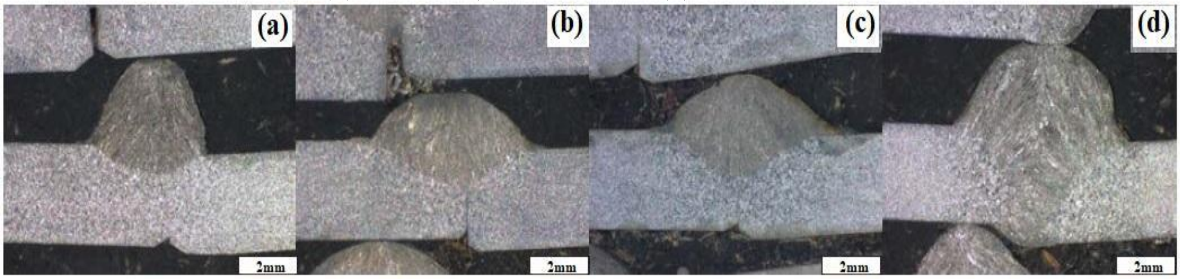
Figure 7: Standard for measuring weld penetration dimensions.



Source: Costa et al (2024).

Figure 8 (a) to (d) shows the macrographs of the cross sections of the joints with different percentages of gases that showed higher penetration. According to (DE ALMEIDA, D. T. et al, 2018, p. 333-340), CO2 dissociates in the arc and forms carbon monoxide CO and oxygen O2, creating an oxidizing atmosphere that becomes active at high temperatures. These gases have high thermal conductivity and increase the efficiency of heat transfer to the base metal, producing high penetration at higher percentages, but also increasing the amount of slag.

Figure 8: Macrograph of the welded joints showing the cross-section of the joints: (a) 100% Ar, (b) 92% Ar, (c) 75% Ar and (d) 100% Ar.



Source: Costa et al (2024).

Similar behavior was found when quantifying the size of the chamfer elements, which can be seen in Graph 1. It can be seen that the mixture with Ar - 100% obtained the greatest penetration E1 and E2 compared to the other mixtures and with the greatest reinforcement R. The mixture that obtained the second greatest penetration was with the proportion of Ar - 75%, this mixture also presented the greatest weld length S2.

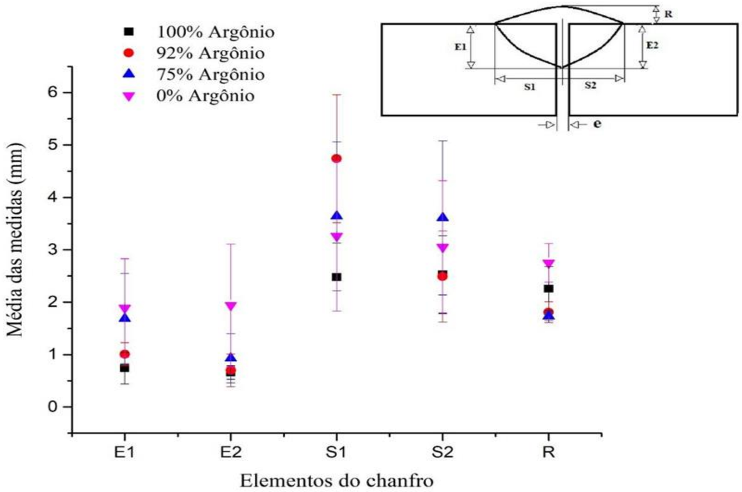
According to (LYTTLE; STAPON, 1990, p.21-28), the more concentrated CO2 gas produces a wider, rounder bead profile, which may be related to greater heat transfer to the base metal.

The 92% - Air combination showed slightly higher values than Ar - 100% in penetration E1 and E2 and high weld length S1 and medium S2, with only slightly higher reinforcement than 75%. And the 100% Ar mixture had the lowest penetration and weld widths.

In general, the higher the CO2 content, the more heat is retained in the shielding gas and the deeper the arc penetration. However, the optimum limit of CO2 content in the mixture is unclear. According to (ZIELINSKA et al, 2008, p. 111-122), arc stability is reduced at 9% CO2 in the mixture. (STENBACKA et al, 1989, p. 41-48) indicated that

15% CO_2 in the shielding gas mixture destabilizes metal migration and increases smoke and spatter. According to (SODERSTROM et al, 2008, pp. 124s-133), the higher the CO_2 content in the mixture, the higher the current density and the lower the anodic point on the droplet surface, which increases spatter and continuity failures.

Graph 1: Graph of the average measurements of the chamfer elements (E1 and E2): Depth of penetration, (S1 and S2): Reinforcement width/weld length, (R): Reinforcement.



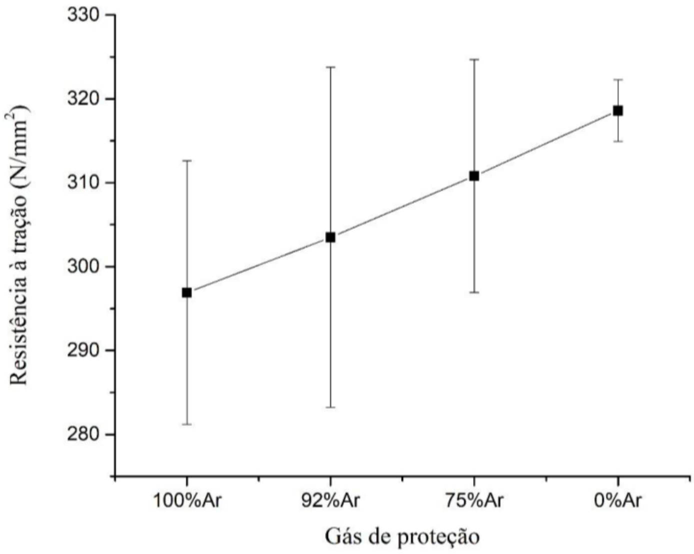
Source: Costa et al (2024).

Tensile tests

The tensile test was conducted to assess the weld's ability to resist joint separation. When evaluating the relationship between tensile strength and the proportions of gases, it was observed that as the amount of CO_2 increased, the maximum tension also increased, although only in small increments. All the ruptures occurred in the base metal. According to (BOHRER, C.B, 2013), rupture in the base metal shows that the mechanical properties of the bead are superior to those of the base metal, indicating the good quality of the welded joints. According to (KUMAR et al, 2014 p. 996-1003), the presence of CO_2 affects tensile strength because it increases weld penetration.

Graph 2 illustrates the variation in tensile strength of specimens with different proportions of gases. All the test results obtained values above 240 MPa, which is the maximum stress of the steel used.

Graph 2: Variation in tensile strength according to the proportion of gas.



Source: Costa et al (2024).

Bending test

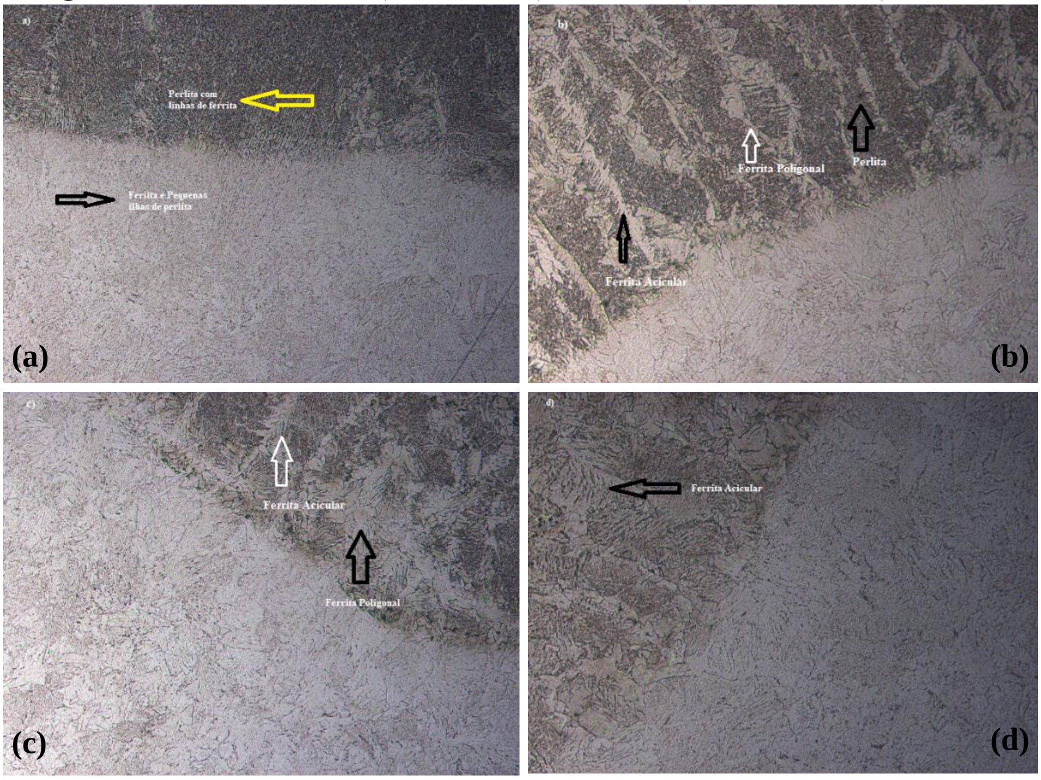
Through this test, it was possible to analyze the behavior of the weld when subjected to internal stress, since the weld can be subjected to various types of stress, both internal and external. It can be seen that the gas in the proportion of Ar - 100% has the lowest resistance to bending and the mixture with Ar - 92% has the highest resistance and as the proportion of CO2 increases, the less resistant it becomes. This is due to the fact that the CO2 in the shielding gas increases the carbon content of the weld metal, reducing ductility. The lower the ductility, the lower the resistance to bending.

Metallography

The microstructure is the parameter that explains some of the results previously obtained. Figure 9 (a), (b), (c) and (d) shows the bonding zones between the weld pool and the HAZ for the gases used.

The microstructure of the bond zone changes with increasing CO2 content. At 100% CO2, the shielding gas has no chemical reaction with the weld metal and its microstructure consists of equiaxed ferrite grains with small pearlite islands (CALLISTER, 2011). At 8% CO2, the ferrite veins grow and the pearlite decreases slightly. At 25% CO2, there is a small chemical reaction with the weld metal. The microstructure consists of elongated ferrite grains with several pearlite islands. The bond zone shows discontinuities in the base metal and some spatter on the surface. At 100% CO2, the shielding gas becomes more active and has a stronger chemical reaction with the weld metal. The microstructure consists of columnar ferrite grains containing many pearlite islands, (PARRISH, G. 1980).

Figure 9: Microstructure of a) 100% Ar, b) 928% Ar, c) 75%25% Ar, d) 100% Ar.



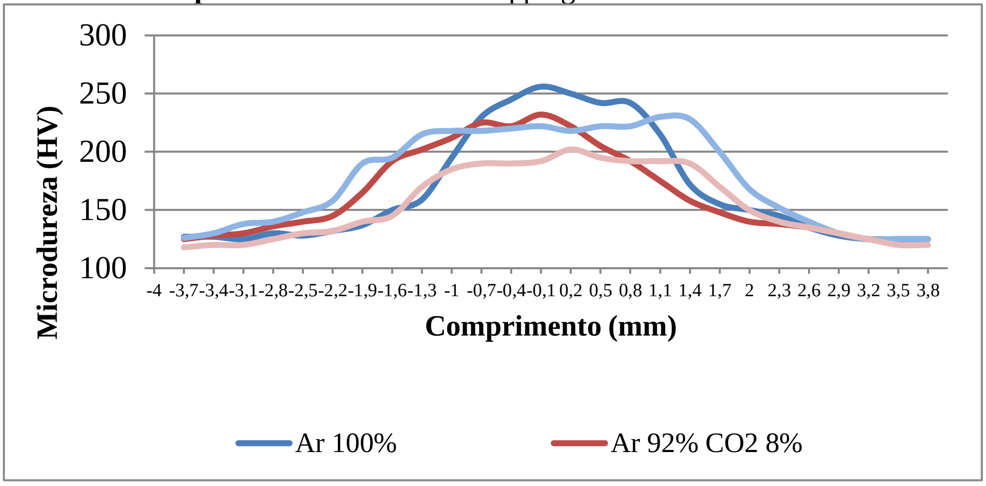
Source: Costa et al (2024).

Microhardness

The microhardness test was carried out to check the surface hardness of the cross-section of the welds. Analyzing the results in Figure 9, it can be seen that the surface hardness decreases as the proportion of CO2 increases. According to (DE LIMA, R. B. E. 2019) increasing the amount of CO2 in the shielding gas can increase the amount of inclusion after gas dissociation and porosity in the weld, thereby also increasing the formation of acicular ferrite, which improves the toughness of the weld and decreases the hardness.

According to (DE ALMEIDA, D. T. et al, 2018, p. 333-340), this fact may be related to the precipitation of fragile phases, due to the lower cooling speed in the molten zone region, which may contribute to higher microhardness values in this region.

Graph 4: Surface hardness mapping of the weld cross-section.



Source: Costa et al (2024).

CONCLUSION

The results obtained in this work are also very close to those obtained by other authors who have investigated the relationship between welding parameters, such as the percentage of gases, and the mechanical properties of joints in aluminum alloys, stainless steel and carbon steel, welded using processes that use gases.

Based on the analysis carried out, we can draw some conclusions about the effects of CO_2 on the properties of GMAW welding of JSC270C steel:

a) Increased weld penetration: CO_2 reacts with the weld metal, increasing the thermal efficiency of the gas, increasing metal transfer and weld depth.

b) Increased carbon content in the weld metal: up to 8% CO_2, carbon is disassociated and deposited in the weld. This increases the hardness and mechanical strength of the weld metal, but also decreases ductility and toughness. In addition, the increase in carbon can affect the corrosion resistance of the material.

c) Alteration of the microstructure of the molten zone and the thermally affected zone: CO_2 affects the cooling rate of the molten and solidified metal, altering the crystalline phases present. In the case of JSC270C steel, the main phases are ferrite and pearlite. Ferrite is a body-centered cubic (BCC) phase that contains little carbon and is light in color. Pearlite is a lamellar mixture of ferrite and cementite, which is an orthorhombic phase that contains a lot of carbon and is dark in color. The microstructure can vary from equiaxed to acicular grains, depending on the degree of cooling.

d) Change in the mechanical properties of the molten zone and the thermally affected zone: for tensile strength, the higher the CO2 content, the more resistant it will be to tensile strength, mainly due to the greater penetration of the weld. In bending, CO2 is only beneficial up to 8% more than this and it reduces the toughness of the part. The same goes for hardness, due to the increase in acicular ferrite and decrease in pearlite.

e) Based on these observations, we can optimize the process by standardizing the ideal amount of CO2 between 8-25%. Up to 8% for thin welds of up to 3mm and up to 25% for thicker plates.

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