VOL. 5 Nº2 - 2023

UTN IBARRA - ECUADOR
Facultad de Ingeniería en Ciencias Aplicadas
Innovation & Development in Enginnering in Applied Science
IDEAS

Study of the effect of the combination of protective gases on the structure of the weld bead for the GMAW process using pulsed arc and short circuit

http://doi.org/10.53358/ideas.v5i2.892

Juan C. Segovia[1]; Carlos M. Segovia[2]; Tamara S. Monar[3]

[1] Universidad de Otavalo, Otavalo, Ecuador

[2] Universidad Técnica del Norte, Facultad de Ingeniería en Ciencias Aplicadas, Ibarra, Ecuador

[3] Escuela Politécnica Nacional, Facultad de Ingeniería Mecánica, Quito, Ecuador

Fecha de envío, mayo 8/2023 - Fecha de aceptación, septiembre 14/2023 - Fecha de publicación, septiembre 28/2023

Abstract: A weld bead's geometry directly influences the welded joint's physical characteristics and mechanical performance. The composition of the shielding gas directly affects the form of metal transfer during the welding process and, therefore, modifies the geometry of the weld seam obtained. In addition, metal transfer methods also influence the configuration of the weld bead profile. The objective is to analyze the geometry of the weld bead with different combinations of shielding gases and metal transfer modes in the continuous wire electric arc welding process with gas shielding (GMAW). To achieve this objective, a methodology is proposed to analyze the weld bead's penetration and other geometric parameters. This is achieved by varying the percentages of the gas mixture between Ar and CO2 and by employing different types of metal transfer, such as short circuit, pulsed, and PMC multi-control pulsed. Generally, when using only CO2 as shielding gas, a wide, round weld bead is obtained. If Ar alone is used, the weld bead profile has a very thin shape and deep penetration. With the mixture of Ar and CO2, a bead is obtained with good penetration and sufficient width to cover the two test tubes without empty spaces between the base and filler materials. The macrographic analysis of the chords with their respective measurements is presented, and the geometric parameters of the obtained chords are tabulated. The penetration of the bead is directly proportional to the percentage of CO2 present in the mixture. In a comparison between the three transfer modes used with the same gas composition, it is found that the pulsed spray mode produces greater penetration.

Keywords: Shielding gas, pulsed arc, pulse multi-control, penetration.

Resumen: La geometría de un cordón de soldadura influye directamente en las características físicas de la junta soldada y en su desempeño mecánico. La composición del gas protector afecta directamente a la forma de transferencia de metal durante el proceso de soldadura, y, por lo tanto, modifica la geometría del cordón de soldadura obtenido. Además, Los métodos de transferencia de metal también influyen en la configuración del perfil del cordón de soldadura. Se tiene como objetivo analizar la geometría del cordón de soldadura con diferentes combinaciones de gases de protección y modos de transferencia de metal en el proceso de soldadura por arco eléctrico con alambre continuo y protección gaseosa (GMAW). Para lograr este objetivo, se propone una metodología para analizar la penetración y otros parámetros geométricos del cordón de soldadura. Esto se logra al variar los porcentajes de la mezcla de gas entre Ar y CO2 y al emplear diferentes tipos de transferencia de metal, tales como: cortocircuito, pulsado y pulsado multicontrol PMC. En general, cuando se utiliza solo CO2 como gas de protección, se obtiene un cordón de soldadura redondo y muy ancho. Si se utiliza solo Ar, el perfil del cordón de soldadura tiene una forma muy delgada y con profunda penetración. Con la mezcla de Ar y CO2 se obtiene un cordón con buena penetración y un ancho suficiente para cubrir las dos probetas sin espacios vacíos entre material base y material de aporte. Se presenta el análisis macrográfico de los cordones con sus respectivas medidas y se tabulan los parámetros geométricos de los cordones obtenidos. La penetración del cordón es directamente proporcional al porcentaje de CO2 presente en la mezcla. En una comparación entre los tres modos de transferencia utilizados con la misma composición del gas, se tiene que, el modo spray pulsado produce mayor penetración.

Palabras clave: Gas de protección, arco pulsado, pulsado multicontrol, penetración.

Autor de correspondencia:
Juan C. Segovia, juanksego36@hotmail.com

Introduction.

The GMAW process (gas metal arc welding), also called electric arc welding with shielding gas, can be described as the union of metal parts produced by heating them, by means of an electric arc established between a consumable solid metal electrode. and the work piece [1]. The arc, the weld pool and the resulting seam need to be protected against contamination from elements present in the atmosphere, which is done by a gas or mixture of gases. The process is called MIG (metal inert gas), when the shielding gas used is inert, for example, argon or helium. On the other hand, in the MAG (metal active gas) process, the protection is carried out with the help of an active gas, such as O2 or CO2. [2].

The correct selection of the shielding gas is of vital importance to achieve better results in the welding process. For this reason, the available range of shielding gas mixtures has increased. Shielding gas selection is an important factor for welding process efficiency. The ideal estimation of shielding gas cost is 5–7 % of the welding cost [3].

With a simple variation in the composition of the shielding gas, beads with different widths, reinforcement heights, penetration, wetting and fusion angles, etc. can be obtained. In addition, the metal transfer modes that can be obtained with the new welding machines promise to provide better weld bead properties.

Weld bead width, reinforcement, and penetration measurements also depend on other welding parameters such as voltage, wire feed speed, and welding speed. The higher the voltage, the greater the width, reinforcement, and penetration. If the wire feed speed is increased, the measurements also increase. On the contrary, if the welding speed increases, the measurements of the bead decrease, since it has less metal transfer time the faster the welding progresses. [4].

Therefore, this project aims to develop a methodology to perform the analysis of the form and depth of penetration that is obtained with the GMAW process. For this analysis, different compositions of the shielding gas mixture will be used: argon and carbon dioxide. In addition, the same analysis will be carried out for conventional metal transfer modes with respect to the most technological ones on the market. The results of this analysis can be used to study the influence of the composition of the shielding gas and the different modes of modern metal transfer to optimize the fusion characteristics of the weld.

Background.

In September 2016, Marconi [5] presented their investigation aimed to evaluate the effect of two protection gases (Ar-20%CO2 and 100%CO2), of three working angles (30, 45 and 60º) and two displacements (45° by push and 60° by drag) on the dimensional aspects of the bead and the mechanical resistance of the fillet joint of a high-strength microalloy steel, welded by the process GMAW.

Chao li [6] studied the effects of shielding gases on the chemical composition, microstructure, purity, and low-temperature impact toughness of weld metal. They used two different shielding gases, which are Ar + CO2 and Ar + He + N2. It was found that N-containing shielding gas can modify the solidification mode of deposited metal, shorten ferrite content in the weld metal, and substantially enhance the low-temperature impact toughness of deposited metal.

Kuang [7] proposed to determine the effects of pulse mode on microstructure and properties of the material 2219 aluminium alloy using pulse MIG. With the inclusion of ultra-high frequency pulse (UFP) current to traditional pulsed MIG could synchronously enhance the strength and ductility of welded joints. Like conventional pulse MIG welding process (CP-MIG), the columnar dendrites at the edge of UFP-MIG weld turned into narrow, fine, and dispersed, and the number of columnar crystals declined progressively with the gain of pulse frequency.

Castillo [8] presented the investigation related to the effect of the type of shielding gas in the arc welding process on the microstructure of a weld bead deposited. The results show that there is a significant effect of the type of shielding gas in the arc welding process has on hardness and microstructure. The carbon content in the welding deposits increases when the active CO2 gas percentage is higher in the Ar-CO2 mixture, this influences the solidification structure.

Ulloa [9] concluded that the Ar+2%N2 mixture was the one that presented the best behaviour in reference to mechanical properties (closer to those of the base material), ferrite-austenite phase balance, chemical composition (higher number of PREN), and lower weight loss in corrosion tests.

Thermal conductivity of the shielding gas

It is the ability of the gas to conduct heat through it. The thermal conductivity, like the electrical conductivity of a gas at low pressure, increases with an increase in temperature. This conductivity influences the heat loss from the centre to the periphery of the plasma column, as well as the heat transfer between the plasma and liquid metal. While pure argon has low thermal conductivity, helium, a mixture of argon with hydrogen and argon with carbon dioxide, has high conductivity.

Figure 1 shows the arc column that is formed with the gases Ar and CO2. Because argon has a low thermal conductivity, the heat is concentrated in the core of the arc. In contrast, carbon dioxide has a broader arc column because it has a higher conductivity. For these reasons, it is stated that thermal conductivity directly affects the profile of the bead and the geometry of the penetration [9].

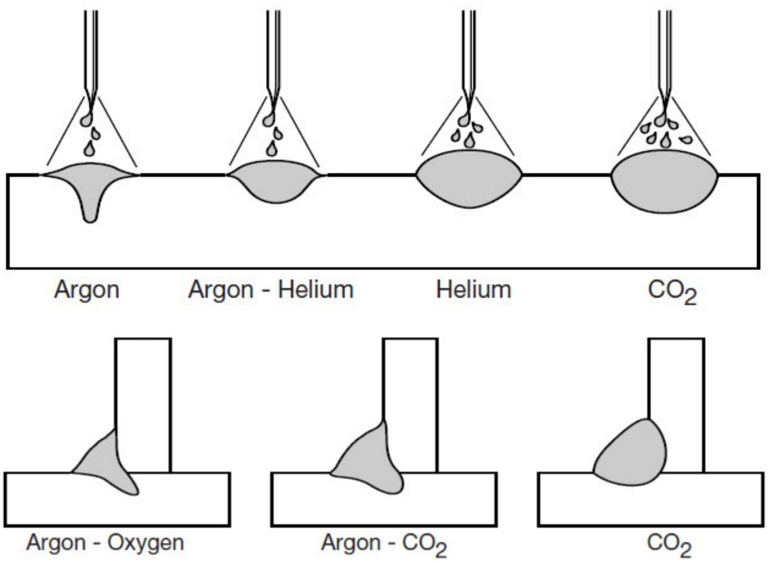


Fig. 1. Bead contour and penetration patterns for various shielding gases [9].

Properties provided by the shielding gas to the weld metal.

The shielding gas used in the welding process can directly influence the properties of the weld metal such as strength, ductility, hardness, and corrosion resistance.

As explained above, the addition of a percentage of oxygen or carbon dioxide to the shielding gas mixture increases its oxidation potential. Therefore, as the oxidation potential of the gas increases, the strength and hardness of the weld decreases. This occurs because the oxygen components increase the number of oxide inclusions and reduce the level of magnesium and silicon in the material [10].

In addition, when using mixtures with percentages of carbon dioxide, a transfer of carbon can be produced in the weld from the gas, and this can increase the concentration of carbon in the material until reaching unacceptable levels of it.

Profile and weld quality

Although gas mixtures with low levels of oxygen or carbon dioxide provide high mechanical properties to the weld bead, there may also be greater fusion defects than when using gases with higher oxidation potentials. In addition, blends with low oxidation potentials produce beads with a narrower profile in the shape of a wine glass. However, increasing the percentage of carbon dioxide increases the width of the bead, its penetration and roundness, reducing the risk of fusion defects.

Additionally, shielding gas can improve weld quality by decreasing the height of the bead reinforcement. If this height is relatively large, it increases the stress concentrations in the change of section between the base metal and the chord. The common method of removing or reducing excess bead reinforcement is by grinding the bead, but this is both costly and time consuming. Proper selection of the shielding gas mixture will reduce the surface tension of the weld metal and allow the solidifying metal to sink and achieve lower reinforcement.

The use of pure carbon dioxide as a shielding gas for welding carbon steel can cause large amounts of spatter. Removing the spatter after the welding process is not only expensive but can also cause aesthetic problems [11].

Short circuit transfer mode

In this type of transfer, the filler metal is transferred when the electrode is in direct contact with the weld pool and the electrode is fed at a constant speed. At this instant there is no arc and the current increases by heating the electrode. At the same time the electrode wire is deformed due to the electromagnetic Pinch force. As a result of the increase in current and the Pinch Effect, a drop of metal is produced that is transferred to the welding pool. After a new arc is generated, this occurs between 50 to 250 times per second.

In the short-circuit transfer mode, it is necessary to consider the welding technique and the procedure to be carried out when welding materials of considerable thickness, because with this mode there is a low heat input rate and a relatively shallow melt rate. The characteristics of this type of low heat input transfer produce rapid cooling of the weld puddle, making it an ideal process for welding in all positions [11].

Pulsed spray transfer mode

This type of transfer occurs with each of the pulses of the welding current in a controlled manner without short circuits. To achieve this type of transfer, a power source is necessary that provides two levels of energy: background current and pulse current. The background current is too low in magnitude to produce the transfer, but it is necessary to maintain the arc flash and heat input. On the other hand, the pulse current has a high energy level and is what produces the formation of molten metal drops from the electrode. This current occurs at controlled time intervals. Finally, there is a current that varies from high to low intensity in hundreds of cycles per second.

Pulse transfer was developed for better control of spatter and the elimination of incomplete fusion defects that appear in globular transfer and short circuiting. In addition, it is possible to reduce the rate of heat input compared to the axial spray method, which results in lower levels of material distortion due to heat. Like spray transfer, the shielding gas used must be argon or argon mixtures. The transfer of the metal is carried out only at the peaks of the pulse current, in this way a drop is transferred with each pulse. The frequency at which the pulses occur increases proportionally to the wire feed speed [12].

Multi-Control Pulsed Arc (PMC)

PMC a process developed by the company Fronius. It is the conventional pulsed, but with new functions and stabilizers.

Its main features are:

- Increased process stability through precise control.
- Optimized pulse characteristics and improved ignition.
- Better stability of reduced energy per unit length (welding speed and arc length).
- Penetration stabilization to make it more consistent.
- ncreased arc stability by means of an arc length stabilizer that helps the welder to set the perfect welding parameter for each weld joint.
- Useful for making mechanized welds especially in tight areas and hard to reach positions [12].

Methodology.

Base material

In the present analysis, the ASTM A36 material is used, which is one of the most used and commercial steels in Ecuador for projects that do not require a high-strength material. It is a ferritic-perlitic steel with low carbon content that has good weldability, which facilitates the project. 8mm (5/16") thick, 50mm (2") wide and 400mm long plates are used.

Input material

For the welding process of the specimens, the AWS ER70S-6 electrode wire with a diameter of 1.2mm is used, which is widely used in the Ecuadorian industry and has a high contribution rate. It is a continuous low carbon steel electrode coated with a thin layer of copper. It presents good weldability when CO2 or Ar/CO2 mixtures are used as shielding gas.

Shielding gases

The protection gases used in this project are Argon, Carbon Dioxide, and mixtures of both. These have been selected for their high application in the GMAW process and their wide commercialization in Ecuador. The two gases separately provide specific characteristics in the appearance and process of forming the weld bead that have been specified in the previous chapter. Therefore, the main objective of this project is to use mixtures of both gases to observe the influence of each one in the different compositions and determine the optimal composition in which the best geometric characteristics are obtained.

Welding of the specimens of short circuit probes

Keeping the type of short-circuit metal transfer and the welding advance rate constant, two types of specimens are welded: one of the simple metal filler types and the other of a T-joint, fillet weld. For each of the test tubes, the following protective gas mixture compositions are used:

- 100% carbon dioxide
- Argon mixture to 10% carbon dioxide
- Argon mixture to 25% carbon dioxide

In total, 6 test tubes are welded, which consist of a filler cord and a T-joint for each type of protective gas.

Conventional Pulsed and Pulsed Multi-control (PMC) Specimens

It is welded with two types of metal transfer, conventional pulsed and PMC pulsed, to make the comparison, the welding advance speed is kept constant.

For each type of transfer, the same procedure mentioned above is carried out, that is, two types of test tubes are welded: one with a simple contribution and the other with a T-joint. For each one, the following protective gas mixture compositions are used:

- Argon mixture to 10% carbon dioxide
- Argon mixture to 15% carbon dioxide
- Argon mixture to 25% carbon dioxide

In total, 6 specimens are welded for the pulsed transfer and 6 for PMC.

Designation of the test pieces

Table 1. Designation of the test pieces to be welded [12]

Mode	Gas Type	WELDING Simple Bead	WELDING Fillet Weld	TIPE
SHORT CIRCUIT	100% CO_2	x		CDD
	100% CO_2		x	CDF
	90%Ar- 10%CO_2	x		C10D
	90%Ar- 10%CO_2		x	C10F
	75%Ar- 25%CO_2	x		C25D
	75%Ar- 25%CO_2		x	C25F
PULSED SPRAY	90%Ar- 10%CO_2	x		SP10D
	90%Ar- 10%CO_2		x	SP10F
	85%Ar- 15%CO_2	x		SP15D
	85%Ar- 15%CO_2		x	SP15F
	75%Ar- 25%CO_2	x		SP25D
	75%Ar- 25%CO_2		x	SP25F
PULSED (PMC)	90%Ar- 10%CO_2	x		P10D
	90%Ar- 10%CO_2		x	P10F
	85%Ar- 15%CO_2	x		P15D
	85%Ar- 15%CO_2		x	P15F
	75%Ar- 25%CO_2	x		P25D
	75%Ar- 25%CO_2		x	P25F

Procedure for obtaining macrographs: Cutting of the specimens.

It is proposed to obtain 2 macrographic specimens of each welded specimen to determine if the penetration remains constant throughout the specimen. The recommended length for each macrographic specimen is 1 inch or 25mm. This length is the one necessary to have an easy handling of the specimen and security when the process of preparing the macrographs is carried out. Figure 2 shows the position of the cuts that are made to each test tube.

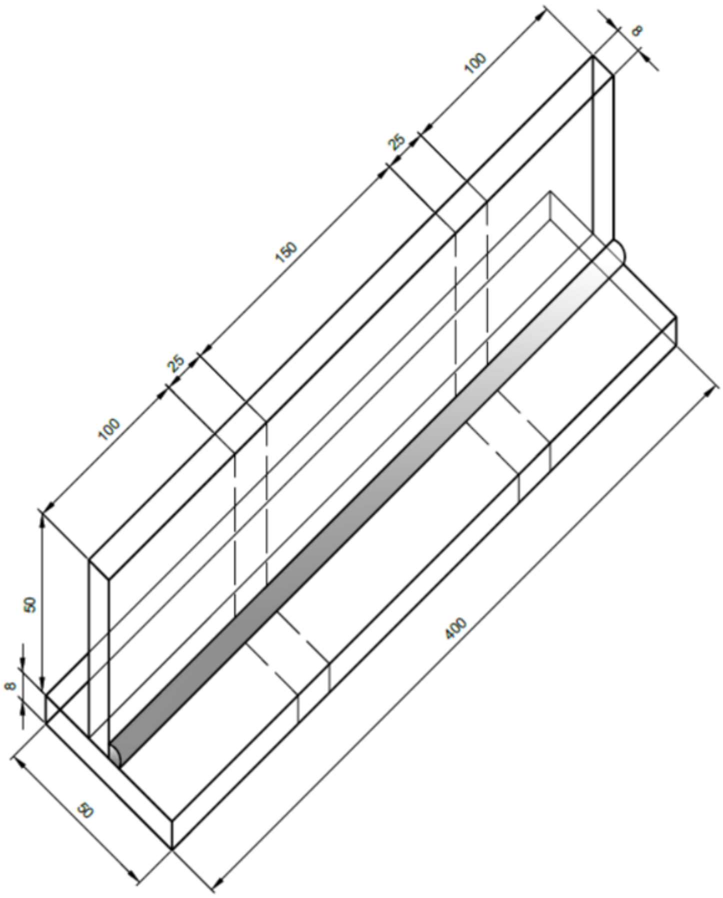


Fig. 2. Scheme for cutting welded joints [12]

Coarse roughing

The objective of this process is to obtain a completely flat surface free of marks produced by the reciprocating saw. To obtain this surface, a canvas sandpaper number 100 is used. Both for the coarse and fine grinding process, a cooling medium such as water must be used.

Fine roughing

It is a consecutive process in which the macrographic specimen is passed through increasingly fine-grained sandpaper. These sandpapers must be on totally flat and hard surfaces, to avoid scratches that interfere with the visualization of the macrographs. To obtain a better surface finish, it is necessary to perform a fine grinding using 5 different sandpapers with the following numbering: No. 240, 320, 400, 600, 1000.

Chemical attack

This procedure is carried out to demonstrate the structure or alloy of the material. The reagent that is generally used to carry out the chemical attack on irons and carbon steels is Nital. As can be seen in the table above, it is made up of 5% concentrated nitric acid in ethyl alcohol.

Measurement of the geometric characteristics of the chord

In order to carry out a comparative analysis between the welded beads with different composition of the protective gas and different transfer mode, it is proposed to carry out the following measurements:

- Convexity or concavity
- Effective throat
- Real throat
- Theoretical throat
- Horizontal and vertical leg length
- Horizontal and vertical bead size
- Fusion depth
- Weld width

Below is a diagram with the measurements that will be made in the macrographs of the weld deposits.

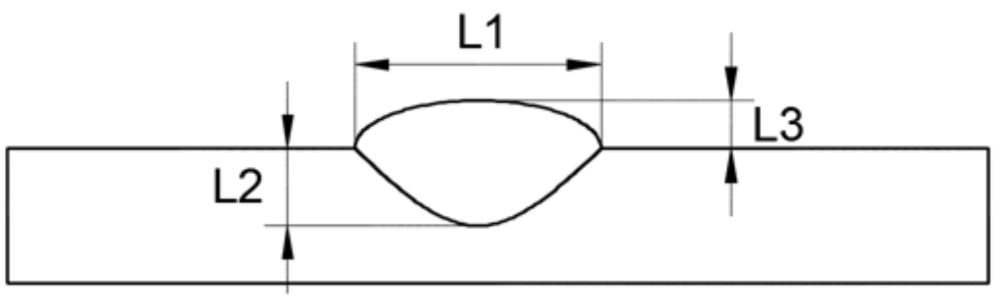


Fig. 3. Dimensions for weld deposit macrographs.

Where:

L1= Bead wide

L2= Weld Penetration

L3= Weld Reinforcement

Figures 4 and 5 show the measurements to be made on the macrographs of the T-joints

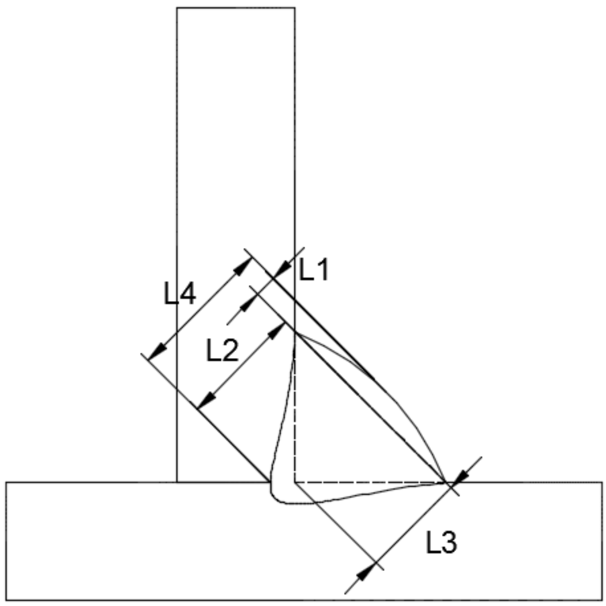


Fig. 4. Dimensions for macrographs of T-joints.

Where:

L1= Convexity or Concavity

L2= Effective Throat

L3= Theoretical Throat

L4= Actual Throat

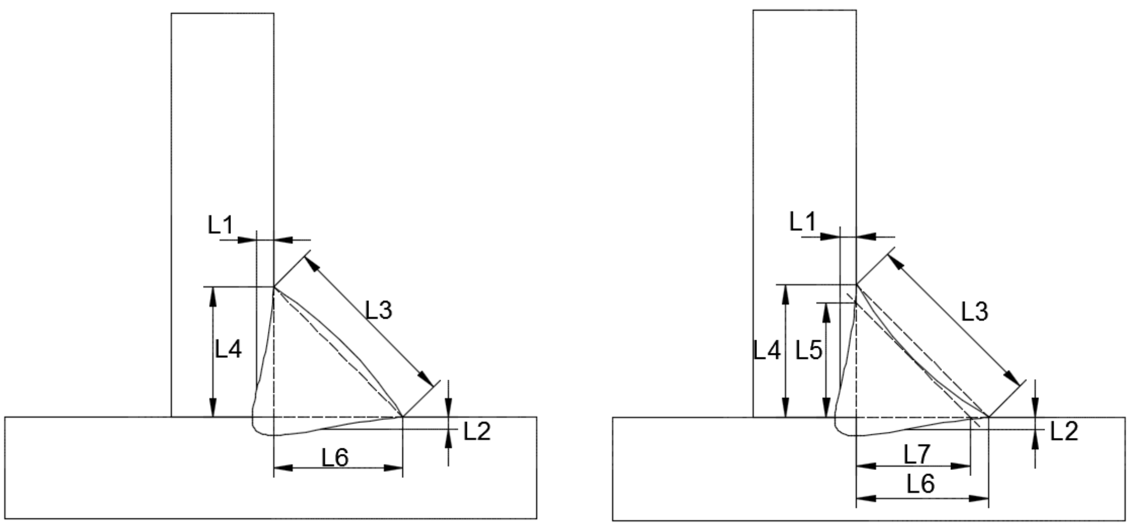


Fig. 5. Other dimensions for macrographs of T-joints.

Where:

L1= Vertical fusion depth.

L2= Horizontal fusion depth.

L3= Width of the bead.

L4= Size of the vertical weld bead.

L5= Vertical leg length.

L6= Size of the horizontal weld seam.

L7= Horizontal leg length.

Weld data recording

It is important to emphasize that the selection of the welding parameters considers the thickness of the base material and the type of joint to be made. Because the base material is 8 mm thick plates, and some manufacturers of welding machines such as Fronius recommend choosing an amperage counting from 50 A for each mm of thickness. However, in the case of thicker metal plates, this factor is reduced to 27.5 A per mm. So, the amperage value of 220 A is calculated. This section shows the main parameters used for each welding process. Table 2 shows the welding parameters obtained by using the short-circuit transfer method.

Table 2. Welding parameters in short circuit method.

Shielding gas composition.	100% CO2	10% CO2 – 90%Ar	25% CO2 – 75%Ar
Voltage [V]	24	24	24
Amperage [A]	220	220	220
Feed speed [m/min]	7	7	7
Welding speed [cm/min]	40	40	40
Input head [KJ]	302.6	304.8	306.1

Table 3. Welding parameters in pulsed arc method.

Shielding gas composition.	10% CO2 – 90%Ar	15% CO2 – 85%Ar	25% CO2 – 75%Ar
Voltage [V]	24	24	24
Amperage [A]	220	220	220
Feed speed [m/min]	7	7	7
Welding speed [cm/min]	40	40	40
Input head [KJ]	315.8	298.3	322.3

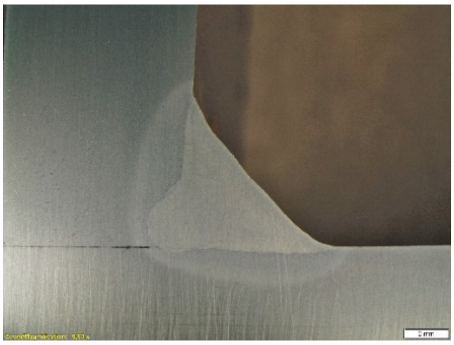
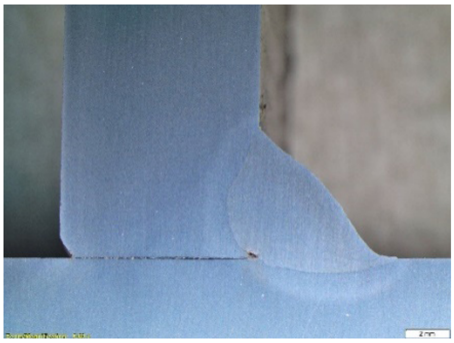
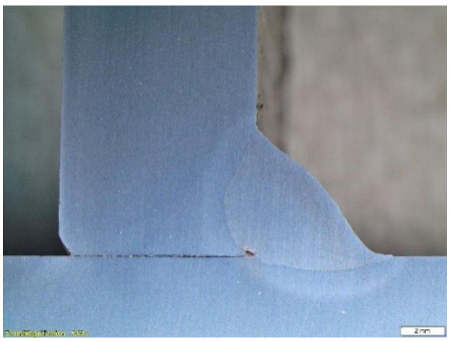
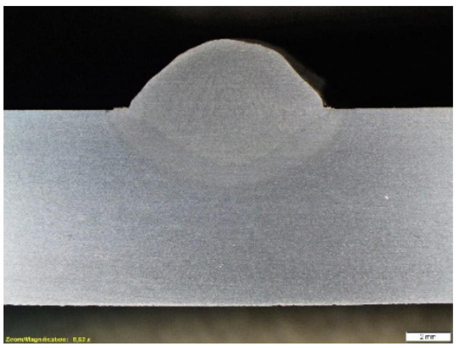
Table 4. Welding parameters in pulsed arc PMC method.

Shielding gas composition.	10% CO2 – 90%Ar	15% CO2 – 85%Ar	25% CO2 – 75%Ar
Voltage [V]	24	24	24
Amperage [A]	220	220	220
Feed speed [m/min]	7	7	7
Welding speed [cm/min]	40	40	40
Input head [KJ]	346.7	337.9	348.8

Macrography

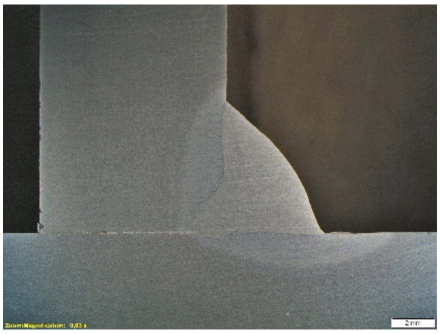
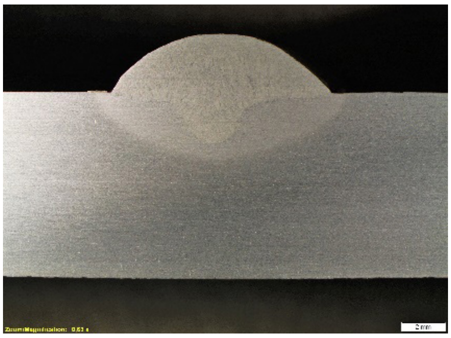
Two macrographic specimens of each welded specimen are made to verify if the penetration remained constant throughout the entire specimen. Table 3 shows the macrograph of a specimen of each welded specimen.

Table 5. Macrographs obtained from welding [12]

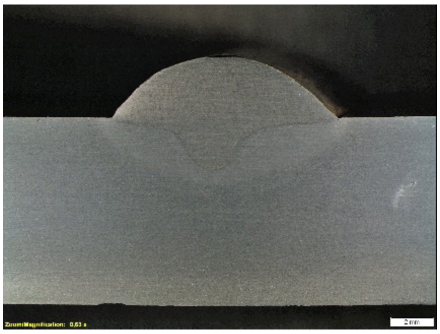
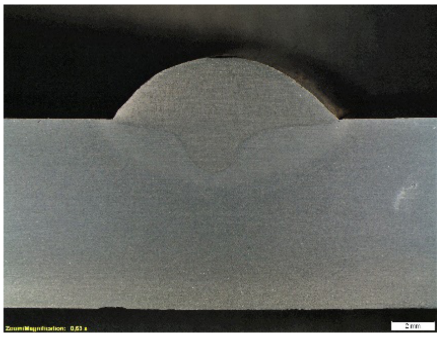
	Short circuit	
	Fillet weld	Weld bead
10% CO2 – 90% Ar		
25% CO2 – 90% Ar		
100% CO2		

Pulsed arc

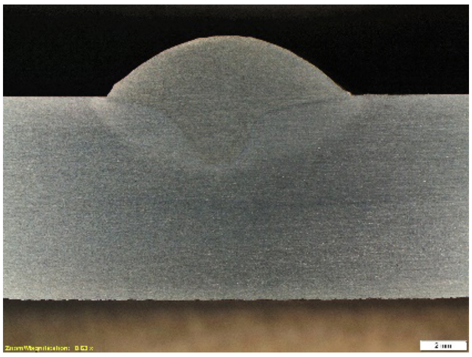
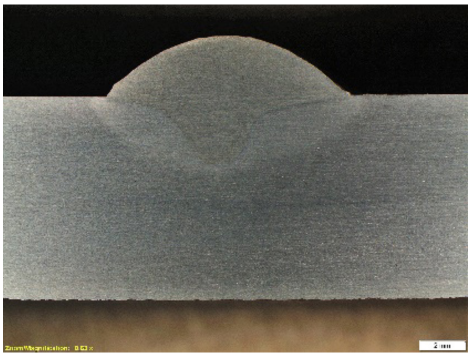
10% CO_2 – 90% Ar

15% CO_2 – 85% Ar

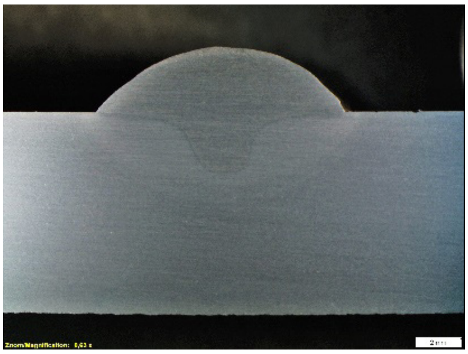
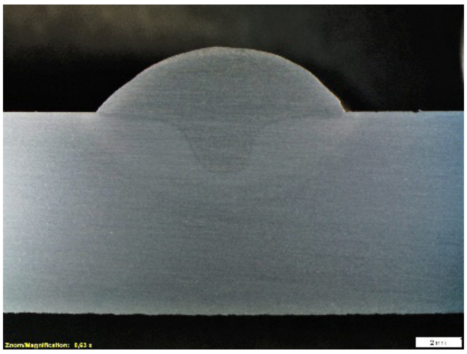
25% CO_2 – 75% Ar

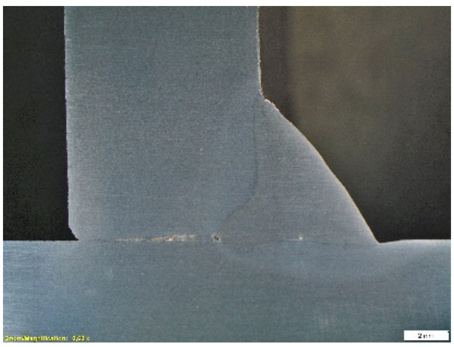
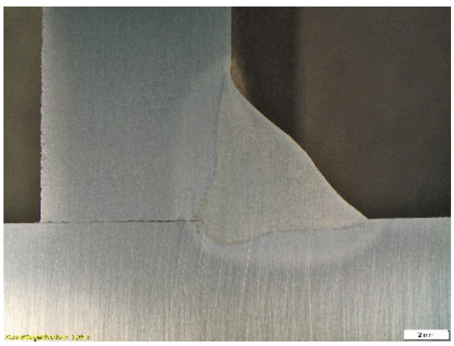
Pulsed arc PMC

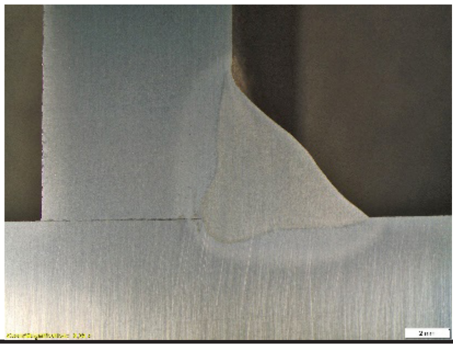
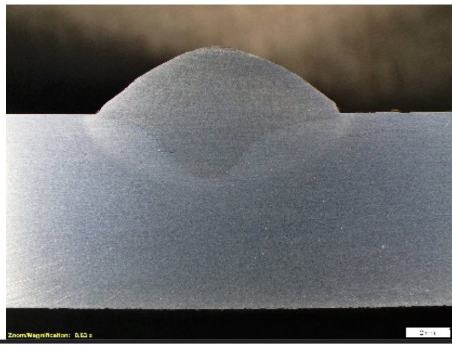
	Fillet weld	Weld bead

10% CO_2 – 90% Ar

15% CO_2 – 85% Ar

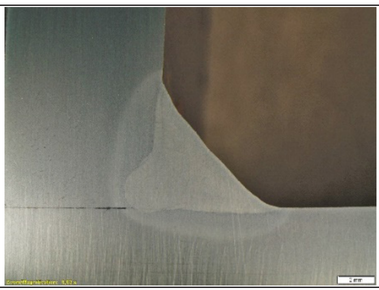
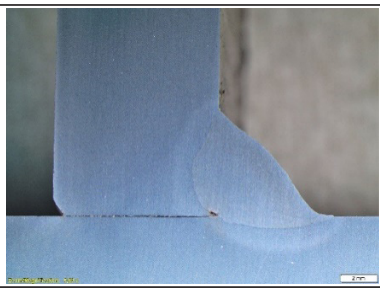
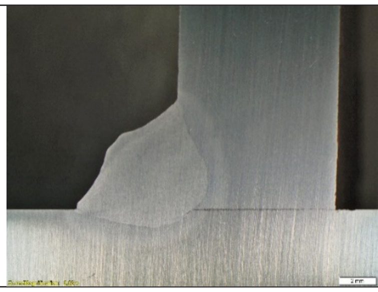
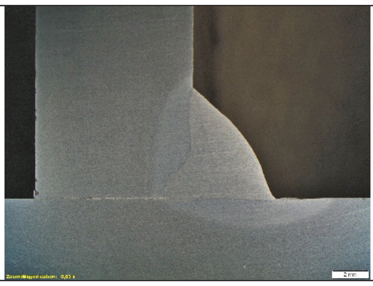
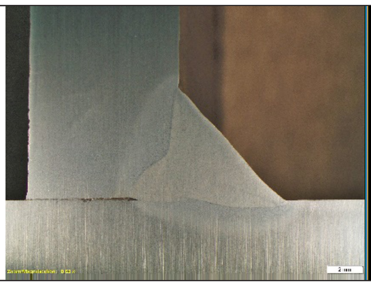
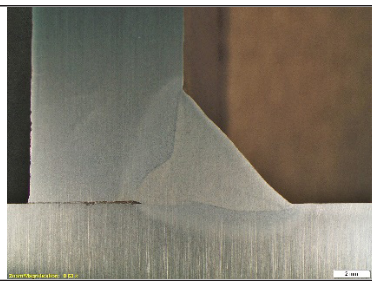



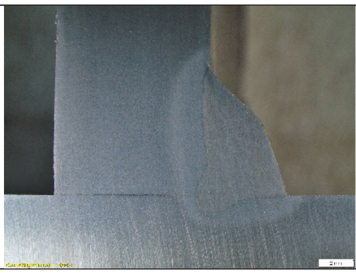
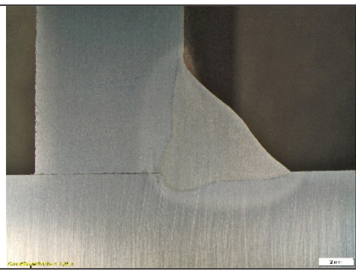
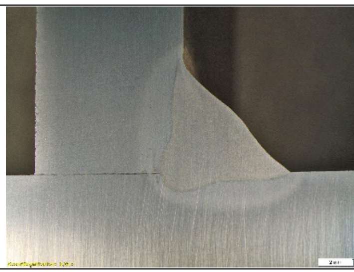
25% CO_2 – 75% Ar		

Results and discussion.

In this section, the welding defects identified in each macrograph are analyzed, as well as the dimensions measured in the test tubes of the weld seams in flat position and of the T-joints. In addition, the discussion of these results that serve as a reference for welding work. Table 4 shows the visual inspection of the macrographs according to the criteria of the AWS D1.1 standard.

Table 6. Detail of the visual inspection of the macrographs obtained [12]

Welded profiles with the short circuit method		
		
C10F	C25F	CDF
Default: None	Defect: Lack of root fusion	Default: None
Acceptable welding profile	Unacceptable welding profile	Acceptable welding profile
Welded profiles with the pulsed method		
		
SP10F	SP15F	SP25F
Default: Non-uniform weld	Flaw: Lack of fusion and bite	Default: None
Unacceptable welding profile	Unacceptable welding profile	Acceptable welding profile
Welded profiles with the PMC pulsed method		

		
P10F	P15F	P25F
Defect: Non-uniform weld	Default: None	Default: None
Acceptable welding profile	Acceptable welding profile	Acceptable welding profile

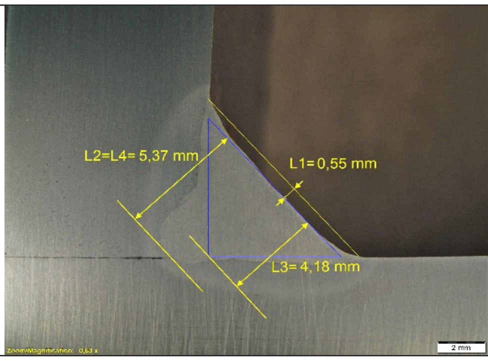
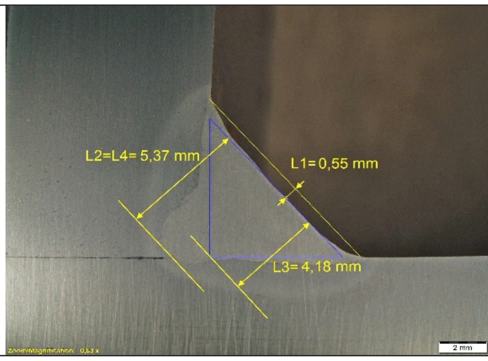
Through a visual inspection of the macrographs obtained of the T-type joints welded with the short-circuit transfer method, it is observed that in the C25F specimen (25% CO2) there is a lack of fusion that remains constant throughout the welded bead. This is due to the semicircular shape of the weld profile, which has low penetration. These results can be seen in Table 4.

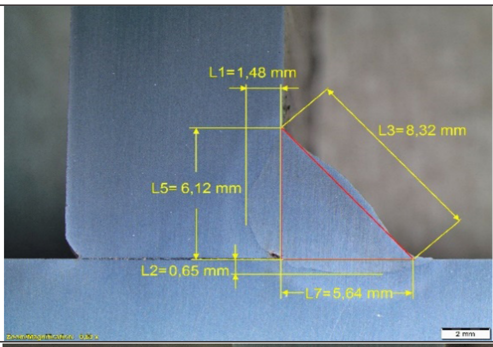
According to the criteria mentioned in the methodology for the acceptance of macrographic tests, the C25F specimen presents an unacceptable weld profile. On the contrary, the C10F and CDF specimens present acceptable weld profiles. In the macrographs obtained from the T-type joints welded with the pulsed arc method, it is observed that in the SP15F specimen (15% CO2) a lack of fusion and a bite were found. The formation of bites is produced by excess heat input. These results can be seen in table 4.

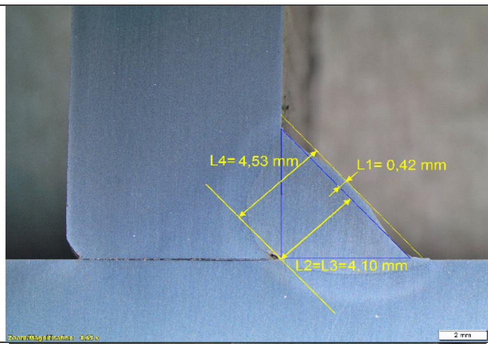
In addition, it is observed that the SP10F specimen (10% CO2) has a leg length of less than 5mm. This is considered an unacceptable weld profile because one of the weld legs does not meet the minimum length required for thicknesses from 6 to 12mm. This type of profile was formed due to the lack of precision in the inclination of the specimen.

In the macrographs obtained from the T-type joints welded with the multi-control pulsed transfer method, it is observed that in the P10F specimen (10% CO2), the profile of the bead has a non-uniform shape. The vertical side is longer than the horizontal side. This is considered an unacceptable weld profile because one of the weld legs does not meet the required minimum length of 5mm for thicknesses of 8mm.

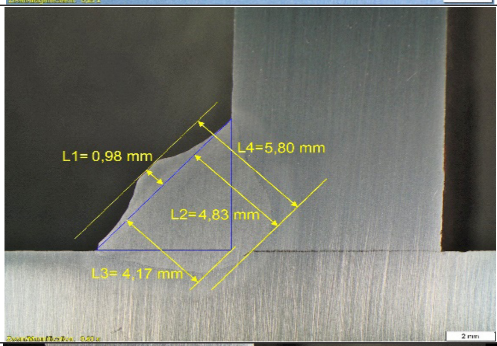
Table 7. Measurement of the geometric characteristics of the T-Joints [12]

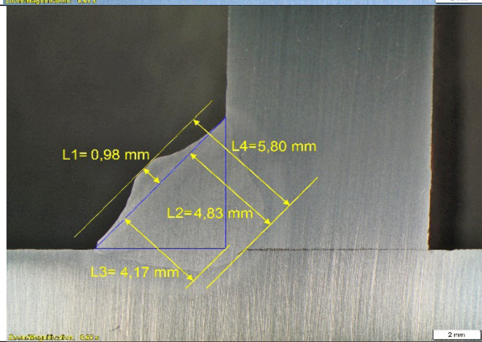
Macrograph – Leg thickness – Penetration	Macrograph – Effective and theoretical throat	
		C10F



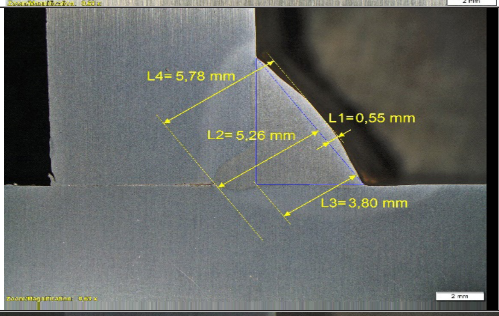


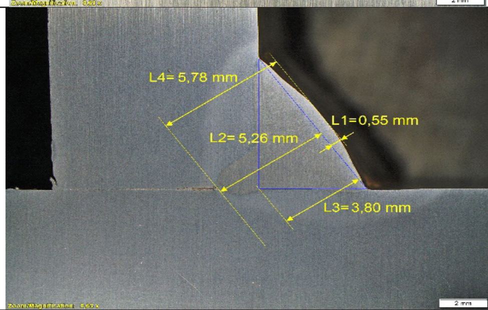
C25F



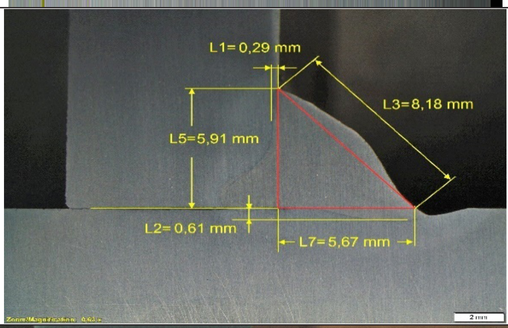


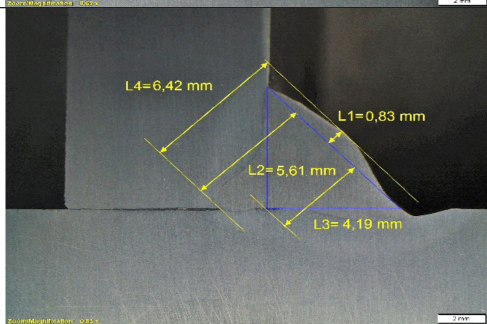
CDF



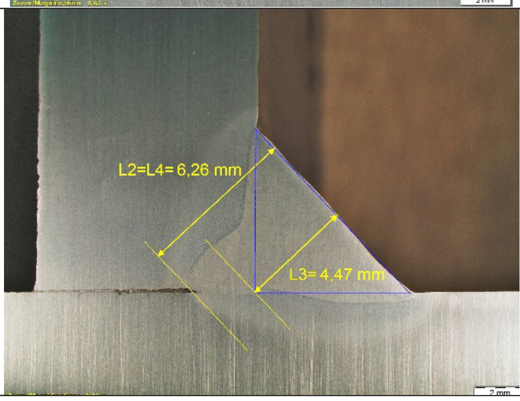


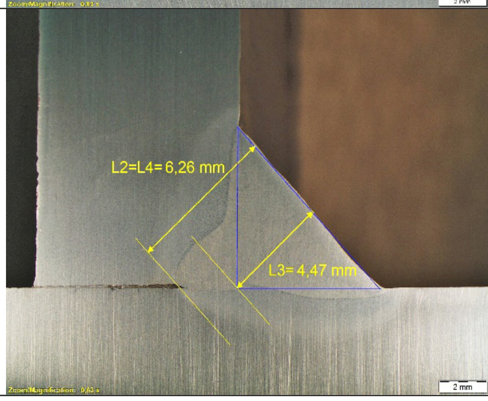
SP10F



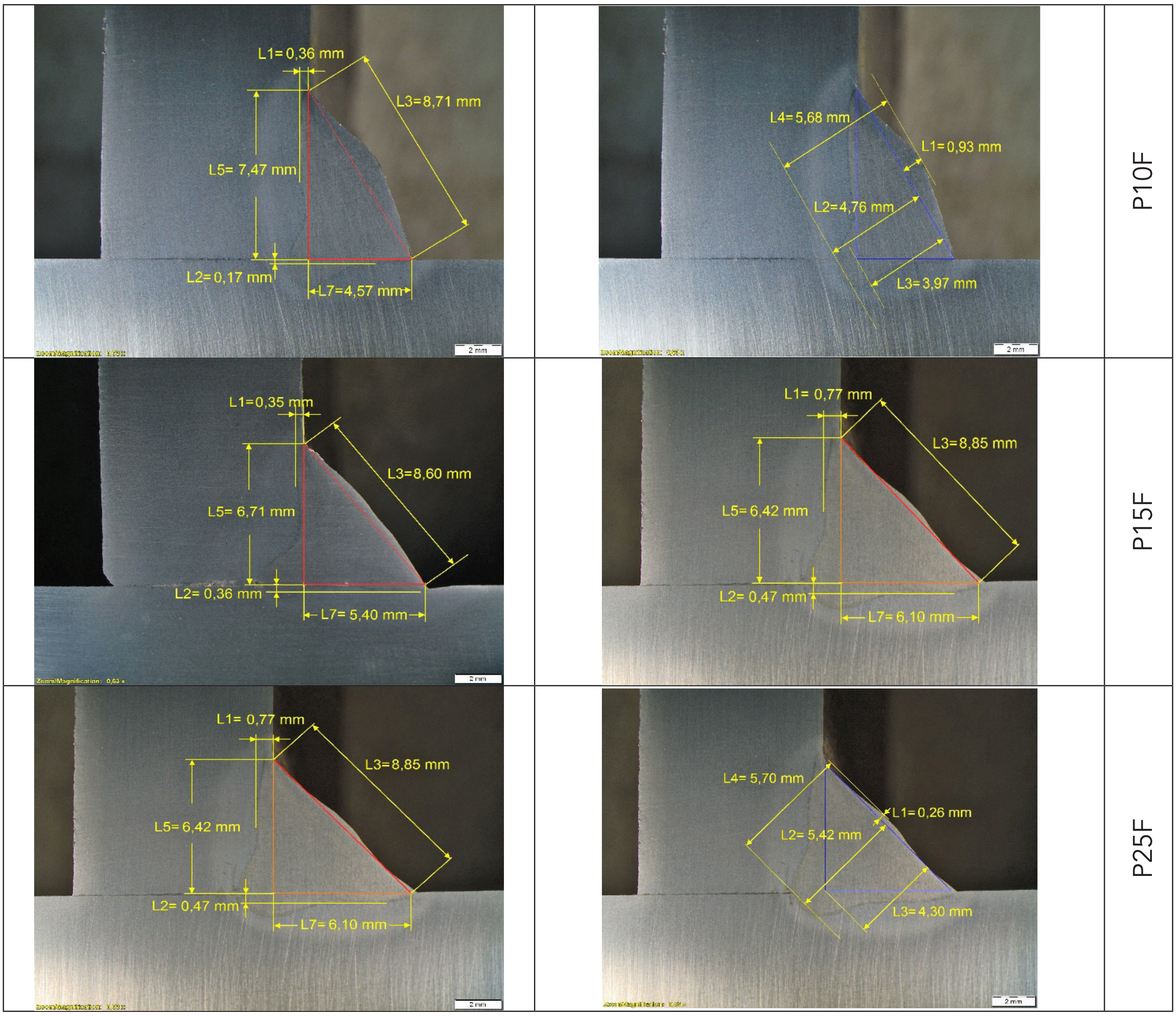


SP15F





SP25F



As can be seen in Figure 6, using the pulsed spray transfer mode, the greatest effective throat length is obtained compared to short-circuit and multi-control pulsed. However, due to the high heat input obtained with the pulsed spray mode, there is a tendency for undercuts to occur in T-joints. The throat in fillet welds represents the penetration obtained. In addition, it is observed that at 25% CO2 a considerable increase in penetration is obtained compared to 10% CO2.

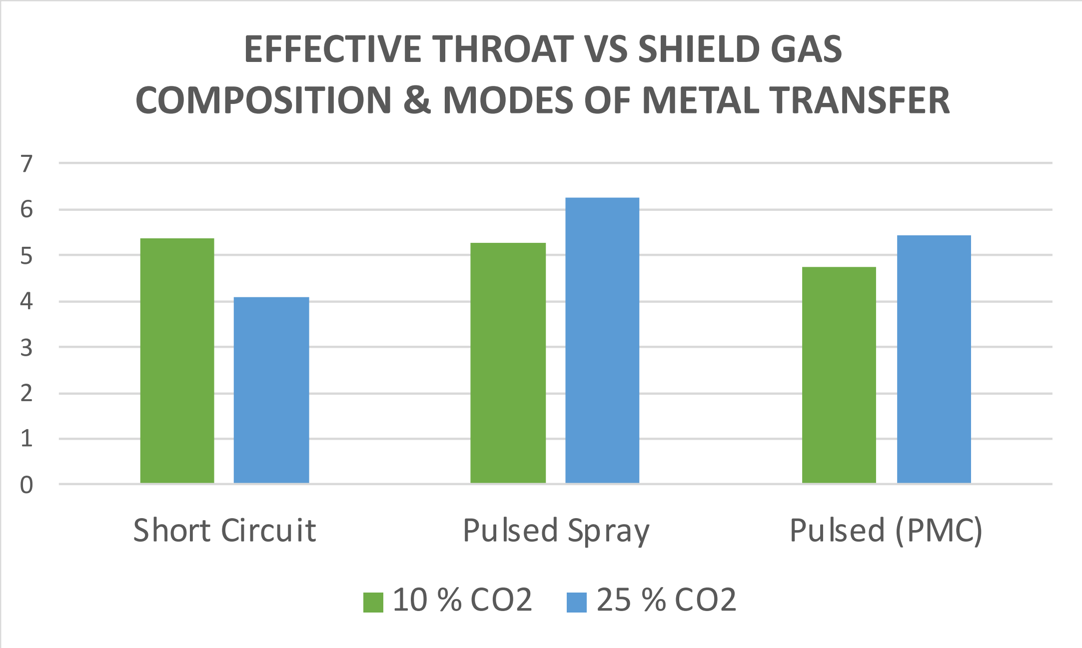
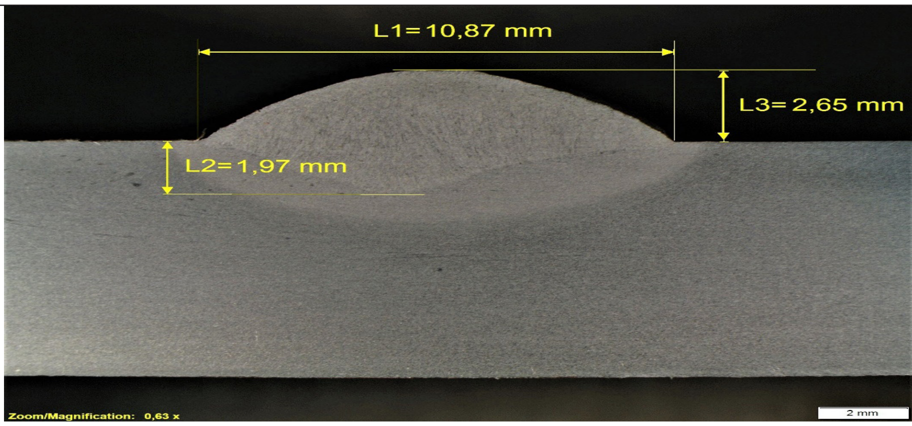
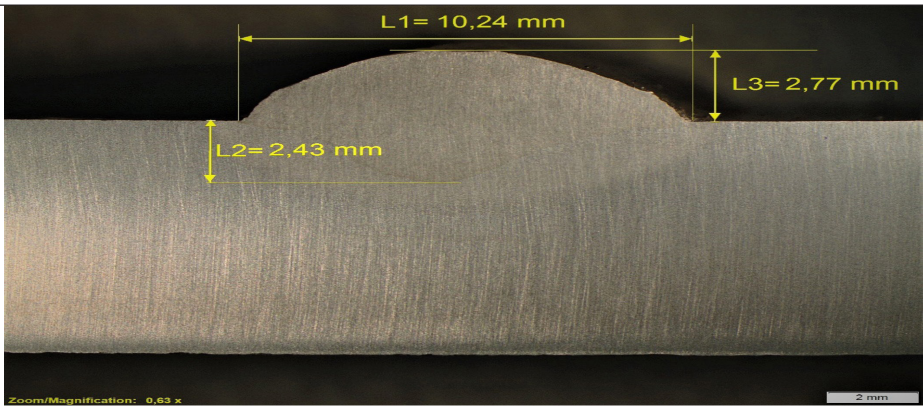


Fig. 6. Analysis of the throat obtained with respect to the composition of the shielding gas.

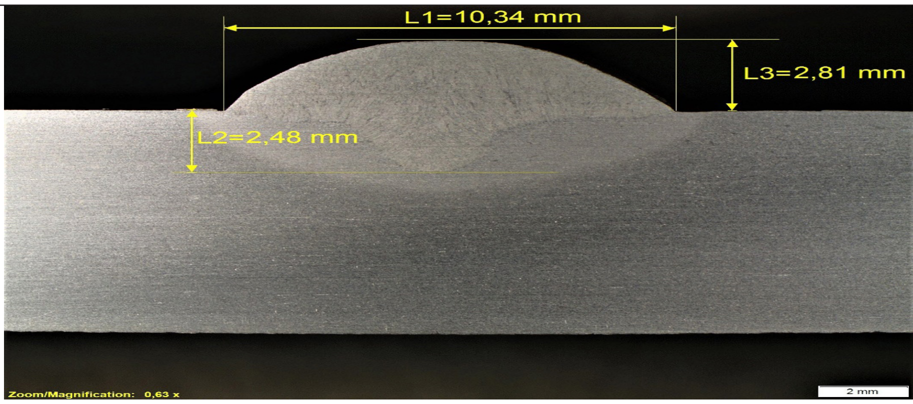
Table 8 shows the images of the macrographs of the weld beads made on the plates with their reinforcement, width and penetration dimensions. The shape of the weld bead is evident, which has been influenced by the percentage of CO2 and Ar present in the protective gas mixture. In addition, another factor that influences the shape and geometric characteristics of the weld bead is the mode of metal transfer. When the short circuit mode is used, lower penetrations were obtained, then with the Pulsed Spray mode, and the highest penetrations are obtained with the PMC pulsed mode.

Table 8. Measurement of the geometric characteristics of the welded Beam

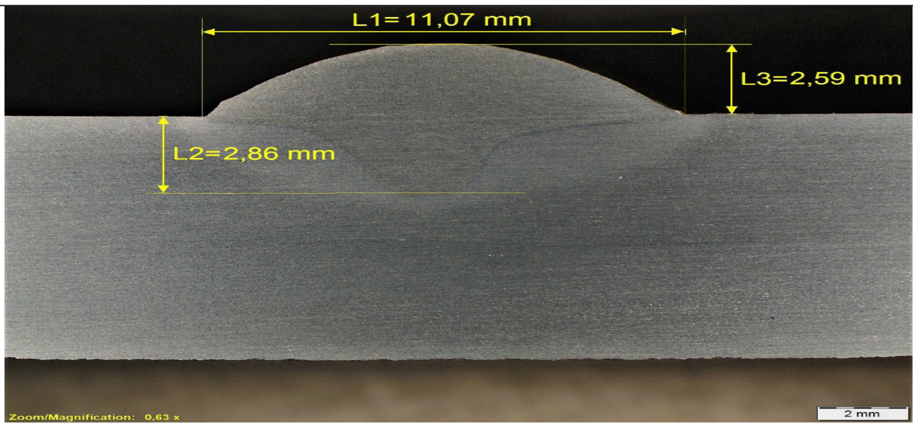
Measures of Welded Beam	Types
	C10D



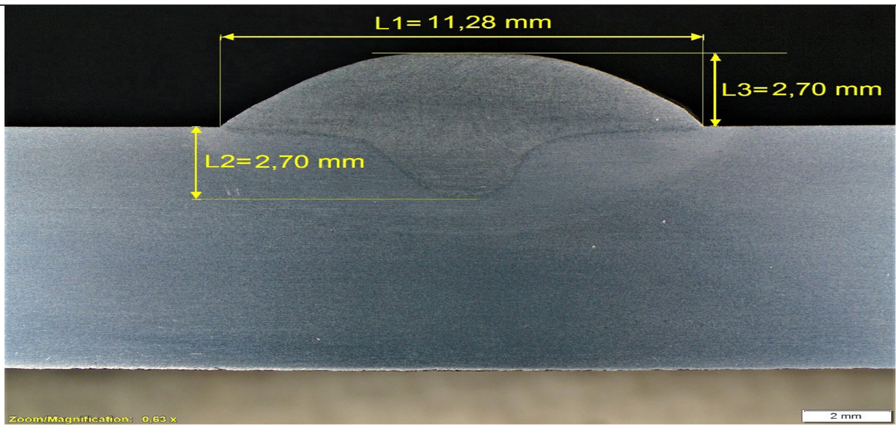
C25D



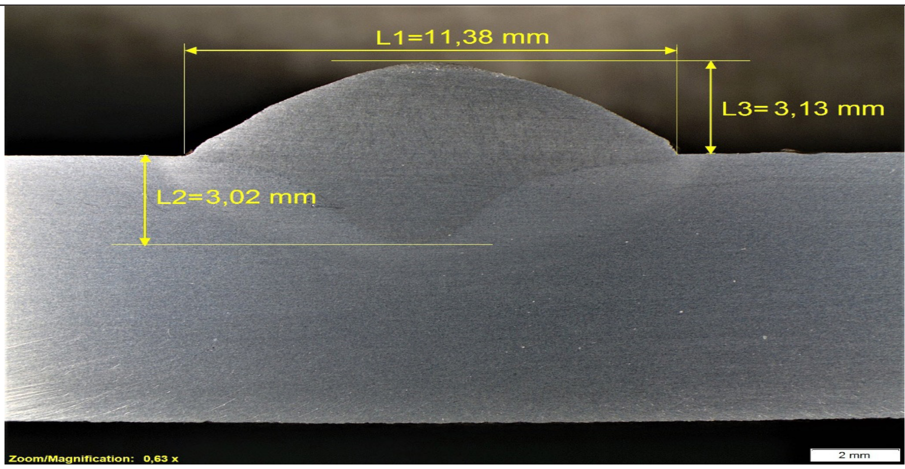
SP10D



SP25D



P10D



P25D

Figure 7 shows the results of the filler beads made where a greater penetration is observed when the multi-control pulsed transfer mode (PMC) is used, both in the 10% and 25% CO2 composition. Besides, The higher the percentage of CO2 present in the mixture, the greater the penetration obtained in the weld bead.

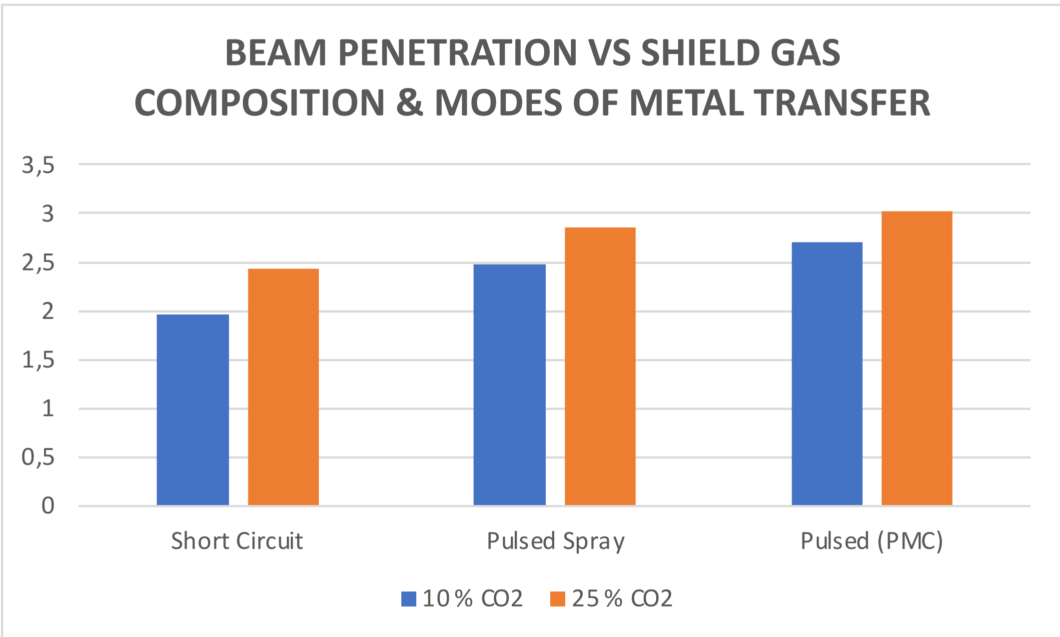


Fig. 7. Analysis of the penetration with respect to the composition of the shielding gas

Conclusions.

In the three metal transfer processes and with the different mixtures of shielding gases, good weld seams were obtained for the fillet joint. Of the 9 welded joints, only 2 beads had small welding defects.

The ASTM A36 steel used in this study is very versatile for the manufacture of welded and bolted structures in industrial or civil construction works in Ecuador. For this reason, this study provides a reference of what percentages to use in the mixture of protection gases in order to obtain weld bead shapes according to the application that is required.

The best welded bead profile achieved is the one with a gas mixture of 10% CO2 -90% Ar (test C10F) due to its well penetration and depth of fusion, slight concavity and does not present welding defects. And the profile welded with 25% CO2 has a lack of root penetration due to the semicircular shape of the profile.

It is observed that the pulsed spray mode produces greater penetration compared to the other 2 metal transfer modes used with the same mixture of protective gas. This is because this is the mode that produces the greatest heat input to the base metal. The PMC mode produces less heat input since it controls the feed speed when there are differences in the arc length.

Acknowledgment

A sincere thanks to the company "Commerce and Technology MIG-MAG Cía. Ltd." and to all the people who work in it, for their support in carrying out this project. In addition, we thank you for allowing us to use your equipment and facilities for the development of the tests.

References.

1. Castellanos, O. M., Moreno-Uribe, A. M., Ramón-Ramón, S. A., & Jácome, J. L. (2021). Evaluación de la transferencia metálica y estabilidad del proceso gmaw. Revista UIS ingenierías, 20(3), 47-60.

2. Batista, L. A. (2018). Soldagem MIG/MAG com fluxo ativo do aço inoxidável austenítico AISI 304L, Master Thesis, University Federal de Minas Gerais.

3. Mvola, B., & Kah, P. (2017). Effects of shielding gas control: welded joint properties in GMAW process optimization. The International Journal of Advanced Manufacturing Technology, 88, 2369-2387.

4. Moncayo E. (2020). Modelado y control de las características geométricas del cordón de soldadura en el proceso gmaw. La Ingeniería y sus Aplicaciones: Una Perspectiva desde la Industria, la Investigación y la Educación. Edición 2020, 24, 263-272.

5. Marconi, C., Castillo, M. J., Ramini, M., & Svoboda, H. (2016). Efecto del gas de protección, ángulos de trabajo y desplazamiento sobre las características de juntas de filete obtenidas por GMAW en un acero microaleado de alta resistencia. Soldagem & Inspeção, 21, 303-316.

6. Li, C., Duan, C. H., Qi, Y. C., Sun, Y. F., & Ma, C. Y. Effect of shielding gas on MIG welding performance with austenitic wire. Materials Letters, 339, 134118, (2023).

7. Kuang, X., Qi, B., & Zheng, H. (2022). Effect of pulse mode and frequency on microstructure and properties of 2219 aluminum alloy by ultrahigh-frequency pulse Metal-Inert Gas Welding. Journal of Materials Research and Technology, 20, 3391-3407.

8. Castillo Díaz, G. B., & Chero Angulo, A. G. (2020). Efecto del gas de protección en el proceso de soldadura por arco en la microestructura de un cordón de soldadura depositado con electrodo e316lsi.

9. Ulloa, J. A. B., & Monrroy, R. M. N. (2019). Evaluación de la Influencia de los Gases de Protección de Soldadura en las Propiedades del Acero Inoxidable UNS S32707 (Doctoral dissertation, Pontificia Universidad Catolica del Peru).

10. Niebles, E.E.; Silgado, J. U.; Torres, J. E.; Ramirez, A. J.: Influencia de las Mezclas de gases Ar-He y Ar-He-O2 en la Soldabilidad de la Aleación de Aluminio AA5083-O usando Proceso GMAW-P Automatizado, Soldag. Insp. São Paulo, Vol. 19, No. 3, pp. 238-246 (2014)

11. Hashmi, S.: Comprehensive Materials Processing. Finlandia: Elsevier Science & Technology Books, pp. 224 (2014) https://www.elsevier.com/books/comprehensive-materials-processing/hashmi/978-0-08-096532-1

12. Monar, T., Segovia, J. (2016). Análisis de la Influencia de la Composición del Gas Protector en la Conformación del Cordón de Soldadura Para el Proceso GMAW Utilizando Arco Pulsado y Cortocircuito. 125 hojas. Quito: EPN. http://bibdigital.epn.edu.ec/handle/15000/14055