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DEMOUCHE MANSOUR

Title

Design and implementation of Gas Metal Arc Welding Machine

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بسم الله الرحمن الرحيم

In the name of ALLAH, the Gracious, the Merciful. (l)

All praise is due to ALLAH alone, Lord of all the worlds. (2)

The Gracious, the Merciful. (3)

Master of the Day of Judgment. (4)

THEE alone do we worship and THEE alone do we implore for help. (5)

Guide us in the straight path. (6)

The path of those on whom THOU hast bestowed THY favours,

those who have not incurred THY displeasure and those

who have not gone astray. (7)

Holv Qur'an

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Dedications

I dedicate _ my _ graduation and thanks

To the honorable parents (Abd El hafid ,Sabira),

And to all my family (**Ben Salem**),

My Brothers (Bilal ,youcef ,Abd el Rahmane) and my sister (Rym),

My friends, and loved ones, in reality and in the sites without exception, and to all my teachers and colleagues.

Dedications

In memory of my great father **Demouche Ahmed**

This work is dedicated to my grandfather, who died too early, who always pushed me and Motivated in my studies. it is appreciated and humble gesture as proof of knowledge on the part of your cherished grandson who 'it is always prayed that God will give you mercy and grant you the energy in paradise

To my dear parents.

Whatever you do, I cannot thank you properly, and no dedication can express my respect, eternal love and consideration. Your love covers me, your kindness guides me, and being by my side has always been my strength to face various obstacles. I hope this work reflects my gratitude and affection. God saves you and gives you health and happiness to keep the torch that shines our ways.

To my beautiful sisters Amani and Nour El Imane

To all my friends and family **DEMOUCHE**

Attract God to give you health, happiness, courage and above all success

Abstract

Abstract

The GMAW-S process occurs from sequences of arcing and short-circuit welding periods. For modeling purposes, many researchers believe that the metal transfer occurs only in the period of short circuit (consideration to be taken into account in the present work), in which the link between the electrode and the welding pool is generated through a liquid metal bridge. From this exact moment, it can be observed changes in the metal bridge geometry due to electromagnetic (pinch effect), gravitational, and surface tension forces. This paper is aimed to model the dynamic geometry of metal bridge during the short circuit period, considering the fusion and feed rate electrode wire balance. This model was represented by state equations building from applying Kirchof's, Lorentz, Young–Laplace law, Bernoulli's principle, the equation of fluid continuity, and concepts of analytic geometry. The model implementation was developed in Simulink could be used to study the metal transfer control, as well as, the appropriate welding parameters selection, aiming to achieve a higher level of welding quality.

Keywords: Gas metal arc welding. Short-circuit mode. Drop detachment. Characteristic equations. Dynamical behavior.

Résumer

Le processus GMAW-S se produit à partir de séquences de périodes d'arc et de soudage en court-circuit. À des fins de modélisation, de nombreux chercheurs pensent que le transfert de métal se produit uniquement pendant la période de court-circuit (considération à prendre en compte dans le présent travail), au cours de laquelle la liaison entre l'électrode et le bain de soudure est générée par un pont métallique liquide. . À partir de ce moment précis, on peut observer des changements dans la géométrie du pont métallique dus aux forces électromagnétiques (effet de pincement), gravitationnelles et de tension superficielle. Cet article vise à modéliser la géométrie dynamique du pont métallique pendant la période de court-circuit, en considérant l'équilibre des fils d'électrodes de fusion et de vitesse d'alimentation. Ce modèle était représenté par des équations d'état basées sur l'application de la loi de Kirchof, de Lorentz, de Young-Laplace, du principe de Bernoulli, de l'équation de continuité des fluides et des concepts de géométrie analytique. L'implémentation du modèle a été développée dans Simulink et pourrait être utilisée pour étudier le contrôle du transfert de métal, ainsi que la sélection des paramètres de soudage appropriés, dans le but d'atteindre un niveau plus élevé de qualité de soudage.

Mots-clés : Soudage à l’arc sous gaz métallique. Mode court-circuit. Laisser tomber le détachement. Équations caractéristiques. Comportement dynamique.

ملخص

تحدث عملية GMAW-S من تسلسل فترات اللحام بالقوس الكهربائي وقصر الدائرة. ولأغراض النمذجة، يعتقد العديد من الباحثين أن نقل المعدن يحدث فقط في فترة الدائرة القصيرة (يجب أخذ الاعتبار في العمل الحالي)، حيث يتم إنشاء الرابط بين القطب وحوض اللحام من خلال جسر معدني سائل . ومن هذه اللحظة بالتحديد، يمكن ملاحظة التغيرات في هندسة الجسر المعدني بسبب قوى الكهرومغناطيسية (تأثير القرص)، والجاذبية، والتوتر السطحي. يهدف هذا البحث إلى نمذجة الهندسة الديناميكية للجسر المعدني خلال فترة الدارة القصيرة، مع الأخذ في الاعتبار توازن سلك الإلكترود ومعدل التغذية. وقد تم تمثيل هذا النموذج بمعادلات حالة مبنية على تطبيق قانون كيرشوف، ولورنتز، وقانون يونغ لابلاس، ومبدأ برنولي، ومعادلة استمرارية الموائع، ومفاهيم الهندسة التحليلية. يمكن استخدام تطبيق النموذج الذي تم تطويره في Simulink لدراسة التحكم في نقل المعادن، بالإضافة إلى اختيار معلمات اللحام المناسبة، بهدف تحقيق مستوى أعلى من جودة اللحام.

الكلمات المفتاحية: اللحام بالقوس المعدني الغازي. وضع ماس كهربائي. إسقاط الانفصال. المعادلات المميزة. السلوك الديناميكي.

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Notations

Symbole	Désignation	Unité
R_S	System resistance	mΩ
L_s	System inductance	mH
r_w	Wire radius	mm
ρ	Linear resistivity	Ω/m
ρ_w	Mass density	Kg / m^3
S	Wire feed speed	m/min
CT	Contact tip to work-piece distance	mm
μ_0	Permeability	H/m
γ N/m	Surface tension	N/m
U_0	arc voltage constant	V
R_a	arc résistance	Ω
E_a	arc length factor	V/m
θ	Arc hanging angle	degree
C_1	Constant for arc heating	m^3 / As
C_2	Constant for Joule heating	m^3/V As
l_S	stick-out	mm
I	current	Ampere
r_d	droplet radius	mm
x_1	droplet displacement	mm
x_2	droplet velocity	m/s
x_3	current	Ampere
x_4	stick-out	mm
x_5	droplet mass	kg
U_{arc}	arc voltage	V
R	wire-droplet system	mm
U_{oc}	open-circuit voltage	V
K	Boltzmann constant	J/k
L	electrode extension	mm
A	area of the electrode	mm^2
Q_{joule}	Joule heat	joule

$\emptyset$	heat flow	J /s
ΔH_{trans}	heat of crystalline transition	kJ/mole
ΔH_m	heat of fusion	kJ/kg
$\boldsymbol{F_T}$	Total force	N
F_{em}	Electromagnétique force	N
Fg	gravitational force	N
F_s	Surface tension force	N
P_{avg}	Average pressure in the bridge	N/m^2
V_d	Drop volume	m^3
v	Flow velocity	m/s

Abbreviations

Abbreviation	Désignation
GMAW	Gas Metal Arc Welding.
GTAW	Gas Tungsten Arc Welding.
MMA	Manual Metal Arc (stick welding).
MIG	Metal inert Gas.
MAG	Metal Active Gas.
TIG	Tungsten Inactive Gas.
PIT	Pinch Instability Theory.
SFBM	Static Force Balance Model.
DFBM	Dynamic Force Balance Model.
FCAW	Flux-Cored Arc Welding.
SAW	Submerged Arc Welding .
EGW	Electro gas arc welding .
PAW	Plasma Arc Welding.
ER	Electrode rod .

General Introduction

Arc welding is one of the key processes in industrial manufacturing. It is believed that in the entire metal fabrication industry, arc welding is the third largest job category behind assembly and machining. The practice of industrial welding is heavily dependent on the knowledge and vast experience of the welder, and, as such, at present it is more an art than science.

The term arc welding refers to a broad group of welding processes that employ an electric arc as the source of heat to melt and join metals. It is believed that in the entire metal fabrication industry, arc welding is the third largest job category behind assembly and machining in metal fabrication. In particular, two types of processes, gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW), are extensively used in factory automation. Gas metal arc welding with short-circuit transfer is one of the most used manufacturing processes in the metal construction industry. Its advantages include high metallic transfer, high penetration, ease operation in various positions and ease of automation. However, in order to make the welding process more automated and less human (welder) dependent, in the last two decades significant efforts have been made to introduce the ideas of feedback in order to control the welding process to achieve a good weld. Various modeling techniques and automatic control strategies have been suggested to improve the welding process, Some authors have studied the electromagnetic effects [46–47], and others the thermal effects [44] and the fluid dynamics [46].

Choi et al. used the volume of fluid to simulate the spray and globular metal transfer modes [44], as well as the short-circuit mode [37]. The model have been extended by Zhu et al. [43], in the spray and globular modes, These models are clearly less precise but account for the main tendencies. Inspired by these articles, we propose a hybrid model accounting for the switching from the arc mode to the short circuit mode [42] taking into account the main forces acting on the molten metal during a complete cycle.

MIG/MAG welding is an arc welding process in which the filler metal is supplied by a spool of metal wire and is melted gradually by the Joule effect and by an electric arc. In the “short-arc” mode, it is deposited in successive drops to form the weld bead. The welding generator provides the electrical energy necessary to melt the metal and establish and maintain this arc between the parts to be welded and the wire. It operates according to two distinct regulation modes:

- the “arc” mode in which the voltage delivered by the generator is regulated to reach a set point value defined by the welder;

- the “short circuit” mode in which the intensity evolves according to a predefined law.

The approach developed to model the welding process is an analytical approach with the aim of understanding the physics of the process. The latter is represented in the form of a hybrid system with two continuous states (“arc” state and “short-circuit” state); the transition from one to the other being controlled by a switching variable.

This study aims to present an analysis on GMAW, describing its principles and physical phenomena, involved, including a parametric analysis of the equipment and components of the installation. The digital modeling of the process was the subject in this study this dissertation is structured into three chapters. After the introduction of the subject and the objectives of this work. The first chapter presents the welding techniques and the types of the arc welding,its advantages and disadvantages and in the last we present our main subject the GMAW The following chapter presents the process principal of the GMAW and his components , controls and at last the transfer modes the last chapter presents we developed the mathematical models governing the electromagnetic and mechanical phenomena involved during this welding process, these mathematical models are necessary for the development of digital tools, Finally, we close this and outlook with a general conclusion.

CHAPTER 1

ARC WELDING TECHNICS

Introduction

In this chapter, we saw the types of arc welding techniques in general, and represented the classification of welding methods according to consumption. We also explained how these types work, mentioning their components and their Advantages and Disadvantages.

1.1 Types of arc welding

There are several methods of arc welding, including Shielded Metal Arc Welding (SMAW), Gas Tungsten Arc Welding (GTAW), Gas Metal Arc Welding (GMAW), Flux-Cored Arc Welding (FCAW), and Submerged Arc Welding (SAW) …etc, Each type of arc welding uses a slightly different method to create the arc, and has its own set of advantages and disadvantages.

We can regroup these methods into two types: consumable (fusible) electrode and non-consumable (non-fusible) electrode depending on whether the welding rod/wire melts in the process or not.

Table. 1. 1 - Classification of welding methods according to the consumption

Electrode consumption	**Arc welding method**
Non-consumable (non-fusible) électrodes type	- Tungsten Inert Gas Arc welding - Plasma Arc welding
Consumable (fusible) electrode type	-Shielded metal arc welding - MAG welding/ MIG welding (GMAW) - Submerged Arc Welding (SAW) - Flux-Cored Arc Welding (FCAW)

1.1.1 Non-consumable (non-fusible) électrodes type

1.1.1.1 Tungsten Inert Gas Arc Welding (TIG)

1. Definition

TIG (Tungsten Inert Gas) welding uses an inert gas for welding. This type of arc welding does not throw sparks and can be used to weld various metals, including stainless steel, aluminum, and iron. Non-consumable tungsten is used for the discharging electrode and an inert gas such as argon or helium is used as the shielding gas they protected the weld pool from atmospheric.

The process strikes an arc in an inert gas and uses the arc heat to melt and weld the base material. Although a filler material is used, spatter is rare because the weld area is covered with the Inert gas and the arc is stable. [2]

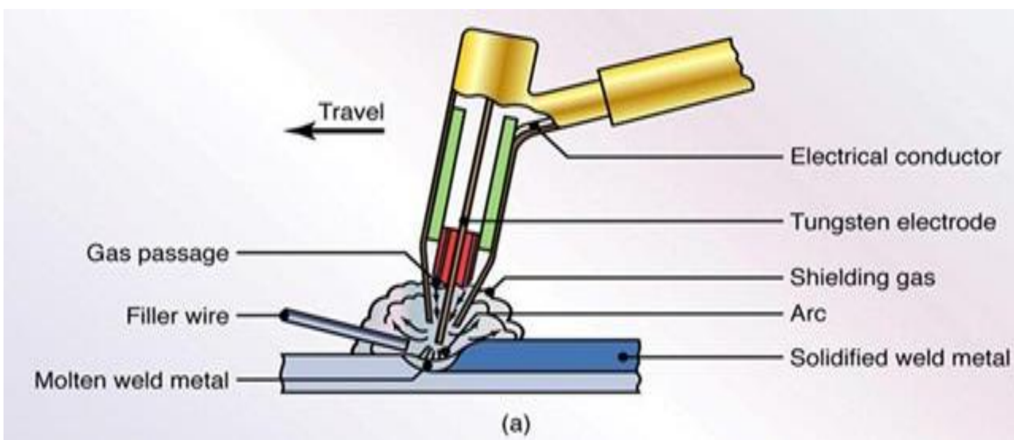

Figure. 1. 1 - Tungsten Inert Gas Arc Welding Process. [A]

2. Equipment Tungsten Inert Gas Arc Welding

The key components of Tungsten Inert Gas welding equipment are:

1-TIG Torch:

- Handle: This is the part of the torch that the welder holds onto while welding. It may be made of heat-resistant materials such as rubber, silicone, or plastic.
- Head: This is the part of the torch that contains the tungsten electrode and the gas nozzle, the head is typically made of copper or brass to help dissipate heat.

- Gas nozzle: This is the part of the torch that delivers the shielding gas to the weld area to protect the molten metal from oxidation and other contaminants.
- Tungsten electrode: This is the non-consumable electrode that produces the arc in TIG welding. The tungsten electrode is held in place by a collet and collet body inside the torch head.
- Gas hose: This is the hose that connects the TIG torch to the gas regulator and delivers the shielding gas to the torch head.

2-Control console.

3-Power supply:

- **AC (Alternating Current) Power Supply**: In TIG welding, AC power supply is used for welding aluminum and other non-ferrous metals. The current in an AC power supply changes direction at regular intervals, typically at 50 or 60 times per second. The frequency of the current affects the width and penetration of the weld. AC current creates a cleaning action, which helps to remove surface contaminants and oxide layers on the work-piece surface.
- **DC (Direct Current) Power Supply**: In TIG welding, DC power supply is used for welding steel and other ferrous metals. The current in a DC power supply flows in only one direction. DC current provides a stable and consistent arc, which makes it easier to control the welding process. It also creates a deeper penetration than AC current.

4-Shielding gases:

- **Argon**: Argon is the most commonly used shielding gas in TIG welding. It provides excellent arc stability and helps to create a smooth, consistent weld. Argon is suitable for welding non-ferrous metals such as aluminum, magnesium, and copper alloys.
- **Helium**: Helium is used in TIG welding for its high heat input and deep penetration capabilities. It's often mixed with argon to create a helium/argon blend that's suitable for welding thicker materials.
- **Argon/Helium Mix**: Argon/helium mixtures are commonly used in TIG welding for welding thick materials or for creating deep penetration welds. The exact mixture of argon and helium will depend on the specific welding application.

- **Argon/Carbon Dioxide Mix**: Argon/carbon dioxide mixtures are used for welding steel and stainless steel. The carbon dioxide helps to stabilize the arc and increases the heat input to the weld area.
- **Argon/Oxygen Mix**: Argon/oxygen mixtures are used for welding non-ferrous metals such as titanium and zirconium. The oxygen helps to create a more stable arc and provides additional heat input to the weld area

5-Workpiece.

6-Cooling-water supply.

7-Foot pedal.

8-Drain.

9- Tungsten:

Table. 1. 2 - classification of tungsten electrodes. [26]

Color	Type	Current	For welding	Arc Ignition	Arc Stability	Current Carrying Capacity	Lifetime
Green	Pure	AC	Aluminium, Magnesium, Nickel and their alloys	Medium	Good	Low	Low
Red	Thoriated ThO_2 - 2%	DC	Carbon steel, Stainless steel, Nickel alloys and Titanium	Excellent	Excellent	Excellent	Very good
Grey	Ceriated CeO_2 - 2%	AC & DC (low amp)	Carbon steel, Stainless steel, Nickel alloys and Titanium	Very good	Very good	Very good	Very good
Gold	Lanthanated La_2O_3 - 1,5%	AC & DC	Carbon steel, Stainless steel, Titanium, Aluminium and its alloys	Excellent	Excellent	Excellent	Very good
Blue	Lanthanated La_2O_3 - 2%	AC & DC	Carbon steel, Stainless steel, Nickel alloys, Aluminium, Magnesium, Titanium, Cobalt, Copper alloys, etc.	Excellent	Excellent	Excellent	Excellent

10-filler wire:

- ER70S-2: This is a mild steel filler wire that is commonly used for welding carbon and low alloy steels.
- ER308L: This is a stainless steel filler wire that is used for welding 304 and 304L stainless steels.
- ER316L: This is a stainless steel filler wire that is used for welding 316 and 316L stainless steels.

- ER4043: This is an aluminum filler wire that is used for welding aluminum alloys.
- ER5356: This is another aluminum filler wire that is commonly used for welding aluminum alloys.
- ER70S-6: This is a mild steel filler wire that is commonly used for welding higher strength steels.

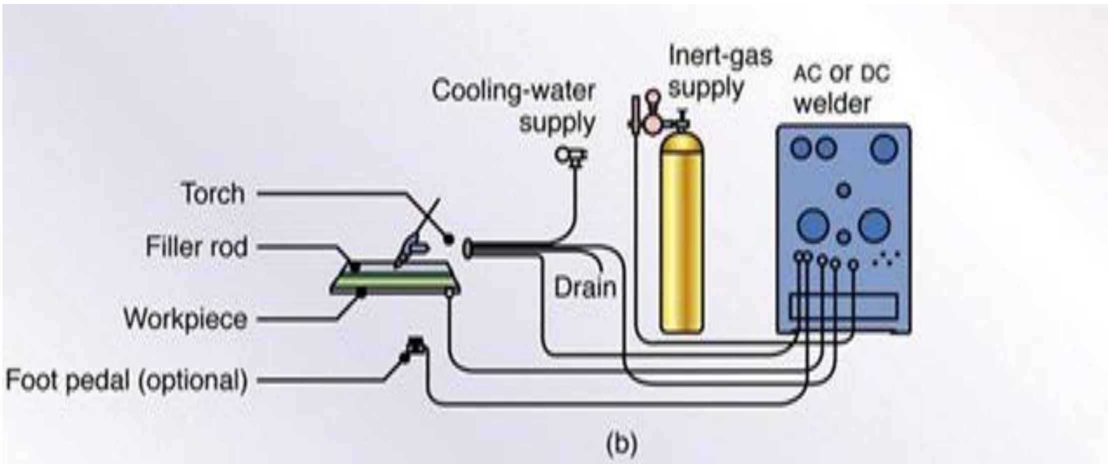

Figure. 1. 2 - Tungsten Inert Gas Arc Welding equipments. [B]

3. Advantages of Tungsten Inter Gas Arc Welding

- In TIG welding, the weld composition is close to that of the parent metal.
- The Weld structure is of high quality.
- Slag removal is not required (on slag).
- Thermal distortions of work-pieces are minimal due to the concentration of heat in the small zone.

4. Disadvantages of Tungsten Inter Gas Arc Welding

- Low Welding rate.
- TIG welding is comparatively expensive.
- TIG weld,(a highly skilled operator is required).

5. Applications

TIG welding is often used for jobs that demand high quality welding such as for instance:

• The offshore industry.

• Combined heat and power plants.

• The petrochemical industry.

• The food industry.

• The chemical industry.

• The nuclear industry.

I.1.1.2 Plasma Arc Welding (PAW)

1. Definition

Plasma welding is an arc welding process that uses a plasma torch to join metals. The principle of this method is derived from GTAW aka TIG welding, where an electric arc is struck between the electrode and the work-piece.

Plasma arc welding (PAW) is a fusion welding process that uses a non-consumable electrode and an electric plasma arc to weld metals. Similarly to TIG, the electrode is generally made out of throated tungsten.

Its unique torch design produces a more focused beam than TIG welding, making it a great choice for welding both thin metals and creating deep narrow welds. [3]

2 .Plasma Arc Welding Process

The plasma arc welding process revolves around the principle of striking an arc between a non-consumable tungsten electrode and the work-piece. The plasma nozzle has a unique design feature, where the electrode is located within the body of the torch. This allows the arc plasma to exit the torch separated from the shielding gas envelope. Additionally, the narrow opening of the nozzle increases the plasma gas flow rate, allowing for deeper penetration. While filler metal is typically supplied at the weld pool's leading edge, it is not the case when creating root pass welds.

The complexity of the plasma welding torch sets it apart from gas tungsten arc welding. Plasma welding torches operate at very high temperatures**,** which can melt away their nozzle, making it a requirement to always be water-cooled. While these torches can be manually operated. nowadays, most modern plasma welding guns are designed for automatic welding**.**

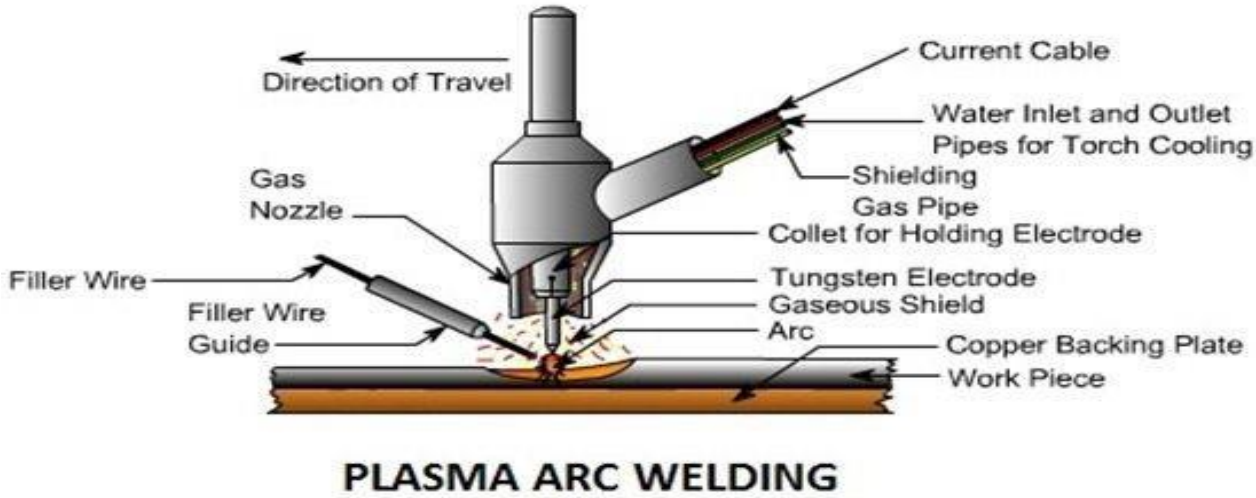

Figure. 1. 3 - Plasma Arc Welding Process. [C]

3. Equipment of Plasma Arc Welding

The key components of plasma welding equipment are:

- Plasma torch.
- Control console (HON).
- Power supply.
- Shielding gases (argon, helium, hydrogen).
- Wire feeder.

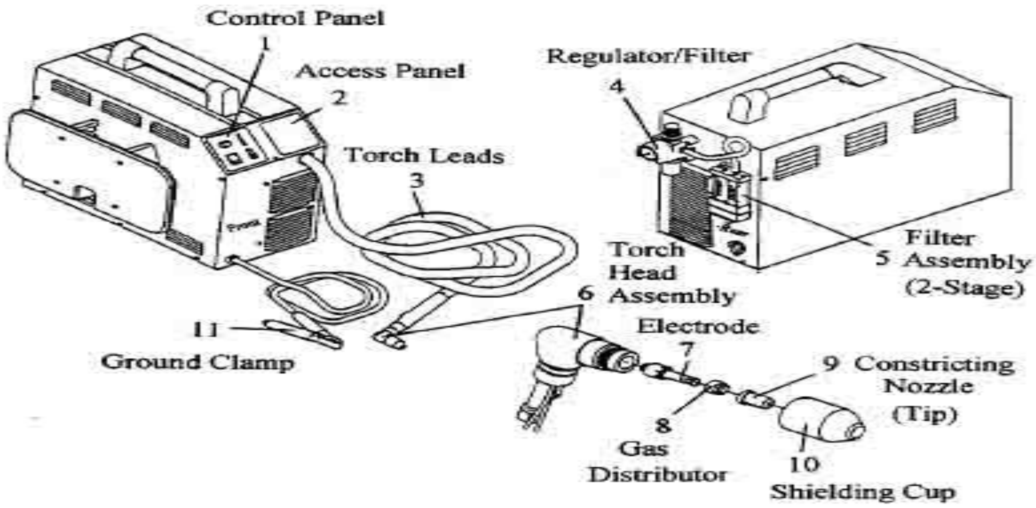

Figure. 1. 4 - plasma arc welding equipments. [D]

4. Applications

a. Steel tubes

PAW is a great welding method in manufacturing steel tubes as it can be performed at high-speed welding with great metal penetration. Some industries prefer the plasma welding process to conventional TIG since its system is faster and uses less filler material.

b. Electronics

One of the welding parameters of the plasma welding process is it can run at low current modes. This mode allows small metal component welding, which deals with delicate materials sensitive to environmental factors.

c. Medical industry

Medical devices require precise components in order to run effectively. PAW is perfect for welding these components as it can reliably create a consistent weld bead.

5. Advantages of Plasma Welding

- Can be operated in every welding position.
- Fast travel speeds from concentrated heat input.
- Keyhole welding allows for complete penetration.

- Low current mode is suitable for thin and sensitive components.

6. Disadvantages of Plasma Welding

- Expensive equipment and components.
- Requires training and skill to create good welds.
- Produces 100dB noise.
- Creates ultraviolet and infrared radiation.
- Water cooling is necessary because of high working temperatures.
- Delicate equipment needs a higher amount of maintenance. [3]

1.1.2 Consumable (fusible) electrode type

1.1.2.1 Shielded Metal Arc Welding (SMAW)

1. Definition

Shielded metal arc welding is an electric arc welding process that joins metals together using a consumable electrode. It was first introduced in 1888 when Nikolay Gavrilovich Slavyanov used consumable electrodes as a tool to arc weld.

Shielded metal arc welding (SMAW), also known as manual metal arc welding (MMAW or MMA) is a welding process that uses a flux-coated electrode to join metals.

An arc forms when the electrode tip comes into contact with the work-piece. Fusion takes place as both the rod and work-piece melt, forming a weld pool from the molten metal.

Simultaneously, the flux coating of the electrode is consumed, forming **a** protective layer of shielding gas and slag in the weld area.

Slag deposits will eventually form in the weld bead as the metals cool down. The deposits in the weld metal can be chipped off using common shop tools.

This manual metal arc welding technique is limited to short weld stints, as the consumable electrode needs to be constantly replaced. [4]

2. Shielded Metal Arc Welding Process

Before welding, it is always recommended to check the condition of your equipment. It is crucial for both safety and welding quality to have a well-functioning power source, clamps, cables and electrode holder.

The next step is to select an electrode that will complement the base metal. Simultaneously, the power supply must be set in the proper setting: direct current electrode negative, direct current electrode positive, or alternating current. One wire in a stick welder is attached to the ground clamp and the other is linked to the electrode holder.

To start the arc welding process, the base metal is struck with the electrode. A welding arc forms as the electrode melts in the weld pool.

Consuming the flux coating releases a shielding gas that protects the weld pool from atmospheric contamination. A constant arc length should be maintained as the covered electrodes slowly join the molten pool. Generally, the arc length should be approximately equal to the diameter of the core wire.

A layer of slag forms as the weld metal cools. It can be removed post-cleanup using a chipping hammer and a steel brus. [4]

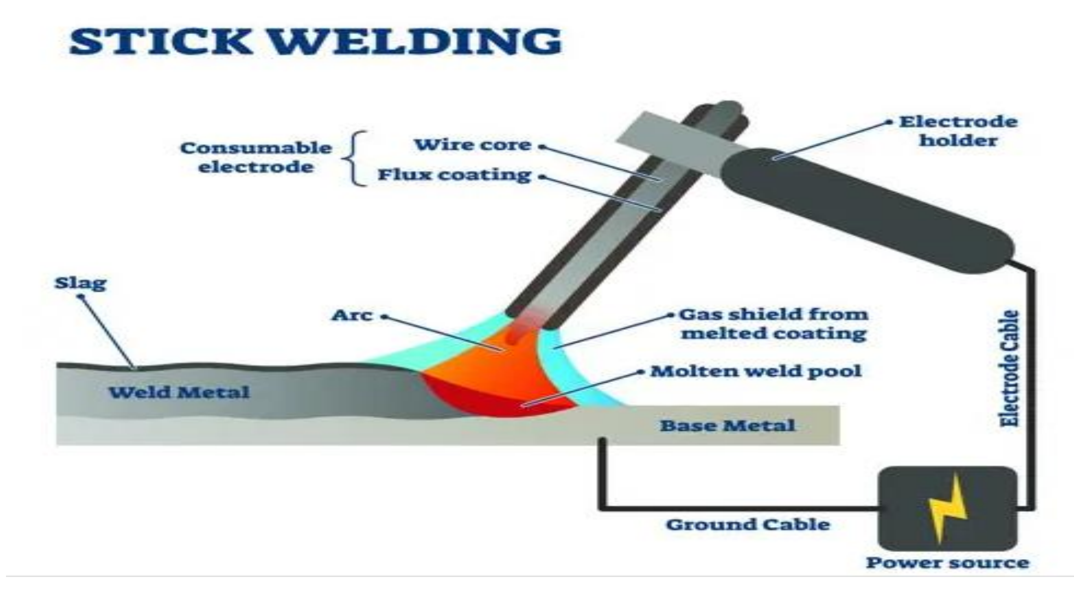

Figure. 1. 5 - Shielded Metal Arc Welding Process. [E]

3. Equipment of Shielded Metal Arc Welding

- Electrode Lead.
- Electrode Holder.
- Welding Electrode.
- Ground Clamp.
- Work Lead.
- Work-piece.
- Power Source.

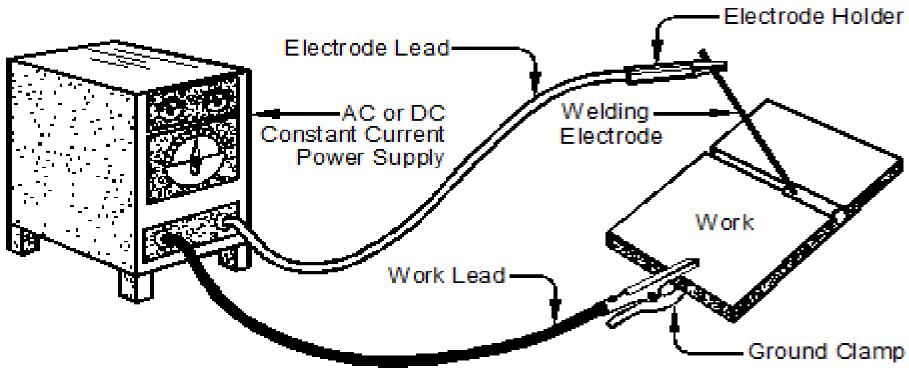

Figure. 1. 6 - Equipments of Shielded Metal Arc Welding. [F]

4. Applications of Stick Welding

a. Maintenance and Repair

Stick welding is versatile and highly mobile, which makes it perfect for quick repairs, even in harsh conditions. A stick welder can be used in windy conditions, rain and underwater, without compromising its weld quality. Stick welding's unique trait is that it can weld unclean or rusty metals.

b. Fabrication

Since shielded arc welding is fairly easy to learn and welding equipment is cheap, it is still one of the most popular methods in fabrication and construction. While some industries are shifting to more automated welding methods, many still prefer to use stick welding.

5. Advantages of Stick Welding

- Stick welding can be performed in almost any environment.
- Equipment is rather cheap and affordable.
- Easy to use in tight spaces.
- Many available electrodes to choose from.
- Metal surfaces don’t have to be cleaned as rigorously as for example in TIG welding
- Can be used for a variety of metals and alloys, along with unique positions.
- Portable and lightweight equipment, no need to carry a gas tank around.
- Gases produced are sufficient for protecting the weld metal.

6. Disadvantages of Stick Welding

- Leaves spatter and slag deposits.
- Produces toxic fumes.
- Metal electrode needs to be replaced constantly and electrode stubs go to waste.
- Difficult to weld thin materials.
- Time-consuming as it is a manual process.
- Requires skill and training to achieve clean welds.
- Not suitable for reactive metals.

1.1.2.2 Submerged Arc Welding (SAW)

1. Definition

Submerged arc welding (SAW) is a welding method where similarly to other arc welding processes, the base metals are joined by forming an electric arc between the work-piece and an electrode.

SAW process’s defining element is how it protects the weld metal from atmospheric contamination. Submerged arc welding uses a powdered flux layer, generating shielding and slag while creating a smooth and clean weld. Other methods use shielding gas (MIG/TIG welding), flux-cored wire (FCAW), flux-coated electrode (SMAW), or controlled environment (plasma welding) for protecting the weld. [5]

2. Submerged Arc Welding Process

Submerged arc welding creates consistent welds by using a blanket of granulated flux. For this reason, the process can be operated only on positions that are flat and horizontal, with the weld advancing by either moving the welding system or the work-piece.

Flux is fed into the joint manually or by using a flux hopper. A single electrode or multiple wire electrode system is placed into the working area, surrounded by the flux blanket.

Parameters such as the welding current, arc voltage, and wire feed speed are set depending on the type of metal, its thickness, and desired mechanical properties. Electric current is supplied to the electrodes, producing intense heat that melts and fuses the base material and the filler wire to the bead.

The molten metal cools down, creating strong uniform welds and reusable granular flux at the surface and slag underneath. A hopper collects the reusable flux, while slag is usually peeled off manually. [5]

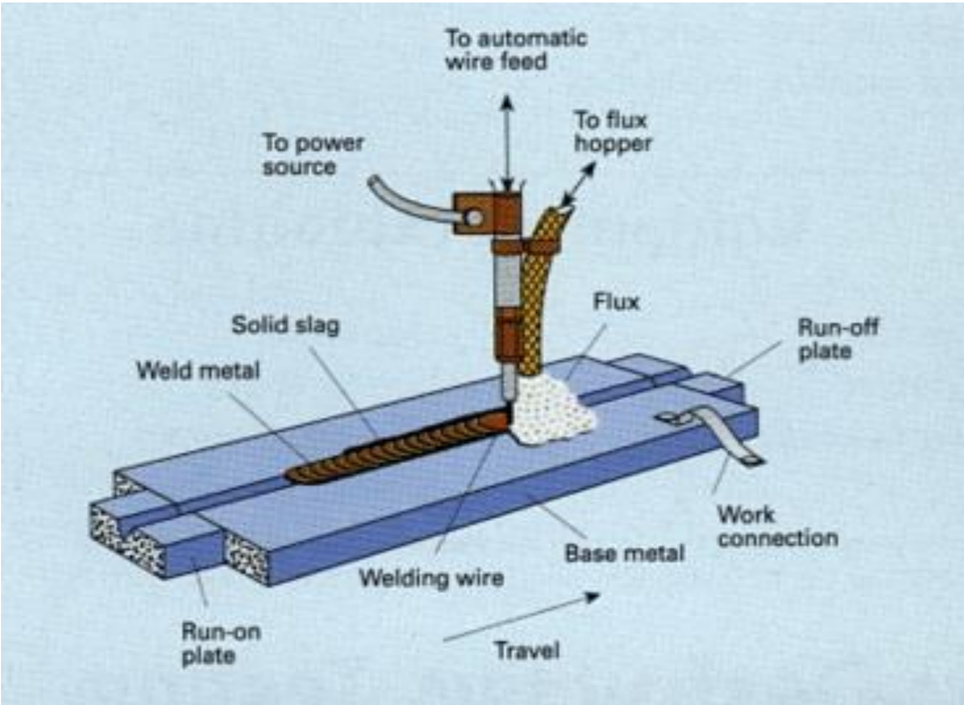

Figure. 1. 7- Submerged Arc Welding Process. [G]

3. Equipment of Submerged Arc Welding

1-Flux:

- Granular Flux.
- Bonded Flux.
- Fused Flux.

2-Wire Electrode .

3-Power Source .

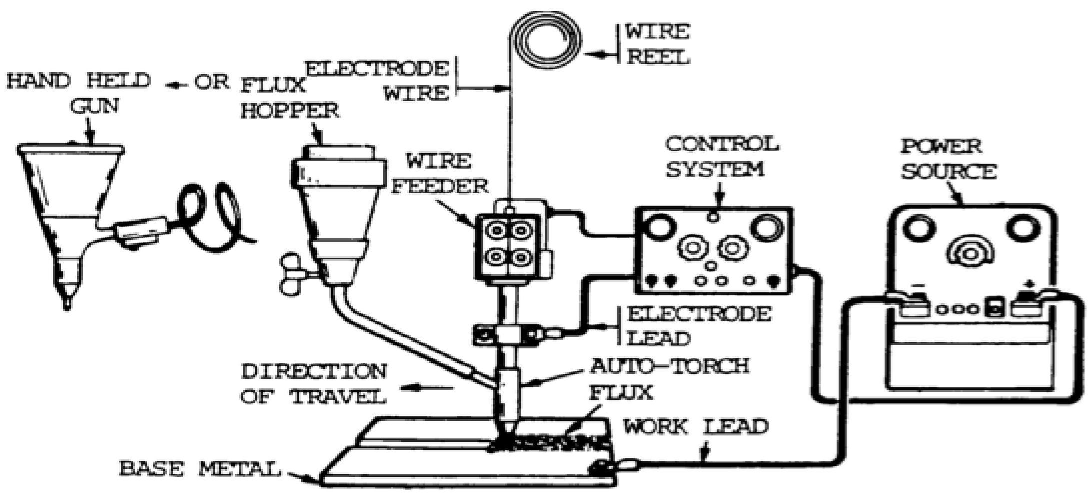

Figure. 1. 8 - Equipments of Submerged Arc Welding. [H]

4. Applications

a. Fabrication

SAW is one of the preferred welding processes in fabricating pressure vessels, pipes, and boilers due to its strength in longitudinal and circumferential welding. This welding operation achieves a smooth weld pool from the continuously fed electrode.

b. Shipbuilding

The flexibility of SAW process allows it to be performed both indoors and outdoors which makes it suitable for shipbuilding. It's perfect for creating long, straight welds for heavy metals which make up ship parts.

c. Automotive

Metals used in the automotive and military industry are fit for SAW, along with the speed and efficiency it brings. This welding method is also perfect for automation, with the option to have multiple or single-pass welds based on the metal's thickness.

d. Railways

The submerged arc process allows deep weld penetration, which is attractive to the railway industry.

5. Advantages of SAW

- The blanket of granular flux creates minimal welding fume and spatter.
- Allows performing semiautomatic or fully automatic welding.
- Flexible for both indoor and outdoor applications.
- Creates smooth, uniform and deep welds.
- Around 50-90% of the flux is reusable and recyclable.

6. Disadvantages of SAW

- Limited to flat and horizontal welding positions
- A rather narrow range of weld able metals.
- Requires post-welding slag removal.
- Practically restricted to circumferential and long straight beads.
- Precise parameters are required to achieve desired weld deposit since welds aren't visible while welding.[5]

1.1.2.3 Flux-Cored Arc Welding (FCAW)

1. Definition

Flux-cored welding is an arc welding process that deposits filler material with a shielding flux in the weld puddle. Fusion takes place when a welding arc is established between the flux-cored electrode and the base metals.

The tubular electrode wire is supplied through a spool and guided by a welding gun to the weld joint. As the electrode melts, the flux inside it releases a shielding gas to protect the weld pool from atmospheric contamination.

Flux-cored welding is often confused with gas metal arc welding (GMAW) as both welding techniques can be performed on the same or similar welding equipment but they do have subtle differences between them.

2. Flux Cored Welding Process

The FCAW process utilizes the heat from the arc generated between the tubular electrode and the work piece. The electrode is hollow, with a flux core inside acting as a shielding agent while it is deposited in the weld zone. As the flux core is consumed, it produces a barrier protecting the weld from atmospheric contamination.

There are two main options for performing FCAW:

- **FCAW-S (Self-shielded)** – Self-shielded welding solely relies on gaseous protection from the flux core and its slag deposits. This process is mostly used for outdoor projects that have unpredictable conditions.
- **FCAW-G (Gas/Dual-shielded)** – Dual shield welding uses flux-cored wires along with external shielding gas to provide additional protection for the weld area. This process allows higher deposition rates and offers better penetration against thicker metals.

  Certain conditions can also influence the choice for the welding process, such as portability, desired mechanical properties and base metal.

3. Equipment of Flux Cored Welding

1) Shielding Gas.
    - Carbon dioxide.
    - Argon and carbon dioxide.
    - Argon and oxygen.
2) Welding Gun.
3) Air-cooled – Normally.
4) Water-cooled.
5) Wire Feeder.

6) Power Source.

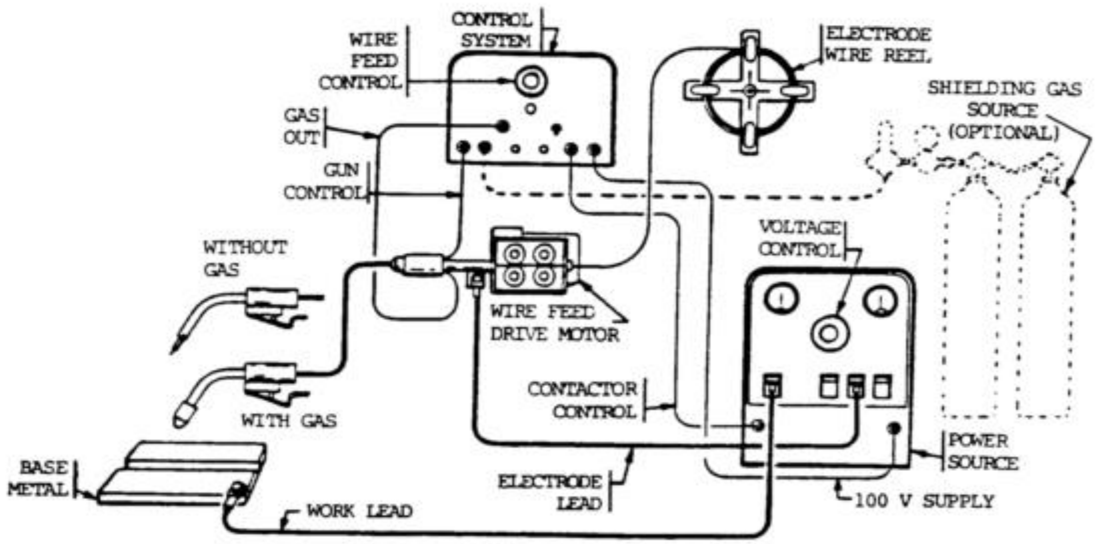

Figure. 1. 9 - Equipments of Flux Cored Welding. [I]

4. Applications of Flux Cored Arc Welding

a) General Repairs

Some prefer using flux-cored welding in performing general repairs for its portability. It can endure harsh outdoor conditions; at the same time it has the ability to weld ferrous metals.

b) Pipelines

Due to FCAW welding producing welds with minimal porosity, the pipeline manufacturing industry prefers operating with this technique. With welds created with consistent mechanical properties, pipes have unparalleled strength and durability.

c) Manufacturing

The manufacturing industry takes advantage of automating the process of flux core arc welding through the use of robots. This results in a precise and consistent welding seam, while all the welding parameters are controlled.

d) Shipbuilding

The continuously fed tubular electrode allows for an efficient operation in shipbuilding. With the number of minor components to weld together, shipbuilders have to constantly change welding positions. Flux-cored welding works best, as it is easy to perform while shipbuilders manoeuvre the welding torch at varying angles.

e) Underwater Welding

Divers take advantage of the protection offered by the protective gas layer produced by the flux-cored electrodes. Performing this wet welding procedure requires skill and training as the hazards are beyond comparison to the conditions above ground.

5. Advantages of Flux Cored Arc Welding

- FCAW offers higher penetration than MIG/MAG welding.
- Ability to weld ferrous metals since the electrode deoxidizes the base metal.
- More portable than MIG welding since we can use FCAW without a shielding gas tank.
- Easier to learn than stick and TIG welding.
- FCAW and MIG welding use the same machine.
- The flux creates a shielding layer, allowing it to work well with outdoor welding.

6. Disadvantages of Flux Cored Arc Welding

- Slag cleanup.
- Semi-automatic FCAW results in poorer weld beads than TIG welds.
- Flux tubular electrodes are more expensive than solid wires.
- Flux disintegration results in excessive toxic fumes.
- Trapped gases in the weld zone can form holes as the metal hardens.
- Changing filler metal is time-consuming since FCAW uses spools compared to some other processes that use short electrodes.

1.1.2.4 MIG /MAG Arc Welding

1. Definition

Metal inert gas (MIG) welding is a subtype of gas metal arc welding (GMAW). In this welding process, the base materials are joined together through a welding current. Filler metal is constantly fed through the welding gun. As the electric arc melts the electrodes wire it is then fused along with the base metals in the weld pool. Simultaneously, the shielding gas travels along the welding gun to keep the weld free from atmospheric contamination.

Although MIG and TIG welding are quite similar in several aspects, they have some key differences. MIG uses a consumable wire electrode which is fused with the base metals in the weld pool, whereas TIG uses a non-consumable tungsten electrode and the use of filler metal is optional and is added to the weld pool separately.[5]

MAG (Metal Active Gas) welding is a type of arc welding that uses an active gas (carbon dioxide [CO2] or a gas mix of argon and CO2). The process is also called as CO2 arc welding or CO2 welding. This process is generally used for automatic or semi-automatic welding of ferrous metals. It is not suited for nonferrous metals such as aluminum because of the chemical reaction of CO2.[25]

2. MIG/MAG Welding Process

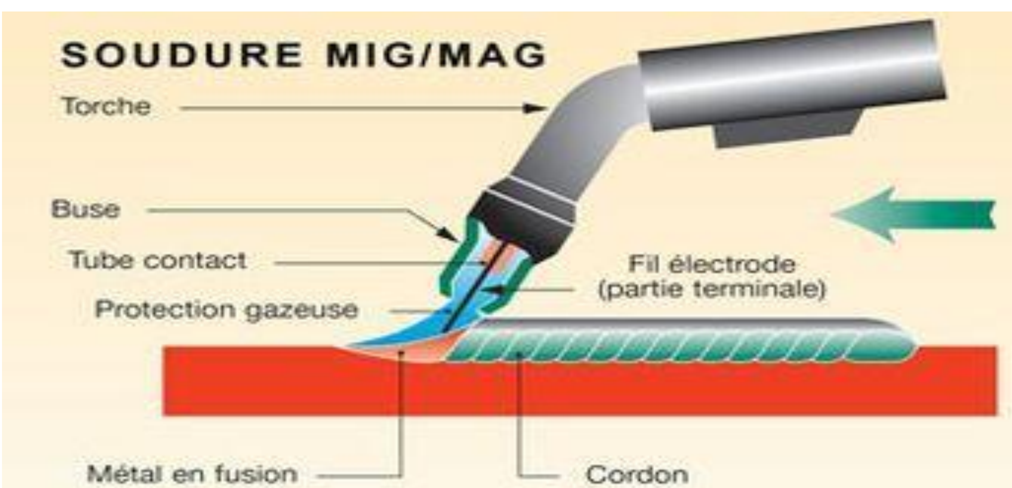

Figure. 1. 10 - MIG/MAG Arc Welding Process. [J]

MIG/MAG welding uses a constant voltage power supply to create an electric arc that fuses the parent material with the wire that is continuously fed through the welding torch. At the same time, an active or an inert gas is extracted from a supply tank and flows towards the gun, allowing the shielding gas to evenly protect the weld pool from impurities.[25]

3. Equipment of MIG/MAG Welding

a) ***Metal transfer mode***

- Short-circuit welding (aka dip transfer or micro wire).
- Globular transfer.
- Spray welding.
- Pulsed mode.

b) ***Wire electrode***

- Hard wire.
- Flux-cored wire.

c) ***Gas uses (Shielding gases)***

- Inert gas (MIG).
- Active gas (MAG).

d) ***Welding torch***

A welding torch or gun is a specialised tool for fusing and melting metals. MIG/MAG torches offer versatility in their application for a variety of metal thicknesses and types of metal. Similar to TIG, MIG /MAG torches are divided into two groups:

- Gas-cooled welding torches.
- Water-cooled welding.

e) ***Powersource***

The power source in a MIG/MAG welder is mostly set into DC as it offers constant voltage in contrast to TIG and stick welding which use alternating current for some materials. Modern MIG welding equipment auto-corrects the current when the arc length and wire feed speed change, allowing the MIG /MAGwelder to create a stable weld puddle.where there are three types :

- DC positive polarity.
- DC negative polarity.
- AC power.

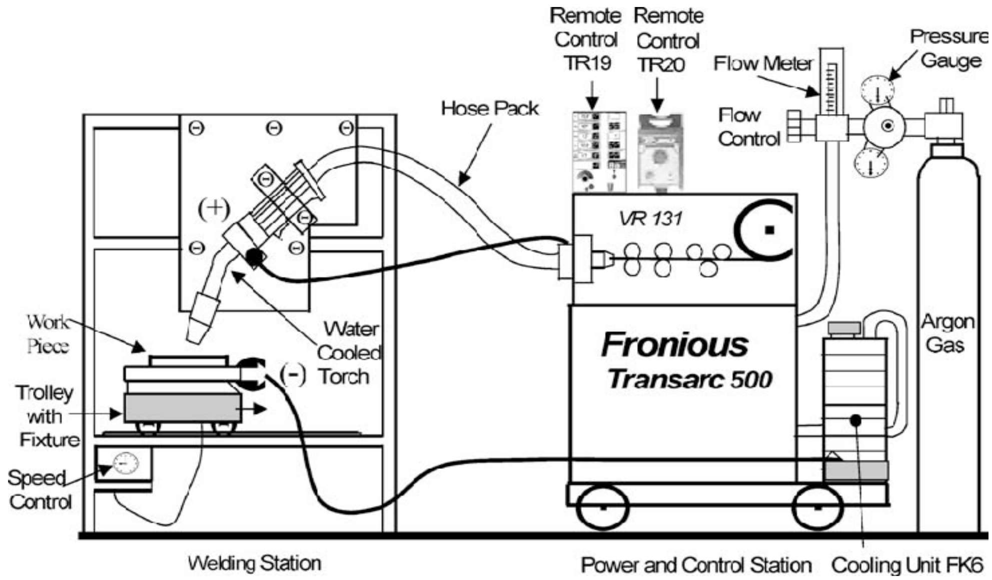

Figure. 1. 11- Equipments of MIG/MAG Welding. [K]

4. Application

- Used for most types of sheet metal welding.
- Fabrication of pressure vessels and steel structures.
- Automotive industry and home improvement industry.

5. Advantages of MIG/MAG Welding

- The continuously fed wire allows for a fast, uninterrupted welding procedure.
- A MIG torch handles horizontal, vertical or flat welding positions with ease.
- MIG welding is cleaner than most welding processes, leaving little slag and minimal spatter compared to stick welding. The quality and looks offered by tungsten inert gas (TIG) welding are still unmatched though.

- MIG welding is one of the simplest welding techniques to learn.
- Suitable for a wide range of metals and alloys.
- The machine allows you to adjust a variety of weld settings, such as wire speed and amperage.

6. Disadvantages of MIG/MAG Welding

- There are other welding processes that offer more control to the weld (e.g. TIG).
- MIG welding equipment has a relatively high initial cost.
- MIG is generally unsuitable for outdoor welding using flux-cored wires is the exception here.
- Portability is an issue as MIG welders are heavy, considering the roll of wire and the tank containing the shielding gas.
- Spatter can form in the nozzle from the molten residue as the welding wire is fed into the torch.

7. Difference between MIG and MAG Welding

Both metal inert gas (MIG) and metal active gas (MAG) are fusion welding processes and belong to the GMAW family. They're often seen as one welding technique because apart from the shielding gas, the welding process is exactly the same. Both of these processes are performed using the same welding machine.

- MIG welding uses inert shielding gases (argon, helium, nitrogen, or a mixture of the three). These inert gases are stable during welding, wherein it does not diffuse particles to the weld bead. MIG is generally used for welding aluminum, magnesium, copper, titanium, and other non-ferrous metals and alloys.
- MAG welding uses active shielding gases or a mixture of active and inert gases (CO_2, Ar + 2 to 5% O_2, Ar + 5 to 25% CO_2 and Ar + CO_2 + O_2). The two common active gases in MAG welding are oxygen and carbon dioxide. Due to the extreme temperature during welding, these active gases disintegrate and alter the chemical composition of the weld bead. This type of welding is generally preferred for carbon steel (especially mild steel) and stainless steel.

Between the two, MAG welding is desired if you need to alter the chemical and mechanical properties of the weld. [25]

1.1.2.5 Other type of arc welding

So far, there are several types of advanced automatic arc welding, including those that work with artificial intelligence, as we mention them. [5]

- Electrogas arc welding (EGW)
- Laser welding
- Electron beam welding
- Friction welding
- Resistance spot welding
- Projection welding
- Seam welding
- Flash welding.

Conclusion

In conclusion, welding is an essential process in many industries, and choosing the right welding technique can be crucial to the success of a project.

There are several welding techniques available, each with its advantages and limitations.

MIG/MAG welding is one of the most popular welding techniques due to its versatility and ease of use, that’s why we prefer it for our study.

When selecting a welding technique, it is essential to consider the material being welded, the thickness of the material, and the desired welding speed.

CHAPTER 2

Physical Principle of MIG/ MAG ARC WELDING

Introduction

In the following sections of this chapter, we will explore in more detail the specific advantages of MIG/MAG welding, as well as the characteristics and functions of each component of this welding method.

2.1. Operating principle of MIG/MAG welding machines

2.1.1. The process principle

In MIG/MAG welding method, an arc is established between a continuous fed filler wire (Consumable) electrode and the work-piece. The electrode is fed automatically from the machine, through a liner, then out of a contact tip in the MIG/MAG gun. The weld metal is protected from the atmosphere by a flow of an inert gas, or gas mixture. The contact tip is hot or electrically charged, when the trigger is pulled and melts the wire for the weld puddle (Figure. 2.1). After proper settings are made by the operator, the arc length is maintained at the set value, despite the reasonable changes that would be expected in the gun-to-work distance during normal operation. This automatic arc regulation is achieved in one of the two ways. The most common method is to utilize a constant-speed (but adjustable) electrode feed unit with a variable-current (constant-voltage) power source.

Welding currents of 50 amperes up to more than 600 amperes are commonly used at welding voltages of 15V to 32V [6]. As the gun-to-work relationship changes, which Instantaneously alters the arc length, the power source delivers either more current (if the arc length is decreased) or less current (if the arc length is increased). This change in current will cause an equivalent change in the electrode melt-off rate, thus maintaining the desired arc length.

The second method of arc regulation utilizes a constant-current power source and a variable-speed, voltage-sensing electrode feeder. In this case, as the arc length changes, there is a corresponding change in the voltage across the arc. As this voltage change is detected, the speed of the electrode feed unit will change to provide either more or less electrode per unit of the time. This method of regulation is usually limited to larger electrodes with lower feed speeds. The characteristics of the GMAW process are best described by reviewing the three basic means by which metal is transferred from the electrode to the work: short-circuiting transfer, globular transfer, or spray transfer.

The type of transfer is determined by a number of factors, the most influential of which are:

- Magnitude and type the of welding current.
- Electrode diameter.
- Electrode composition.
- Electrode extension beyond the contact tip of tube.
- Composition of shielding gas.
- Power supply output.

In short-circuit welding, small droplets of molten wire, heated when short-circuited, flow together to make a puddle as they touch the base metal. The inert gas flows out of the gun cools and keeps the weld puddle shielded from the atmosphere. [7,8]

Short circuit gas metal arc welding is characterized by regular contact between the electrode and the weld pool. Droplet growth occurs in the arcing period, whereas, during the contact period, metal transfer from the electrode to the work-piece takes place. The cyclic behavior of the process can be described in terms of the short circuit time, the arc time or the short circuit frequency. As the arc does not burn during the short circuit period, the overall heat input is low compared to open arc welding. Therefore, GMAW-S always results in a small, fast-freezing weld pool, and, therefore, the process is especially suited for joining thin sections, for out-of-position welding and for bridging root openings. [8,9]

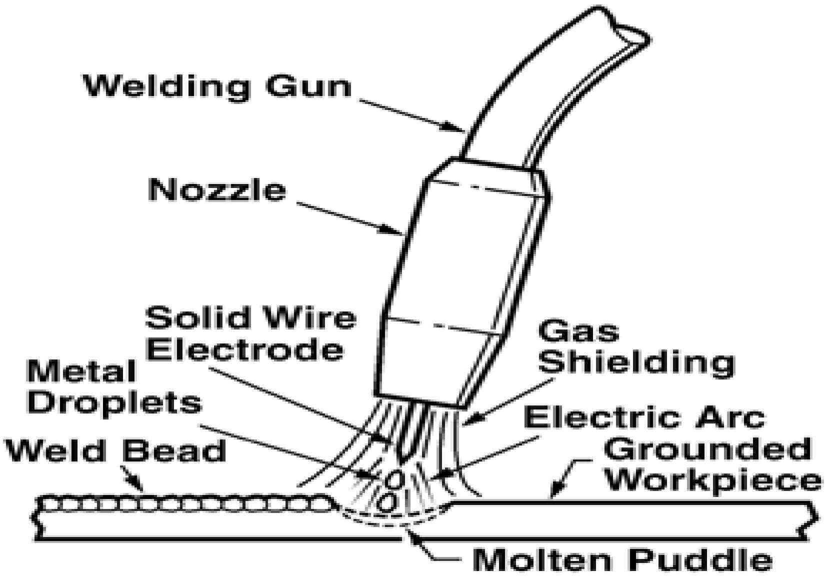

Figure. 2. 1 - Typical GMAW Process Connections. [10]

2.1.2. Electric arc and MIG/MAG plasma source

The acronyms GMA (Gas Metal Arc) and GMAW (Gas Metal Arc Welding), usually used in the technical literature, describe a technological method for assembling metals by applying an electric discharge under gaseous protection between the fusible electrode and the objects to be welded [11, 12, 13]. In this case, an electric discharge is formed in the gas contained between two electrodes of opposite polarizations. At room temperature the gas is a good insulator, but under certain conditions, an electrical breakdown can initiate a discharge. The gas flow ensures the conduction of current and the protection of the molten metal against atmospheric air. The electrons that provide the largest share of conduction because of their lower mass and better mobility, move from a negative end (cathode) to a positive end (anode). A diagram of the plasma torch is shown in (Figure. 2.1). The fusible electrode, most often the anode, is passed to the region of discharge at constant speed. The electric arc is initiated between its end and the surface of the metal plate (most often chosen as a cathode).

By supplying energy to a neutral gas one can cause a formation of elements Charges, which together with non-ionized atoms or gas molecules, become the components of the plasma generates.

In a simpler way, we can say that, to produce plasma, it is necessary to ionize the matter. This can be achieved by collisions of gas particles with electrons or in photo-ionization processes.). But it is the electric field that is the source of energy to produce a plasma, The at5oms or particles of the gas are generally not in this case the only source of the plasma components, and it is also necessary to take into account the metal vapors from the electrodes (MIG/MAG).

The formation of plasma is governed by an extended concept of the law of perfect gases and the law of conservation of mass. The values of the voltage and current determine the character of the discharge in the gas as can be seen in (Figure. 2. 2).

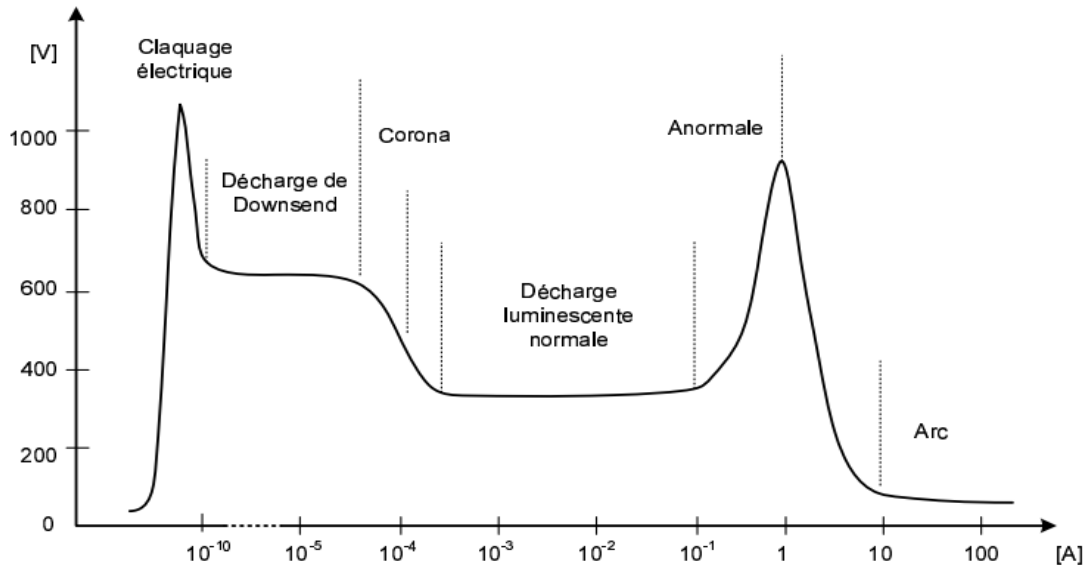

Figure. 2. 2 - Current-voltage characteristics of gaseous discharges. [11]

2.1.3. Equipments of MIG/MAG Welding

1. Power source

The task of the power source is to supply the welding process with the necessary electrical energy. This includes reducing the high grid voltage to values that are safe and useful for welding; at the same time, the high current required is made available. Because only direct current is used for MIG/MAG welding, with a few exceptions, only rectifier machines or inverters are used as power sources. The welding rectifier consists of the mains transformer and a downstream rectifier set (diodes). While the transformer converts the high voltage and low current of the mains grid into electrical power with low voltage (10 to 50 V) and high current (50 to 500 A), the rectifier set converts the alternating current or three-phase current supplied by the transformer into direct current.

Different currents and voltages are required for different welding tasks. The power sources must therefore be adjustable. On simple MIG/MAG welding machines, tap pings of the turns on the transformer are switched using a step switch. (Figure. 2.3) shows a schematic diagram of a step switch-controlled machine. By incorporating more or fewer turns of the primary coil, the transformation ratio of the transformer changes and with it the voltage on the secondary side. [14]

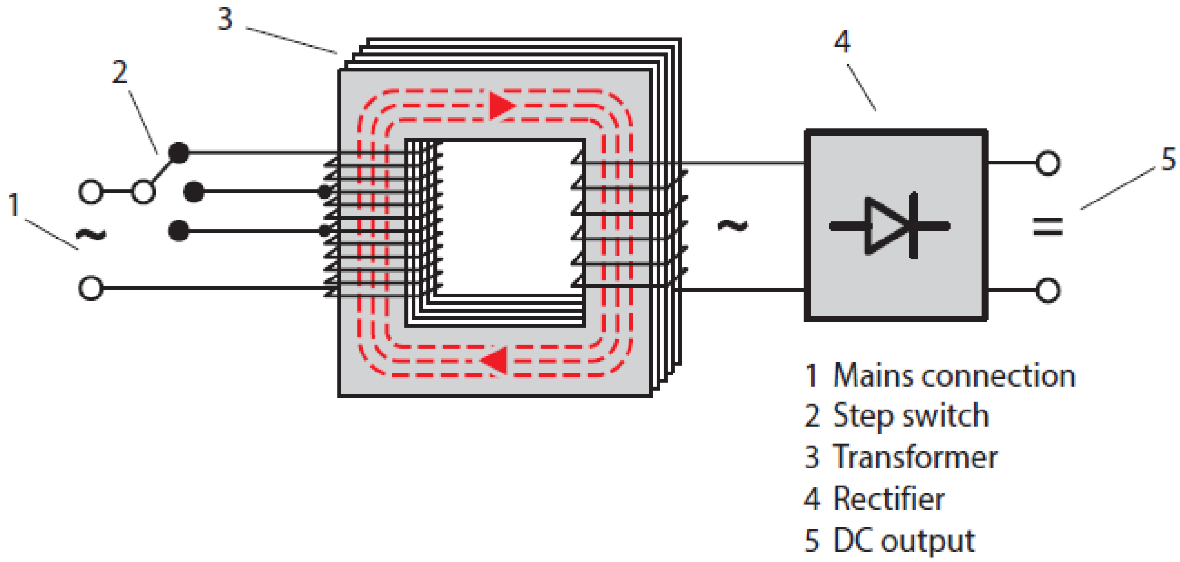

Figure. 2. 3 - Welding power source schematic with step switch control. [14]

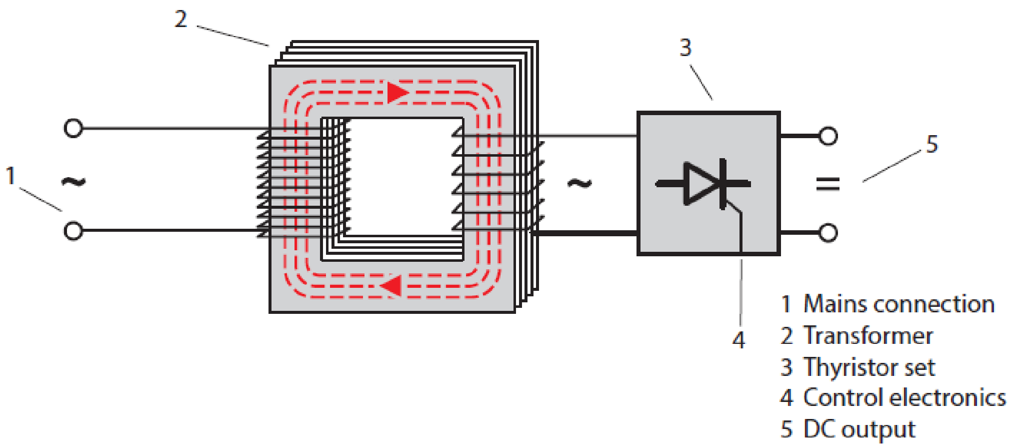

Figure. 2. 4 - Schematic of an infinitely adjustable welding power source with thyristor.[14]

In the case of slightly more complex power sources, the current in the rectifier section is adjusted using a controllable rectifier (known as thyristors). (Figure. 2.4) shows a schematic diagram of such a machine. By controlling the thyristors accordingly, more or less large proportions of the AC half-waves are used. As a result, the welding voltage changes. This relatively simple technology is now obsolete.

More modern MIG/MAG machines are equipped with inverters as power sources. The inverter is an electronically controlled and regulated, primary-switched power source. After using analogue and secondary-switched electronic power sources for decades, development now concentrates on these primary-switched machines. They utilize a completely different working principle than conventional power sources (Figure. 2.5) [14].

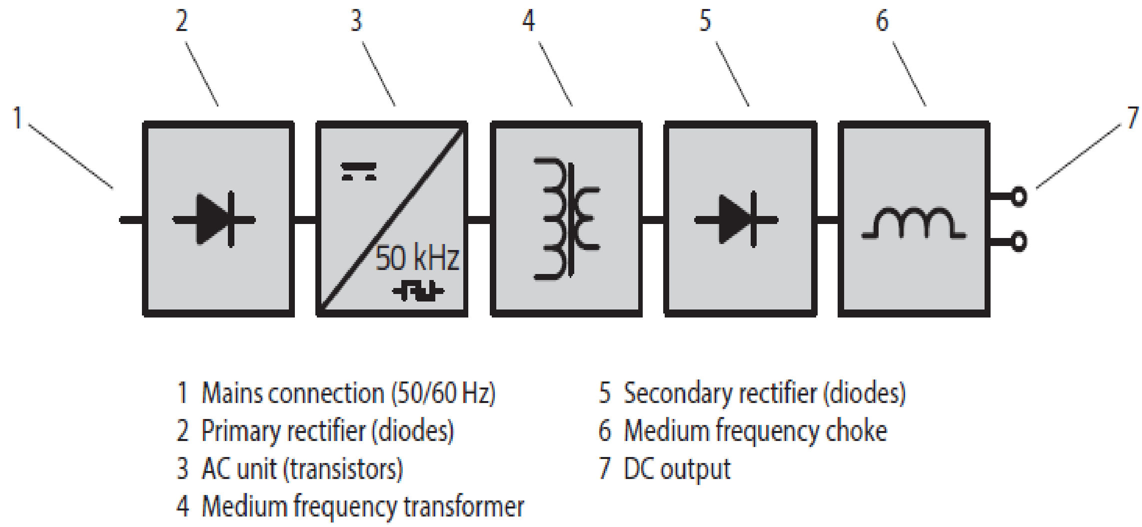

Figure. 2. 5 - Block diagram of a modern inverter power source. [14]

The power supplied by the electrical mains grid (voltage, current, 50 Hz) is first rectified using a set of diodes and then divided into short blocks by fast switching. This switching is performed by fast-working electronic switches, the IGBT transistors. The first transistorized inverters work with switching frequencies of around 20 kHz.

In the meantime, with more developed transistor switches, frequencies of up to 100 kHz are possible. After quickly switching the power on the primary side, it is transformed to the power required on the secondary side at a high current and low voltage. An approximately rectangular AC voltage is created downstream of the transformer, which is subsequently rectified again (diodes). The high switching frequency keeps the required mass of the transformer, which operates at high frequency, very small; it is strongly dependent on the switching frequency. This makes it possible to manufacture light weight power sources with high efficiency.

In modern welding machines, numerous functions that are achieved in conventional power sources using conventional electrical components such as resistors, chokes, capacitors and switches are now electronically solved by the control. The control of these power sources is therefore at least as important as the power unit. To adjust the output power, for example when using with switched sources, the ratio between the on/off times with the lowest losses is changed. The ratio of the on/off times is cyclically altered by the control in order to generate pulsed current profiles. In a similar manner, the current can be ramped up or down as required when the welding process is started and stopped.

Inverter technology made possible the precisely regulated power source, which had long been in demand for welding technology. As a control device, an electronic controller continuously measures welding current and voltage and compares these values with the specified nominal values. If the current actual values change, e.g., due to undesirable changes in the welding process, the control corrects this within a few microseconds (typically 0.1 ms). In a similar way, the short-circuit current in the welding process can be limited to reasonable values. The technology described here results in significantly better efficiencies with minimal open-circuit losses and very good inverter device cos φ (phi).

This reduces the weight of the transformer and inductor to a fraction of what is needed for a 50 Hz unit, making the power unit small and portable. Low losses result in high efficiency, to the order of 80 90%.

The high working frequency also allows the unit to be controlled at a speed that is comparable with the rapid processes occurring in connection with droplet transfer in the arc. Such units can therefore have excellent performance. In comparison with traditional power sources, inverter units offer the following advantages:

- Low weight and small size.
- Good welding performance.
- Several welding processes can be used with the same power source. The fast control necessary for pulsed MIG welding can be achieved.
- High efficiency.

An inverter power sources therefore combines low weight with good control arrangements. Its drawbacks are that it has a more complicated design and is difficult to make adjustable for different mains supply voltages. The reduced losses save energy consumption. If the efficiency of a 500 A/40 V power source is improved by 10% by using an inverter the saving is 2kW.by reducing the ambient temperature, it also improves the welding environment. [14]

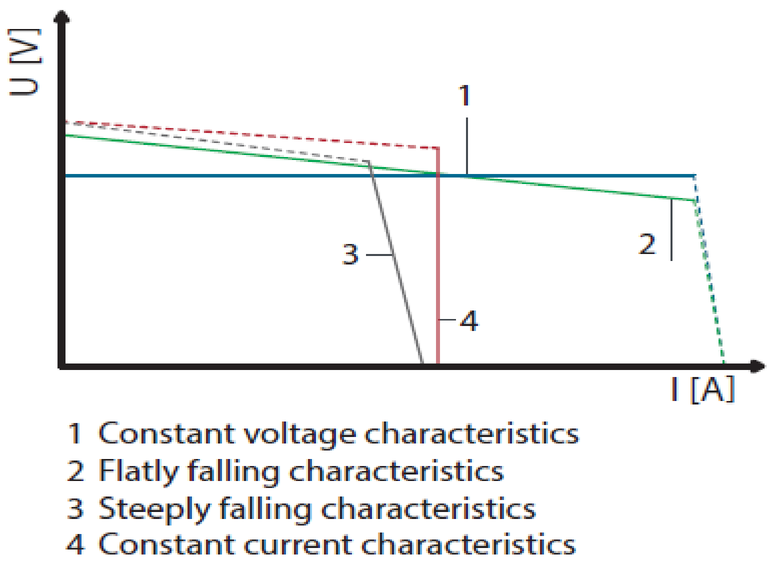

Figure. 2. 6 - I–V characteristics. [14]

In the simplest case, the electrical behavior of the welding machines (power sources) discussed here is characterized by the shape or position of the machine's I–Characteristic. This can be a constant voltage characteristic or what is known as a constant current characteristic. In between these, any other form of I–V characteristic, from flatly falling to steeply falling is possible (see diagram in Figure. 2.6). This description, also referred to as the "static characteristic of the source", has an important influence on the operation and stability of each and any arc process. [14]

2. Wire feeders

In the wire feeder, the wire electrode moves at a selectable speed towards the arc process by means of wire feed rolls. It is drawn from the spool and pushed through the hose package.

The welding torch is located at the end. The rotating speed of the wire feed rolls is driven by an infinitely adjustable DC gear motor. In modern machines that allow a controlled welding process, the motor speed, and thus the wire feed speed, is measured by a speed sensor and precisely controlled regardless of the load. In MIG/MAG welding, wire feed speeds between 1 and 20 m/min are common –depending on the wire diameter – with high performance variants moving up to 30 m/min.

The wire feed mechanism must handle the surface of the wire electrode with care, the wire feed rolls must therefore have a sufficiently large diameter to prevent excessive surface pressure on the wire surface. Compared to a 2-roll drive, the wire can be conveyed with less contact pressure and still slip-free in 4-roll drives.

In the case of 4-rolldrives, all the rollers are frequently interlocked and driven together by a (powerful) motor. (Figure. 2.10) allows a look into a wire feeder with 4-roll drive. This results in a 3-point support of the wire circumference between the rollers, which is gentle on the surface while offering optimal traction. Knurled rollers are often used for flux cored wire and U-groove rollers are used for soft wires (Figure. 2.7). Careful handling of the wire surface is important because abraded wire particles (metal particles) are conveyed into the hose package and may thus clog it after a short. [14]

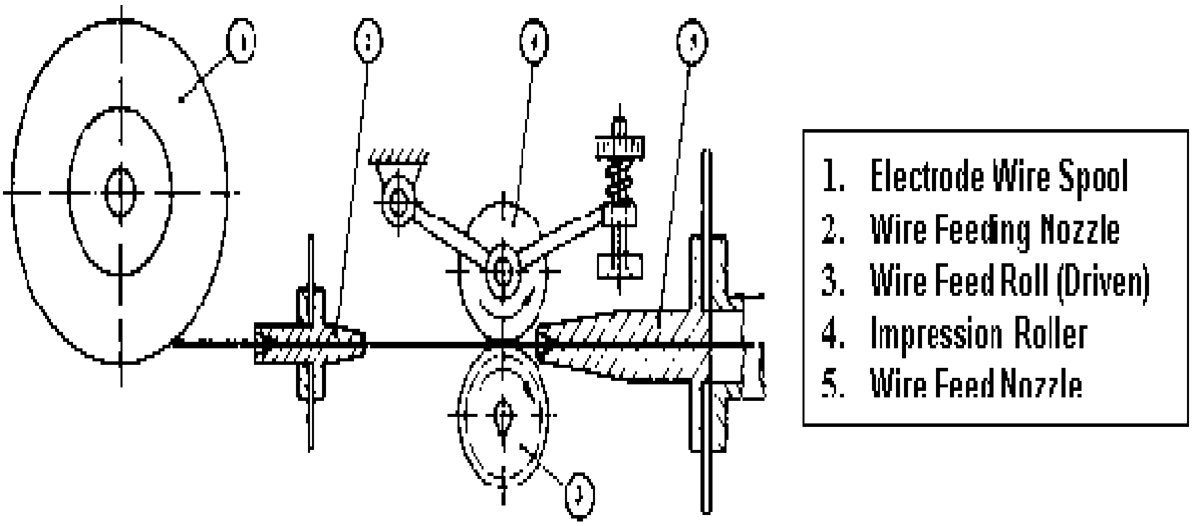

Figure. 2. 7- Wire feed device. [15]

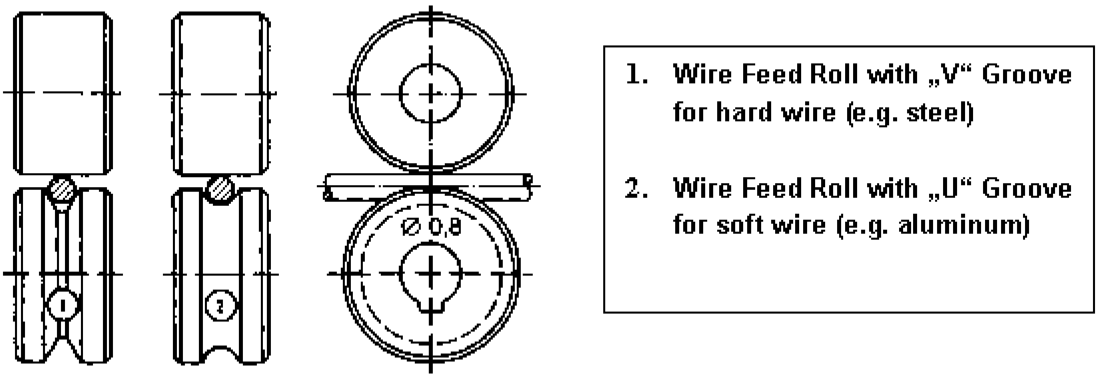

Figure. 2. 8 - wire feed roll kits. [15]

Figure. 2. 9 - Drive rolls with differing groove geometries. [14]

V Groove Rollers: Are used for hard wires such as steel, stainless steel where the wire shape is not deformed due to tensioner pressure.

U Groove Rollers: Are used for soft wires such as aluminum. This type of wire can easily deform its shape making poor current pick up at the contact tip.

Knurled Rollers: used on tubular cored wires which are easily deformed. [25]

Figure. 2. 10 - 4 Roll Drive. [25]

3. Hose package and welding torch

The hose package that connects the MIG/ MAG welding torch to the welding machine or wire feeder contains all the necessary supply lines: the welding current lead, the shielding gas supply, the wire feed hose and the control cable assembly. On machines designed for higher currents, the cooling water supply and return are also included. In water-cooled welding torches, the current lead is within the water return. The line cross-section is therefore smaller and the hose package lighter and more flexible than for welding torches without water cooling. When welding unalloyed and low-alloy steel, the wire guide hose consists of a steel liner. If wire electrodes made of chrome-nickel steel as well as aluminum and other metals are used, a wear-resistant plastic hose (e.g. Teflon) is employed. Plastic guides have a more favorable coefficient of friction than steel. [14]

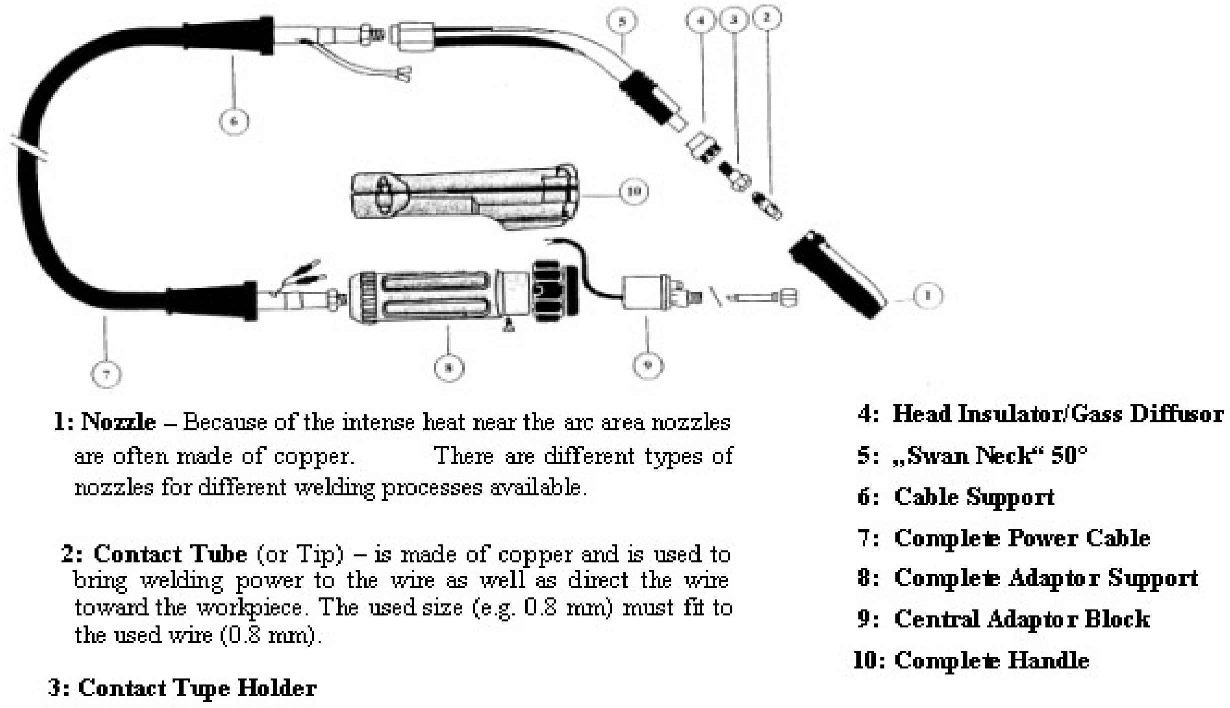

Figure. 2. 11- uncooled semiautomatic gun. [15]

Figures. 2.12 to 2.14 show some common welding torch types. Curved welding torches (Figure. 2.12) are most commonly employed. They are lightweight, and the arc generally reaches the weld location easily. The welding torch in (Figure. 2.13) offers a special technology with the remote control integrated in the handle.

The welding gun is one of the most critical parts of the system. In addition to directing the wire to the joint the welding gun fulfils two important functions. It transfers the welding current to the wire via the contact tip and the shield nozzle directs the shield gas around the arc and weld pool an additional welding torch type is the push/pull torch (Figure. 2.14).

With the push/ pull drive, a wire feed motor mounted in the torch handle pulls the wire electrode, while the drive, which is located in the machine, pushes the wire into the hose package. This allows even soft and thin wires to be fed safely. A push/pull drive is also frequently employed in robot systems and in mechanized welding machines in order to be able to safely transport the wire electrode over long distances. Both drives must be synchronized using electronic means. There are two types of welding guns air/gas cooled and water cooled. [14]

Air Cooled

The air-cooled guns utilize the shielding gas passing through the body to cool the nozzle and have a limited current-carrying capacity.

They are suited for light duty work. Some air-cooled guns are available with current ratings up to 500A but these are often heavy and not suited to extended work periods. [25]

Water Cooled

The water-cooled guns are preferred for high current levels and especially at high duty cycles. They are much lighter in weight due to the lesser amounts of copper made possible by the cooling system. [25]

Figure. 2.12 - Standard MIG/MAG welding torch for. [14]

Figure. 2. 13 - MIG/MAG welding torch with integral. [14]

Figure. 2. 14 - MIG/MAG welding torch with push/pull. [14]

4. Shielding gases

The shielding gas forms the arc plasma, stabilizes the arc on the metal being welded, and shields the arc and molten weld pool so that the chemical and physical reactions are not affected by atmospheric pollutants. It also affects the transfer mode of the metal. There are three primary metal transfer modes: Spray transfer, Globular transfer, and short-circuiting transfer. There are different types of gases that can be used in a particular metal transfer mode.

The principal gases used are can be inert (argon, helium) or oxidizing (CO2, O2). The gases used in the GMAW are mixtures of inert gases which may also contain small quantities of oxygen and CO2. The selection of the best shielding gas is based on the consideration of the material to be welded and the type of metal transfer that will be used. In short circuit transfer mode, the mixtures of these gases depend on the type of base material, the thickness of base material and the characteristic of the weld. [17]

Figure. 2. 15 - General appearance of the shape a gas bottle. [25]

Argon

Most of the gas metal arc welding uses argon as the shielded gas; this is because it gives no spatter, good arc characteristics, mechanical properties and strength of a weld. Welding of ferrous and non-ferrous metals is obvious with argon, but welding of ferrous metal is good with a mixture of CO2 or O2.This is because when used pure argon as shielded gas, there will be lack of transfer of molten metal along the sides of the weld due to relatively low thermal conductivity of argon gas and hence gives the undercut and porosity. Short circuit type metal transfer mode can be better achieved with argon as shielded gas for the welding of sheet metal. Argon creates an excellent current path and gives very good arc stability due to its low ionization potential. Thin arc column can be produced by argon at an elevated current density which causes the arc energy to be concentrated in a small area. This results into deep penetration and good bead shape. Spray transfer mode can also be achieved with argon as shielded gas. [17, 18]

Helium

Helium is best used on welding applications that are requiring the improved of bed wetting, deeper penetration and higher travel speed, this is due of its elevated thermal conductivity and voltage gradient which results in a broader and more shallow penetration pattern than argon. Pure helium gas is appropriate for the welding of thick aluminum, magnesium and copper alloys. The helium arc column is wider than argon which reduces current density.

It is recommended to mix helium and argon together so as to seize the advantages of the good quality of both, e.g., helium improves wetting and weld metal coalescence and argon get better arc stability and cleaning action, in the case of aluminum and magnesiurn. Helium is a very light gas and therefore tends to disperse into the air after coming out from the nozzle, therefore restricted flow is needed. It is rarely available in the world except in Canada, and very much expensive in Europe. [18, 19]

CO2

CO2 is a reactive gas that is mostly used in its pure form in the gas metal arc welding of carbon and low alloy steel. CO2 is only restricted in globular and short-circuiting transfer. It has a high welding speed, greater joint penetration and good weld shape due to its high thermal conductivity. It is easily available, has a lower cost and easily installed. In CO2 shielding, the tip of the electrode should be below the surface of the work ` buried arc ´ in order to minimize spatters. With CO_2 welding, very low sound deposits, good mechanical properties are achieved but may be adversely affected due to the oxidizing nature. The use of deoxidizers in filler wire is recommended while welding with CO_2 to avoid the loss of some alloying elements. To off-set the performance characteristic of pure CO_2 it is often mixed with Argon. To maximize the impact properties of a metal it is recommended to mixed CO_2 and argon in the following proportion 98/2, 95/5, 82/18, 75/25, 50/50 (Figure. 2.16). [16, 18]

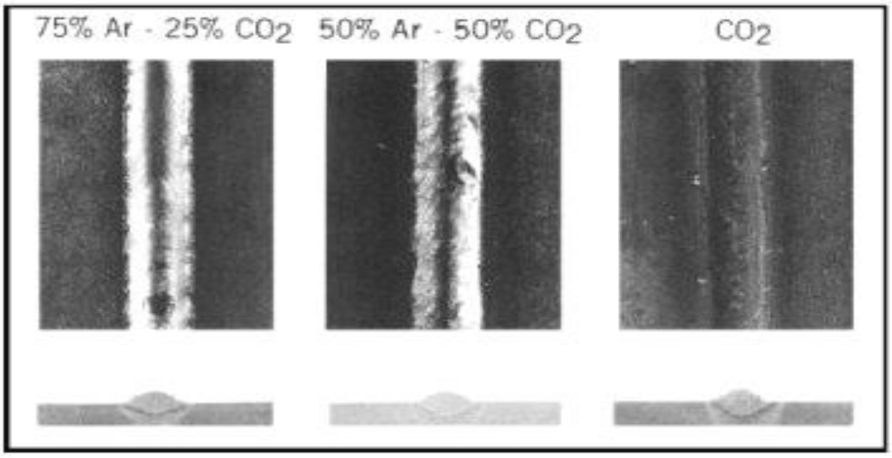

Figure. 2. 16 - Comparison of effect of CO_2, and mixture of CO_2 and Argon. [18]

5. Pressure Reducing Valve and Flowmeter

The pressure in the steel cylinders is between 200 and 300 bar, in order to use the shielding gas, the high pressure must be reduced to a suitable working pressure.

A pressure-reducing valve is used to reduce the pressure; the pressure-reducing valve is usually fitted with a gauge where the actual cylinder pressure can be read. In order adjust the required gas flow for the MIG welding the drawing below shows a pressure reducing valve with incorporated flowmeter.

In the flowmeter there is a small ball which is elevated by the flowing gas thus making it possible to read the gas flow in liters per minute. Please note that the measuring meter of the flowmeter must be placed vertically and that the flowmeter is designed for the used type of shielding gas or else there is a risk for error Reading. [20]

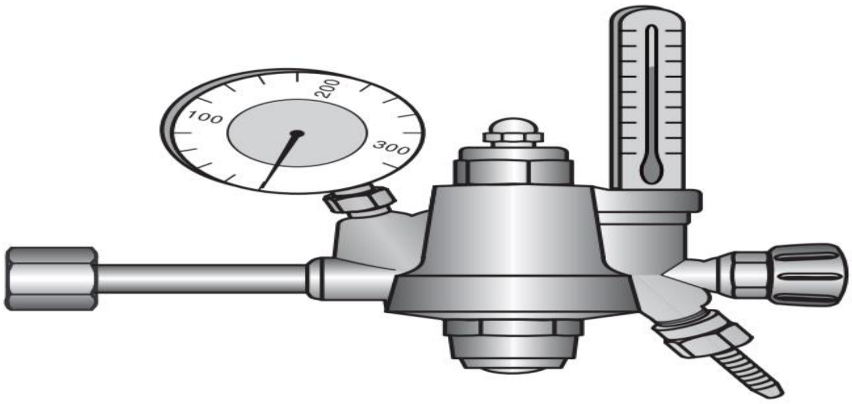

Figure. 2. 17 - Pressure reducing valve with flowmeter. [20]

Not all pressure-reducing valves are equipped with a flowmeter; some types have a working gauge with a liter scale, or use a separate flowmeter.

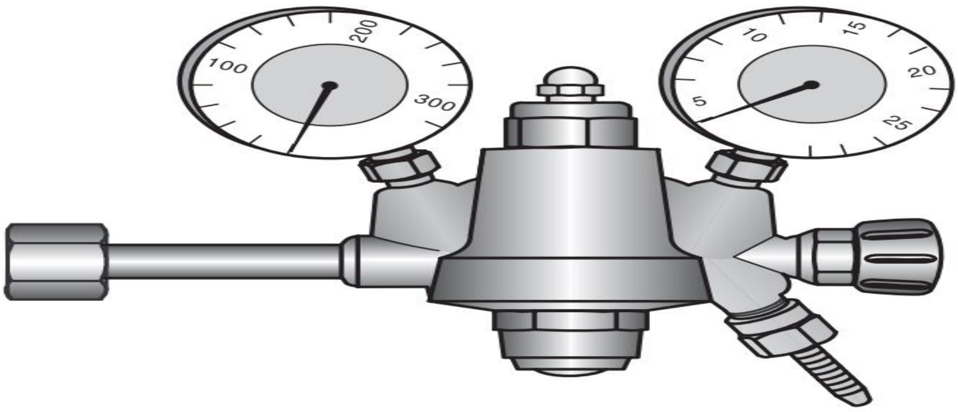

Figure. 2. 18 - Pressure reducing valve with working manometer. [20]

A flowmeter, which measures directly on the gas nozzle, can be used to control that the requested amount of shielding gas exists at the opening of the gas nozzle.

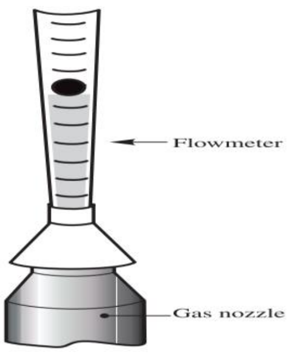

Figure. 2. 19 - Direct measurement on the gas nozzle. [20]

6. Filler Wires

Filler wires for the process come in a range of diameters e.g., 0.6mm to 2.4mm and various sizes of reel weight/diameter. The type of wire selected is chosen normally to match the material to be welded and provide the required strength. Wires of dissimilar materials can be used for some cases which could include hard facing or brazing. Hard wires will utilize wire feed rolls with V style groove whereas soft alloy wires will require wire feed rolls with U style groove to reduce any deformation of the wire shape when pressure is applied. Cored wires can be used for hard facing, high strength or high-speed welding. These wires consist of an outer metal sheath and contain either a flux or metal powder core. Due to the nature of the construction, they often require specially designed knurled feed rolls. For more details on individual wires please consult the material data sheets supplied by the manufacturer. [25]

Figure. 2. 20 - Filler Wires. [25]

The ER70S-6 designates the following [26]:

- **ER –** Electrode rod (electrode and a filler metal)
- **70 –** Indicates in 1000 PSI increments the minimum tensile strength of the weld metal produced by the electrode when tested by AWS A5.18 specification. So, the number 70 here designates a tensile strength of 70,000 PSI.
- **S –** "S" stands for solid wire, while "C" stands for a composite wire (flux core).

- The last digit indicates the chemical additives added to the wire, which affect the resulting bead and the polarity. In this case, the number 6 means that the wire contains additional deoxidizers that help when welding rusty or dirty metal.

The most commonly used solid MIG wire and explain in short what their purpose is so that you can know which to pick for your project.

- **ER70S-3** – The most commonly used general-purpose solid wire for welding mild steel. It contains silicon and manganese deoxidizers, and it's typically used with a 75/25% argon/CO_2 mix, but it can also be used with 100% CO_2.

American Welding Society classifies solid MIG wires in their AWS A5.18 code. So let's break down this classification system with one of the most commonly used solid wire electrodes like ER70S-6.

- **ER70S-6 –** This wire contains more deoxidizers than the ER70S-3. These deoxidizers allow it to weld slightly dirtier metal, and provide better wetting of the puddle. Additionally, you can achieve faster travel speed with it and a flatter bead profile. It is used with 75/25 ar /CO_2 or 100% CO_2.
- **ER308, ER308L** – Commonly used stainless steel MIG wire. The letter L stands for the maximum carbon content of 0.03%, which increases the resistance to intergranular corrosion.
- **ER4043** – MIG wire for aluminum welding. An all-position wire used to weld heat treatable base alloys. Most commonly used for welding 6XXX series of aluminum.
- **ER5356** – Aluminum MIG wire for all position non heat treatable alloys like 5XXX series when 40,000 PSI is not mandated. This is the most often used MIG wire for welding aluminum.

2.1.4. Controls of MIG /MAG

The welding control and the wire feed motor for semiautomatic operation are available in one integrated package (See Figure. 2. 21). The welding control's main function is to regulate the speed of the wire feed motor, usually through the use of an electronic governor in the control. The speed of the motor is manually adjustable to provide variable wire feed speed, which, with a constant-voltage (CV) power supply, will result in different welding current. The control also regulates the starting and stopping of the electrode feed through a signal received from the gun switch. Shielding gas, water, and welding power are usually delivered to the gun through the control, requiring direct connection of the control to these facilities and the power supply. Gas (and water if ….) flow are regulated to coincide with the weld start and stop by use of solenoids. The control can also sequence the starting and stopping of gas flow and energize the power supply output. The control may permit some gas to flow before welding starts as well as a post-flow to protect the molten weld puddle. [26]

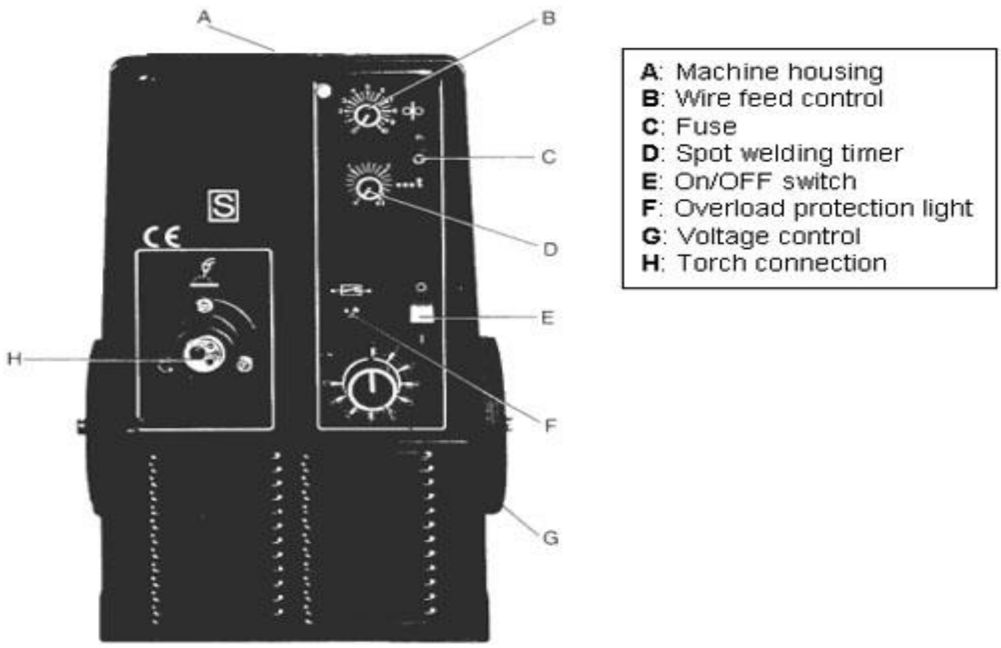

Figure. 2. 21 - "all−in−one" machine with a built in wire feeder. [15]

MIG/MAG arc processes are not intrinsically stable: The feed speed of the wire electrode and the voltage must always be the same. Only in this way can a balance between stick out and the arc length be maintained. To achieve this, certain conditions must apply: The wire feed speed is usually held constant during MIG/MAG welding (see section on wire feeders). If the welding machine supplies the arc process with a stable voltage – that is, constant voltage behavior or a flatly falling I–V characteristic (see Figure. 2 .22) – a "simple" arc process itself (e.g. in spray arc operating mode) can balance the stick-out and keep the arc length stable. External interferences, e.g., caused by changes in distance, may not be completely eliminated, but the welding process remains fundamentally stable.

The main basic controls for the MIG/MAG system are as follows. Controls can be electro mechanical or electronic but the effects will be the same. [14]

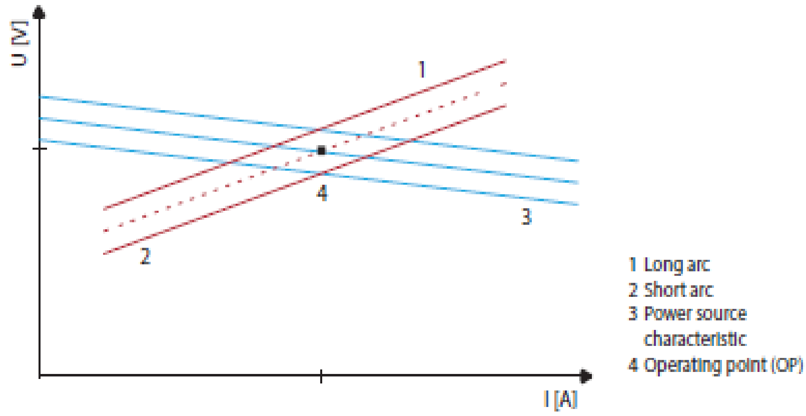

Figure. 2. 22 - Arc ranges for MIG/MAG welding. [14]

Figure. 2. 22 shows how the position of the operating point changes when the settings of the power source and the wire feed speed are changed.

The operating point (OP) is the intersection between the defined power source characteristic and the arc characteristic. It is characterized by the current Is (OP) and the voltage Us (OP). If the wire feed speed is increased, the arc is shortened, and the operating point moves to the right on the source characteristic – the current increases.

If the wire feed speed is reduced, the OP moves to the left instead. The required current can thus be specified via the wire feed potentiometer. However, the arc is shortened as a result of the higher wire feed speed. To prevent it from becoming too short, the voltage must be simultaneously increased. [14]

1. Wire Feed Speed

The wire speed is directly related to the current. The higher the wire speed the more wire is deposited and hence more current is required to burn off the consumable wire.

Wire speed is measured in m/min (metres per min) or sometimes in ipm (inches per minute).

The diameter of the wire also forms part of the current demand e.g., a 1.0mm wire feeding at 3m per min will require less current than a 1.2mm wire feeding at the same rate.

The wire feed is set according to the material to be welded, if the wire feed rate is too high in comparison to the voltage, then a “stubbing” effect happens where unmelted consumable contacts the work piece creating large amounts of weld spatter.

Too little wire feed comparison to the voltage will result in a long arc being created with poor transfer and eventual burning back of the wire onto the contact tip. [25]

2. Voltage Setting

The voltage polarity in MIG/MAG welding is in the majority of cases with the positive (+). This means that the majority of the heat is in the electrode wire. Certain special wires may require the polarity to be reversed i.e., electrode wire negative (-) polarity the voltage is often referred to as the “heat setting”. This will be altered dependent on the material type, thickness, gas type, joint type and position of the weld. Combined with the wire speed it is the main control adjusted by the welder. The voltage setting varies depending on the type and size of electrode wire being used.

Most MIG/MAG welders are a CV or Constant Voltage power source which means the voltage does not vary much during welding. Modern inverter power sources also have control circuits to monitor conditions to ensure voltage remains constant.

The voltage determines height and width of the weld bead. If the operator has no reference to settings required the best method of set up is to use scrap material of the same thickness to obtain the correct setting.

If there is too much voltage the arc will be long and uncontrollable and cause the wire to fuse to the contact tip. If the voltage is too low then there will not be enough heat to melt the wire and then

stubbing occurs.

To obtain a satisfactory weld a balance needs to be made between voltage and wire speed. Characteristics of the voltage are that the higher voltage produces a flatter and wider weld bead but care must be taken to avoid undercut. The lower the voltage the weld bead becomes narrow and higher. [25]

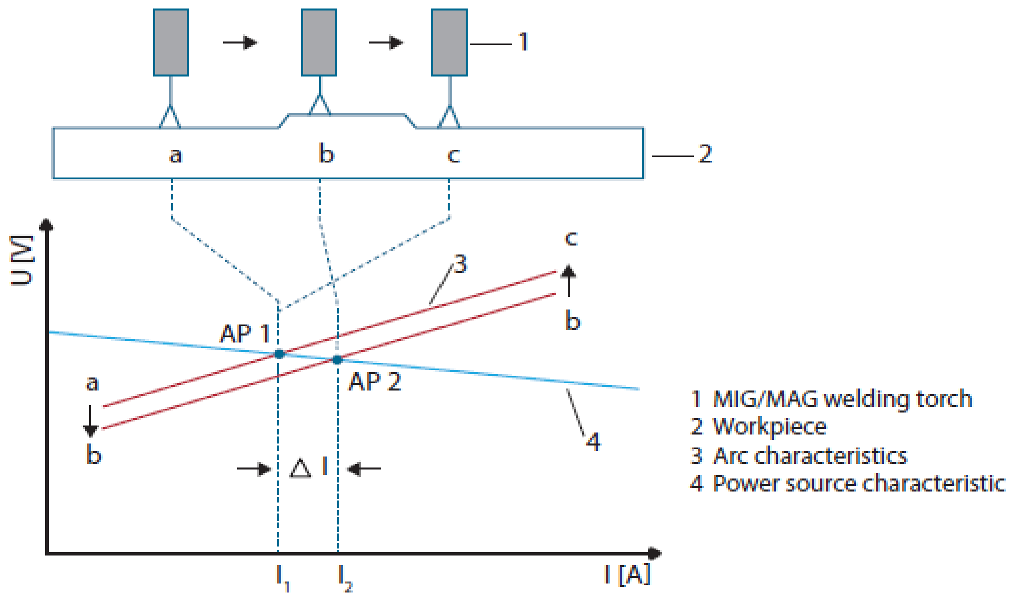

Figure. 2. 23 - Arc length stabilization (delta I control). [14]

This is illustrated in the following diagram (Figure. 2. 23): The arc process characteristic shifts to the right in the I–V diagram as a result of a change in the distance between the welding torch and the work-piece (a -> b); a new operating point OP2 is created with an increased welding current. The higher current leads to a greater wire deposition rate. In turn, this causes the arc to become longer.

It forms a new equilibrium with the shorter stick-out. If the original distance between the welding torch and the work-piece is reached again (b -> c), an equilibrium between the wire and arc length is achieved as in (a). The operating point is once again at OP1.

For a higher voltage, a higher characteristic must be set on the step switch; if a lower arc voltage is desired, a lower characteristic must be set. The source characteristics usually fall.

This means that if one required parameter is adjusted, the other also changes slightly. This mutual influencing is only absent in constant voltage sources (horizontal power source characteristic).

For optimal welding conditions, the arc may be neither too short nor too long. Droplet short circuits and therefore spatter often occur if the arc is too short. The short circuits can be recognized by a typical backfiring noise emanating from the arc. As the length of the arc increases, the risk of ambient air entering the arc area also increases.

This in turn increases the risk of pores and undercuts, among other things. The welder can recognize the excessively long arc optically and from the hissing noise of the arc. The range of favorable operating points runs approximately diagonally through the I–V diagram. This is the working area where welding should be performed. [14]

3. Inductance

When MIG/MAG welding in the dip transfer mode the welding wire electrode touches the work piece/weld pool and this results in a short circuit. When this short circuit occurs the arc voltage will fall to nearly zero. This change in the arc voltage will cause a change in the welding circuit.

The fall in voltage will cause a rise in the welding current. The size of the current rise is dependent upon the welding characteristic of the power source.

Should the power source respond immediately then the current in the circuit would rise to a very high value. The rapid increase in current would cause the short-circuited welding wire to melt similar to an explosion creating a large amount of molten weld spatter.

By adding inductance to the weld circuit this will slow down the rate of current rise. It works by creating a magnetic field which opposes the welding current in the short circuit thereby slowing the rate of rise.

If the inductance is increased it will cause an increase in arc time and reduction in the dip frequency, this will help reduce spatter.

Depending on the welding parameters there will be an optimum inductance setting for the best welding conditions. If the inductance is too low then there will be excessive spatter. If the inductance is too high the current will not rise high enough and the wire will stab the weld pool with insufficient heat.

The modern technology welding power sources often have the ability to provide the correct inductance to provide excellent weld characteristics. Many have a variable inductance control to give precise control. [25]

4. Burn Back

In the event that the welder was to stop welding and all functions of the machine stopped simultaneously then the consumable filler wire would in all likelihood freeze in the weld pool.

In order to avoid this happening, the burn back feature is present on most machines. This facility may be built in or an adjustable control. It will allow the power and gas shield to be maintained on the consumable filler wire when it has stopped feeding thereby burning clear of the weld. In some equipment the burn back is preset within the control circuits others offer an external variable control feature to adjust the time of delay. [25]

5. Other Controls

Other common control features are latching or 2T/4T where the welding can either in 2T mode press the torch trigger to weld and release to stop or in 4T press and release the torch trigger to start, weld without holding the trigger on and stop by pressing and releasing the trigger again.

This is particularly useful when welding long weld runs. Crater fill controls are available on many machines. This allows the crater at the end to be filled helping eliminate welding defects.

A spot-welding timer will allow the time of the weld to be set and after the time has expired the operator will have to release the torch switch to restart the weld.

In smaller auto body type machines, there are sometimes stitch welding timers. These timers set an on and off time which allows the welder to operate the torch switch and weld for the preset time then pause for a preset time without releasing the torch switch. This process will continue until the switch is released.

In many of the new technology machines there are numerous other control features made possible by the use of electronics and microcomputers such as synergic control, pulse and double pulse etc.

These can greatly improve both machine and welder performance and the operator should always read the manufacturer’s instructions to gain a full knowledge of all these additional features. [25]

2.2. Modes of Transfer

The fusion of the wire and the transfer in the arc can be carried out in different ways depending on the nature of the protective gases, the voltage and the intensity of the arc. This paragraph describes the various so-called spontaneous transfers obtained through generators providing continuous voltage and intensity ($50 - 650$ A). It also addresses transfer procedures. Forced resulting from the use of particular wave forms (use of two levels of intensity, use of a source of variable polarity). [21]

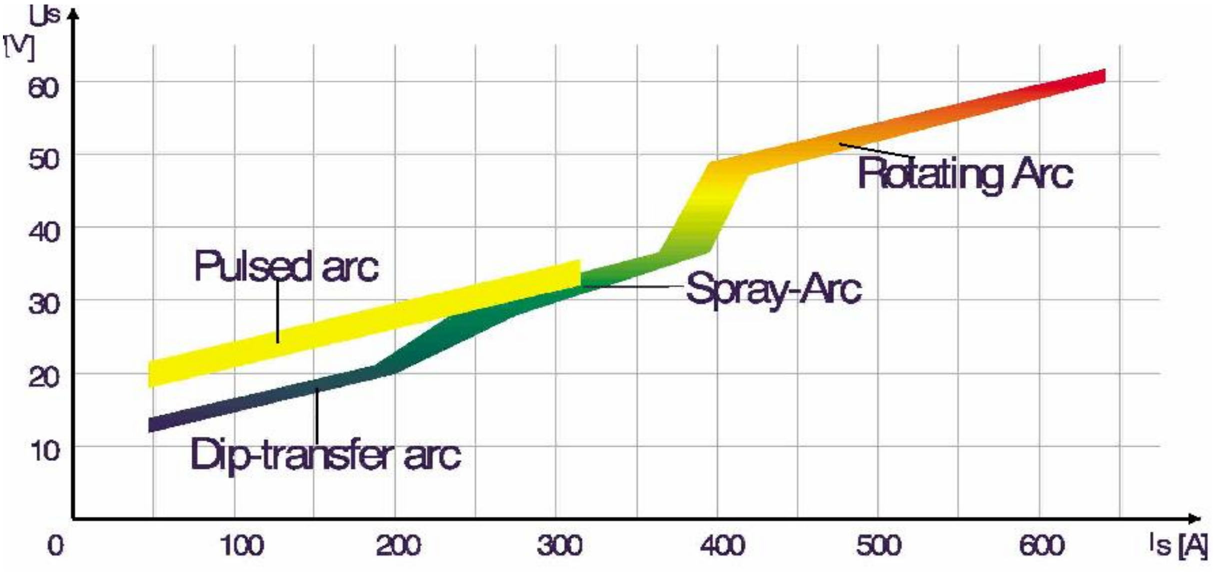

Figure. 2. 24 - Arc area in GMAW. [22]

2.2.1. Short arc

For low arc energies (i.e., an intensity ranging from 50 to 200 A and a voltage from 15 to 20 V) the metal deposit is made discontinuously in an alternation of arc time and short circuit time. (Figure. 2. 25). During the arc time, i.e., during the phase where the electric arc is created, a drop is formed at the end of the wire by Joule effect in the terminal part and by the influence of the electrical arc and enlarges until coming into contact with the bath, thus creating a short circuit. During this short circuit period, the current increases rapidly and generates electromagnetic forces causing a pinch between the circuits.

The solid and liquid part of the welding wire, which then facilitates the separation of the gout. Following this, an arc is established again between the welding wire and the sheet. A new cycle of drop formation can then start again. Due to the low energy of the bow, this regime is called "cold». [21]

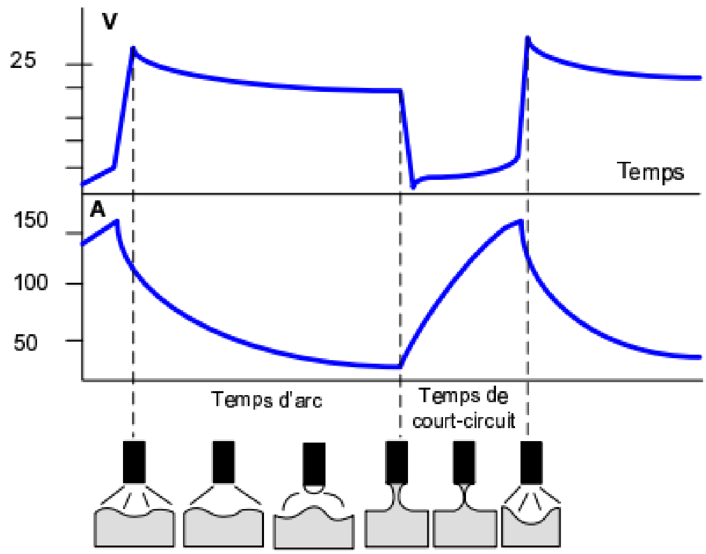

Figure. 2. 25 - Short arc. [21]

2.2.2. Spray arc

For high welding energies, i.e., a current density greater than 250 A.mm−2 depending on the nature of the wire and the protective gas, the transfer of metal occurs in the form thin droplets whose diameter is smaller than the wire. (Figure. 2.26). The thin droplets are projected at high speed into the wire axis. This transfer of metal provides a stable arc with few projections and allows for a large penetration and volume of deposited metal. Given the energy level used, this process applies to thicknesses greater than 5 mm. Signals of tension and intensity observed between the electrode and the sheet this system is almost continuous. From this axial spraying scheme, a derived transfer scheme (spray+) has been developed allowing welding at intensity levels. It has higher tension, allowing for increased depth of penetration. [21]

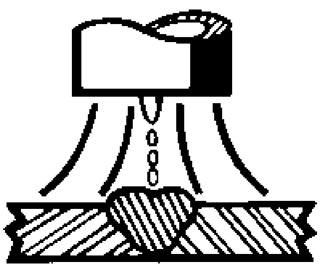

Figure. 2. 26 - Spray arc. [15]

2.2.3. Globular transfer mode

This welding scheme (Figure. 2.27) is set for an energy level between the energy levels of the short circuit scheme and the axial spray scheme. Thus, the drops have a slow growth, and unlike the short circuit regime, the current is not high enough to produce a tightening of the cervical between the liquid and solid phase and therefore a detachment of gout. The transfer is done by short circuit when the drop touches the bath or when, under the effect of gravity, the drop disconnects from the wire. The drop then follows a random trajectory that is not always in the axis of the bow. This mode of transfer is unstable and causes many projections. The form of the electrical signals corresponding to this regimen are those of the short circuit regimen, to The frequency of this phenomenon is no longer regular. This transfer method should be avoided as much as possible [21].

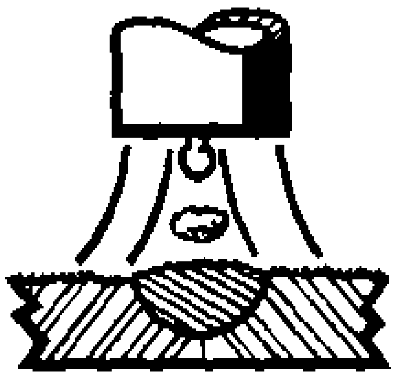

Figure. 2 .27 - Globular Arc. [15]

2.2.4. Pulsed arc

The pulse regime is achieved through the superposition of peak intensity to a base current. The bow is constant lined and there is release of thin droplets of supply metal at the peak of intensity. This particular transfer scheme makes it possible to manufacture cordons with thickness constraints and material characteristics that would require the use of a globular scheme. [21]

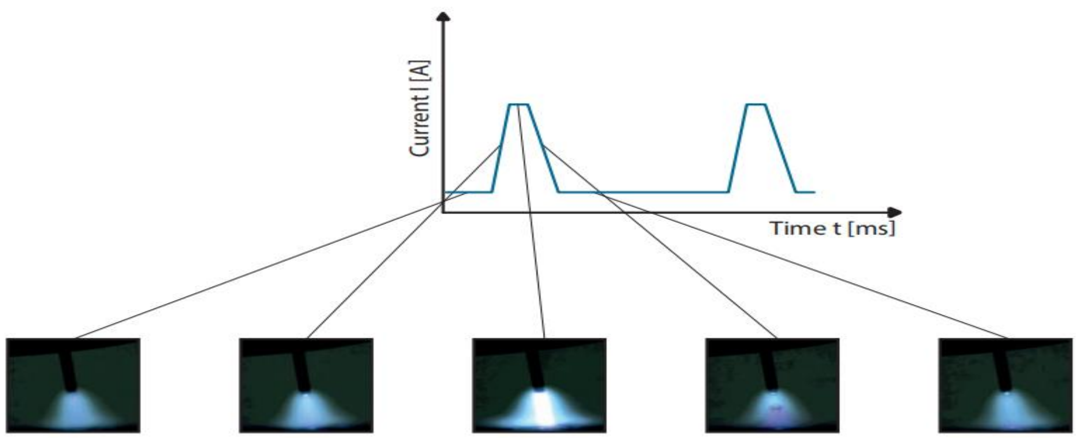

Figure. 2.28 - Droplet transfer in pulsed arc. [14]

2.2.5. Forced short circuit

Forced short circuit transfer (short-arc +) is used in a range of speed shift of the torch where increasing the corresponding intensity would result in the occurrence of a blood transfer. This transfer allows for a transfer. Short circuit and therefore low projection rates. This welding regime is obtained with special welding stations whose wave shapes allow to maintain a regular short circuit frequency. [21]

2.2.6. Rotating arc

For intensities of the order of 500 A and tensions of 45 to 50 V, the transfer by axial spraying is subject to significant electromagnetic forces. At this level of energy, the liquid metal subjected to these forces performs a rotational movement in the arc. (Figure. 2.29). Given the energy provided by the arc, this regime allows for high productivity for Elements to be welded with a strong thickness. [21]

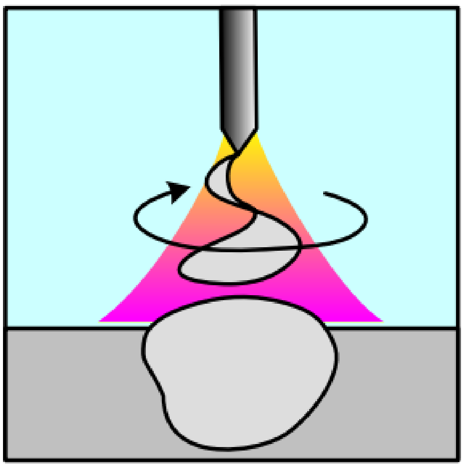

Figure. 2. 29: Rotating arc. [21]

Synthesized

The previously defined welding regimes are represented in an arc tension diagram Intensity of Arc (figure. 2.30). This diagram also shows the result (penetration level wire, wire width, etc.) Of each welding operation for each circuit.

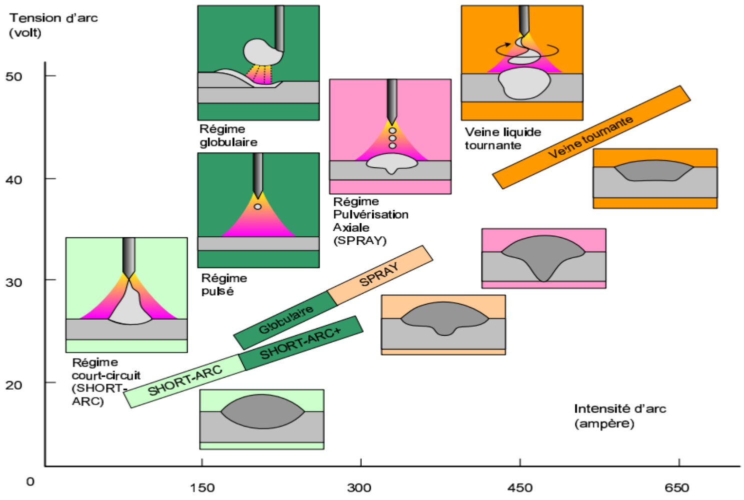

Figure. 2. 30 - Summary diagram of the different transfers. [21]

The user of a welding installation must only intervene on a minimum of elements. Installation of a generator. To do this, it is essential to have perfect wire drainage, without fluctuations in speed, as well as a very good current outlet. At the level of the torch. Generators have so-called synergies. Containing data of fusion curves for a type and diameter of input wire It is also a protective gas. The diagram in (Figure. 2.30) makes it clear that the transfer mode greatly influences the outcome of the welding operation. The choice of a transfer regime helps to better meet the constraints imposed by the assembly to be made (the thickness and nature of the sheets, the position of welding, preparation). [21]

2.3. Factors affecting welding quality

The welding parameters are the factors that affect the quality of the weld, such as the current, voltage, speed, electrode type, and gas flow. The welding parameters determine the amount of heat input, the size and shape of the weld pool, the penetration depth, and the formation of defects. The welding parameters need to be optimized for each material and welding process to achieve a strong and durable weld.

2.3.1. Setting the welding parameters

Some of the common effects of the welding parameters on the welding quality are [26]:

- Increasing the current increases the heat input and the penetration depth, but also increases the risk of burn-through and distortion.
- Increasing the voltage increases the arc length and width, but also increases the spatter and porosity.

- Increasing the speed decreases the heat input and the penetration depth, but also decreases the risk of burn-through and distortion.
- Choosing the right electrode type affects the arc stability, metal transfer, and slag formation.
- Choosing the right gas flow affects the shielding of the weld pool from atmospheric contamination.

These are some examples of how the welding parameters influence the welding quality. A good welder needs to adjust the welding parameters according to the specific requirements of each welding job.

2.3.2 Influence of the protection gas on the transfer of metal in the MIG/MAG

The MIG/MAG process has so far been analyzed only for application purposes. Techniques as one of the most popular methods of assembly of metals. In this in the context, the use of carbon dioxide is linked to the search for a cost reduction production of assemblies, while ensuring the high quality of the welding achieved.

In recent years, work safety has become very important, and additional studies have been conducted on the use of gas mixtures to reduce toxic emissions during the process. But the complexity of the process complicates the work undertaken and the study of the physical properties of the MIG/MAG plasma. The information available is mostly derived from the technical literature of welding, as until now plasmas of this type were little (or not at all) examined in the atomic physics laboratories, and in particular plasma physics. In particular, the diagnosis of the welding arc is difficult, and requires obtaining stable arc conditions; therefore it is essential to know the influence of the nature of the protective gas on the character of the discharge. The speed of the process and the quality of the cord are dependent on the transfer regime of the metal in the arc that determines the sizes, speeds and frequencies of dropling. Under the protection of pure argon, which is the most commonly used gas, the transition from axial spraying mode to a circulatory regime is achieved for a relatively low current. On the other hand, under pure carbon dioxide, it is not possible to this transition, at least with current values accessible to generators used. (Figure. 2. 31). Although these facts are well known, the causes of such essential differences in the behavior of the process depending on the gas used are not always understood or explained. With argon mixtures with low CO2 or O2, the stability of the discharge is improved and the transitional current value decreases compared to the situation with pure argon.

These observations are explained by a change in the surface tension of liquid metals caused by the presence of active gas. Both oxygen and carbon decrease the surface tension of the steel and facilitate droplets. Oxidative gases can increase the emission of the cathode.

When using high levels of carbon dioxide in the protective gas, it is possible to observe the movement of the drop upward, very characteristic of repelled transfer [23, 24], which proves the existence of forces of a repellent character oriented to the opposite. Movement of the Files. If a current passage occurs in a composite body In the case of two components having different electrical conductivity, the distribution of the current within the body is determined by the component whose conductibility is lower.

A similar situation occurs in the case of the welding arc: the electrical conductivity of the plasma is a few orders of magnitude smaller than the conductance of the metal.

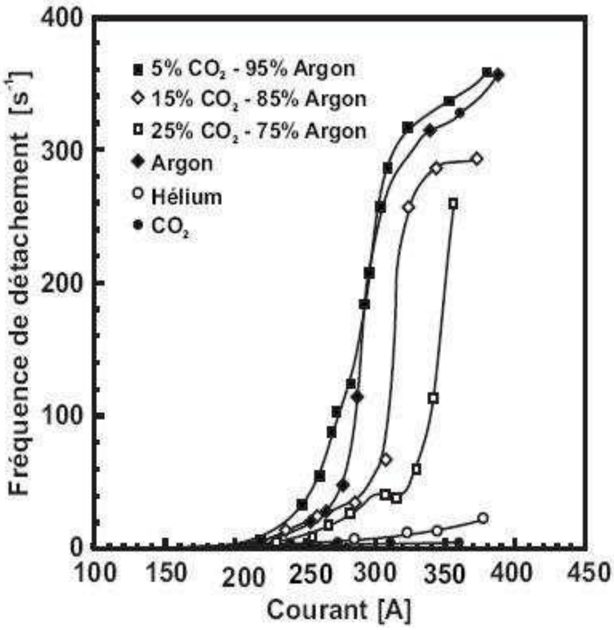

Figure. 2.31 -Effect of shielding gas on detachment frequency. [21]

2.3.3. Torch guidance

The welding torch is tilted in the direction of welding by around 10° to 20° and can be backhand or forehand (Figure. 2.32). The distance between the stick-out and the work-piece, i.e., the between the lower edge of the contact tip and the start point of the arc, should be about 10 to 12 times the wire diameter [mm]. If the welding torch is tilted excessively, there is a danger that air will be injected into the shielding gas, thus creating faults. Forehand welding is generally used when welding with solid wires; backhand welding is used with slag-forming flux cored wires. A slight backhand motion is normally sed in the PG position. Vertical down welding (position PG, vertical down) mainly occurs with thinner sheets. On thicker sheets, there is a risk of lack of fusion owing to weld metal running ahead. This lack of fusion caused by weld metal running ahead may also occur in other positions if welding is performed at too low a welding speed. Wide weaving movements should therefore be avoided wherever possible, except in the PF position (vertical upwards). [14]

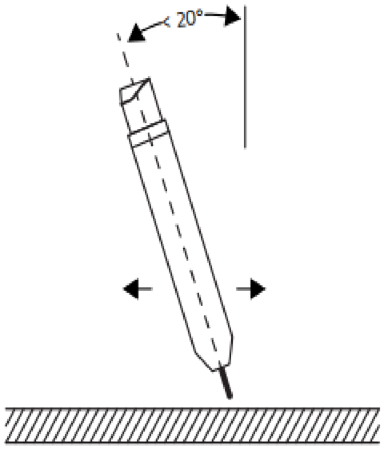

Figure. 2. 32 - Setting the welding torch in the welding direction. [14]

Conclusion

This chapter has covered the basics of the MIG/MAG welding process and the equipment required for it. MIG/MAG welding is a form of arc welding that uses a consumable wire electrode and a shielding gas to produce a weld. The main parts of the MIG/MAG welding machine are the power source, the wire feeder, the torch, the gas cylinder, and the regulator. The MIG/MAG welding process can be applied to various materials and applications, such as carbon steel, stainless steel, aluminum, and thin sheet metal. The quality of the MIG/MAG weld is influenced by the proper selection and adjustment of the welding parameters, such as current, voltage, speed, electrode type, and gas flow. By learning about the MIG/MAG welding process and the equipment used for it, we can improve our welds and our skills as welders.

CHAPTER 3

Modeling of the MIG/MAG welding process

Introduction

The general objective of this chapter is to obtain a model for the MIG/MAG welding process that relies on the theoretical physics of the process In this chapter we present the physical model that was used in the MIG/MAG welding simulator in short-arc mode

The modeling of a welding process in general means the derivation of a set of mathematical equations (ordinary differential equations for lumped parameter systems) partial differential equations for distributed parameter systems) describing the physical process by means of fundamental principles of science we begin with a description.

Then we discuss various aspects of the physics of welding. and the model of two states the first one arc mode (droplet growth and the second one droplet detachment (metal transfer) and we put some figures about simulation and we conclude the chapter by some interpretations about the simulation.

3.1. GMAW system in short arc mode

3.1.1 General description

Short-circuiting metal transfer is a metal transfer whereby a continuously fed wire electrode is deposited during electrical short-circuits. The transfer of a single molten droplet of electrode occurs during the shorting phase of the transfer cycle when physical contact with the molten weld pool occurs.

Figure 3.1 illustrates the time evolution of a droplet together with the corresponding arc voltage and welding current. Metal transfer goes through five steps:

A: The electrode makes physical contact with the molten pool. The arc voltage approaches zero and the current level increases. The rate of rise to the peak current is affected by the amount of applied inductance.

B: This point demonstrates the effect of electromagnetic forces that are applied around the electrode. This force pinches the electrode.

C: This is the point where the bridge of molten metal explodes. The droplet is forced from the tip of the electrode to the welding pool.

D: The molten droplet reforms while current is at its background level.

E: The electrode is once again making contact with the pool, preparing for the transfer of another droplet.

The area of the welding arc, sketched in (Figure. 3.2), is a region of high complexity that is comprised of physical forces and chemical reactions. The interaction of the components of the arc affects metal transfer and the quality of the finished weld. The behavior of the arc is influenced by: the type and the diameter of the filler metal, the base metal conditions, the shielding gas, the welding parameters (voltage and current) and the interaction of physical forces.

The phenomenon of metal transfer in short arc welding can be seen as a hybrid system as sketched in Figure 3.3 Indeed it presents two continuous states: a first one during which the droplet grows and a second one during which the electrode is in physical contact with the work-piece. The jump between the two states is linked to the fulfillment of a guard condition:

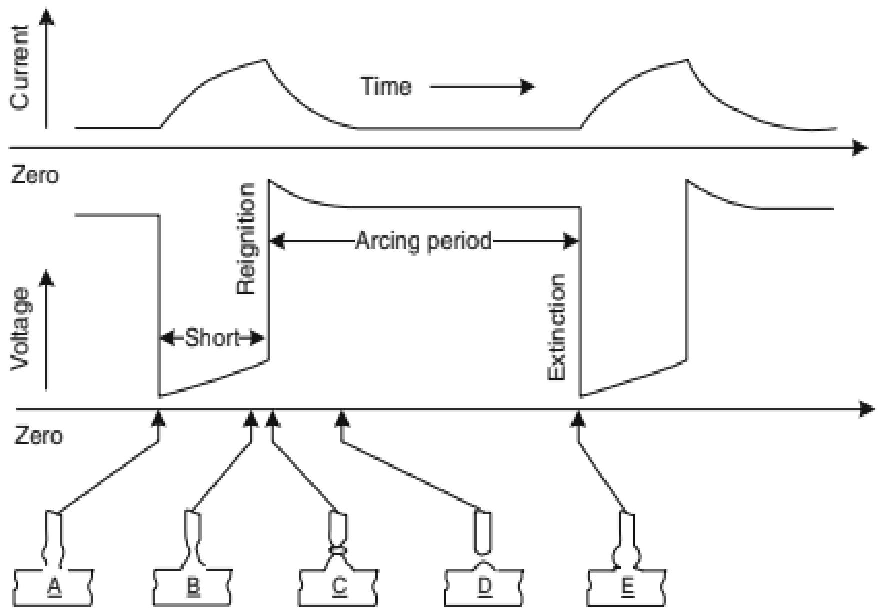

Figure. 3. 1-Oscillograms and sketches of short-circuiting transfer. [39]

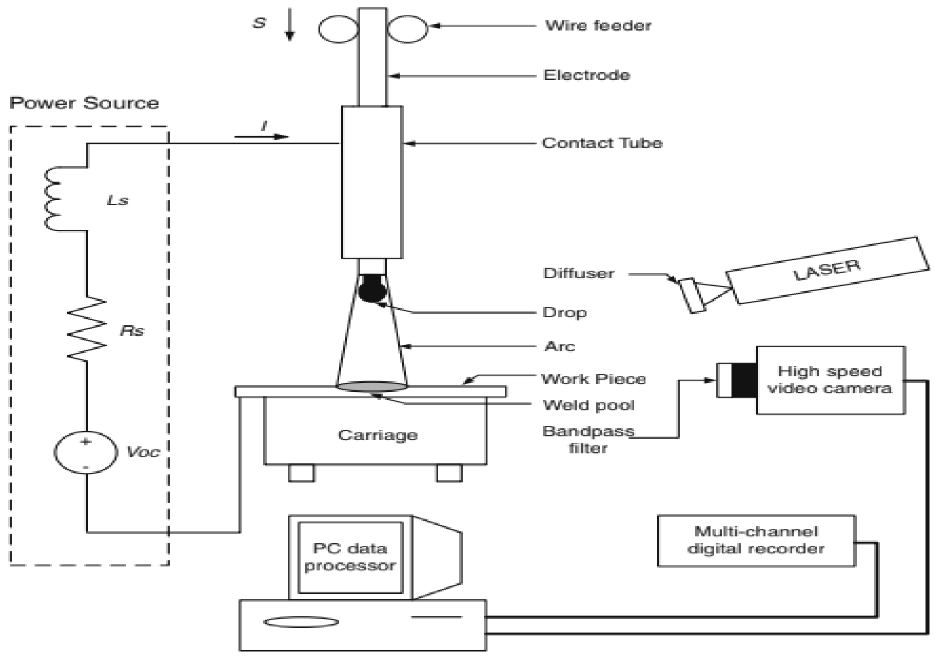

Figure. 3. 2-Sketch of the experimental apparatus. [39]

- Cond 1: The contact-tube to work-piece distance is less than the electrode extension plus droplet length.
- Cond 2: The molten metal bridge diameter is less than a threshold fixed by electrical and material laws.

In each state, a set of differential equations drives the process behavior. These equations stem from power source characteristics, the set of forces acting on a droplet and fluid dynamics for the metal transfer.

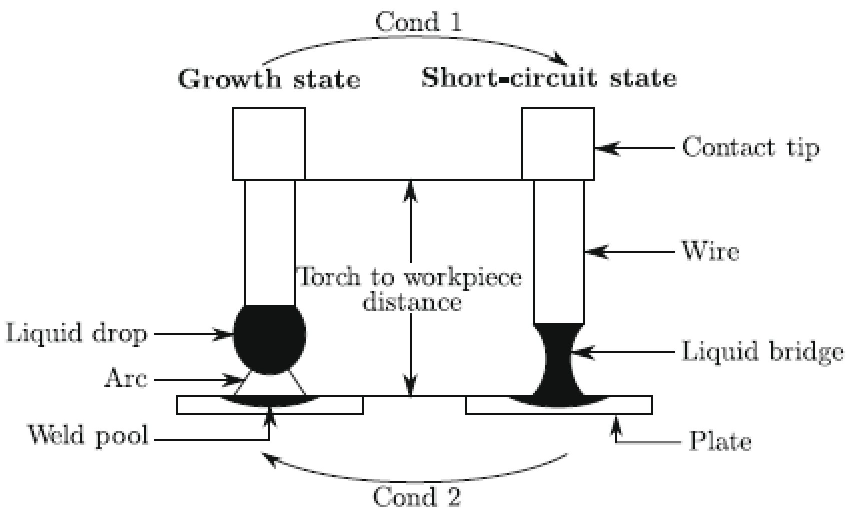

Figure. 3. 3 - States of the hybrid system. [39]

3.1.2 Model of droplet growth

Two categories of forces can arise in our process: detaching ones and retaining ones. Three forces have been identified as relevant:

(1) The gravitational force due to the mass of the drop and acts as a detaching force when welding in the flat position:

$$Fg = \frac{4}{3}\boldsymbol{\pi r_d^3 g \rho_W} \qquad (1)$$

where **rd** denotes the droplet radius, $\boldsymbol{\rho_W}$ the mass density of molten metal, and g the gravity acceleration.

(2) The surface tension is a property of all liquids which comes from the surface of a liquid has an energy (more precisely the interface between the liquid and the phase surrounding it). This energy is reduced by minimizing the area for any volume. This is realized when the liquid takes a spherical shape as the ratio area/volume is minimal for a sphere. In 1864, Tate observed the direct proportionality between the maximum mass of a drop of water detached from a pipe and the radius of the pipe. This relation is known as Tate's law and is given by

$$\boldsymbol{Fs = 2\pi r_w \gamma} \qquad (2)$$

with $\boldsymbol{Fs}$ the weight of the drop, $\boldsymbol{r_w}$ the radius of the tip (in MIG/MAG welding, the radius of the electrode) and c the liquid surface tension.

(3) The electromagnetic force which results from diverging or converging current flow within the electrode. As shown in Figure 3.5, if the current lines diverge in the drop, the Lorentz force, which acts at right angle to these current lines, creates a detaching force; on the contrary, if the current lines converge, the Lorentz force opposes drop detachment. This force is calculated thanks to the Lorentz's law:

$$\overrightarrow{F_{em}} = \vec{J} \times \vec{B} \qquad (3)$$

where $\vec{J}$ is the current density and $\vec{B}$ the magnetic flux. The total electromagnetic force can be obtained by integrating (3) over the current conducting surface of the drop. By assuming that the current density on the drop is uniform, Amson [32] obtained:

$$\boldsymbol{F_{em}} = \frac{\mu I^2}{4\pi}\,\boldsymbol{f_z}$$

(4)

And

$$f_z = \left[\frac{1}{4} - \ln\left(\frac{r_d \sin\theta}{r_w}\right) + \frac{1}{1-\cos\theta} - \frac{2}{(1-\cos\theta)^2}\ \ln\left(\frac{2}{1+\cos\theta}\right)\right] \quad (5)$$

where I is the welding current and μ_0 is the permeability of free space. The geometry used in (5) is shown in (Figure. 3.4).

where θ is the arc hanging angle. The black surface indicates the area of the drop allowing the current to go through.

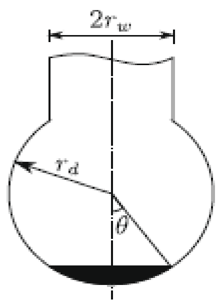

Figure. 3. 4 - Geometry of a drop. [39]

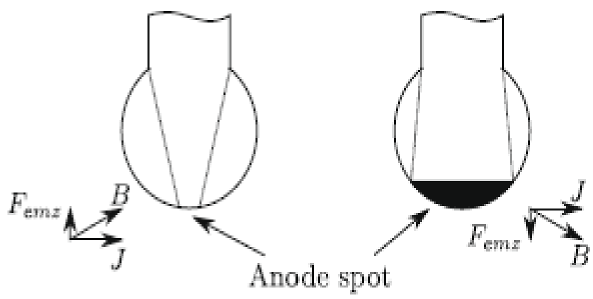

Figure. 3. 5 - Current path and Lorentz force. [39]

In MIG/MAG welding metal, transfer only occurs after the solid is molten and thus the coupling between mass flow and heat transfer is very strong. The main heat sources for melting the electrode are Joule effect and electron condensation [34].

Joule heat is the heat generated by the electrical resistance of the consumable electrode. The heat of electrode condensation results from the plasma high energy electrons condensing on the metal surface and releasing most of their energy.

The Joule heat can be calculated by

$$Q_{joule} = \int \rho(T) I^2 dV = \bar{\rho} A L I^2 \tag{6}$$

where $\bar{\rho}$ is the average electrical resistivity, L the electrode extension and A the area of the electrode. The electrode condensation heat can be obtained by

$$Q_{cond} = \left(\frac{3}{2}\frac{KT}{e} + V_a + \emptyset\right) I \tag{7}$$

with K denotes the Boltzmann constant. The first term of the right hand-side of (7) represents the kinetic energy of the electrons in the plasma, the second term is the acceleration energy of the electrons in the anode drop region and the third term is the work function of the electrode material. If one assumes that the whole heat is consumed in melting the consumable electrode, the melting rate can be obtained by dividing the total heat input into the system by the heat required to melt a unit mass of the material:

$$\frac{dm}{dt} = \frac{\bar{\rho} A L I^2 + \left(\frac{3KT}{2\,e} + V_a + \emptyset\right) I}{\int_{Ti}^{Tm} C_p dT + \Delta H_{trans} + \Delta H_m} \tag{8}$$

where ΔH_{trans} is the heat of crystalline transition and ΔH_m is the heat of fusion. Since the coefficients are constant the melting rate can be expressed as a second order function of the welding current:

$$\frac{dm}{dt} = (C_1 + C_2 \rho l_s I^2) \rho_w \tag{9}$$

where C_1 and C_2 are constant parameters fixed to strike a balance between Joule effect and arc heat fusions, $\rho = \bar{\rho} A$ denotes the linear resistivity of the electrode and l_s represents the solid wire extension (stick-out).

The power supply being converted into the equivalent RL circuit [33], we write the Kirchoff's voltage law for the welding system represented in Figure 3. 2 as:

$$L_s \frac{dI}{dt} + (R_s + R) I + U_{arc} = U_{oc} \tag{10}$$

with L_s and R_s are the inductance and resistance of the welding system, R is the wire-droplet system resistance, U_{oc} is the equivalent open-circuit voltage and U_{arc} is the arc voltage. The latter is expressed by

$$U_{arc} = U_0 + R_a I + E_a (CT - l_s) \tag{11}$$

where U_0 is the arc voltage constant, E_a the arc length factor, CT the contact-tube to work-piece distance and R_a the arc resistance.

The stick-out evolution is controlled by

$$\frac{dl_s}{dt} = S - \frac{1}{\pi r_w^2}\frac{dm}{dt} \tag{12}$$

with S the wire feed speed.

We have used these expressions of forces, of melting rate and of evolution of the welding current to write a state-space representation of the governing differential equations of droplet growth. Five state variables have been retained: droplet displacement x_1, droplet velocity x_2, current x_3, stick-out x_4 and droplet mass x_5. State equations are:

$$\dot{x_1} = x_2 \tag{13}$$

$$\dot{x_2} = \frac{1}{x_5}\left(F_g + F_{em} - F_S\right) \tag{14}$$

$$\dot{x}_3 = \frac{1}{L_S}\left[U_{oc} - (R_a + R_s)x_3 - U_0 - E_a(CT - x_4) - \left[x_4 + x_1 + \left(\frac{3x_5}{4\pi\rho_w}\right)^{\frac{1}{3}}\right]\rho x_3\right] \tag{15}$$

$$\dot{x}_4 = S - \frac{1}{\pi r_w^2}(C_1 x_3 + C_2 \rho x_3^2 x_4) \tag{16}$$

$$\dot{x}_5 = (C_1 x_3 + C_2 \rho x_3^2 x_4)\rho_w \tag{17}$$

The switching from the droplet growth state (arc mode) to the metal transfer state (short-circuit mode) is archived when the sum of the stick-out (l_S), the drop displacement (x_1) and the droplet radius (r_d) equals to the CT, $l_S + x_1 + r_d = CT$.

3.1.3 Model of metal transfer

We present here a simple model of metal transfer during short-circuiting period. Through this work we aim at checking some ideas often encountered when dealing with welding.

The power supply being converted into the equivalent RL circuit [33], we write the Kirchoff's voltage law for the welding system represented in Figure 3.2 as:

$$L_s\frac{dI}{dt} + (R_s + R)I = U_{oc} \tag{18}$$

The metal transfer is controlled by three relevant forces:

(1) The gravitational force.

(2) The electromagnetic force which results from diverging or converging current flow within the electrode. When the current path diverges in the drop, the Lorentz force presents an axial component acting, normal to the current path and creating a detaching force, and an orthoradial component which squeezes the molten metal bridge.

(3) The surface tension which is normal to the surface of a molten droplet. It serves to support the form of the molten metal bridge.

An exhaustive welding simulation would solve a set of coupled partial differential equations governing the fluid, thermal and electromagnetic fields. These equations would include the continuity and Navier–Stokes equations. The following assumptions [35] are made to simplify the complex behavior of short-circuiting transfer:

(1) The initial bridge shape is spherical and the contact diameter within the weld-pool surface is equal to the wire diameter.

(2) Flow velocity within the bridge and pressure within the weld pool are neglected.

(3) The bridge shape is described by two principal radii.

(4) The pool surface remains flat and metal transfer is stable.

Thanks to these assumptions and taking into account only the three forces mentioned above we expect to model the sequence of events represented in (Figure.3. 6).

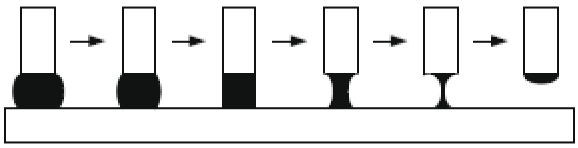

Figure.3. 6 - Short-circuit modeling. [39]

The bridge shape was explained with two principal radii [36, 37, 38], but in this work, the spherical shape (Figure 3.7 a) is approximated by a double-cone shape (Figure 3.7 b); therefore, the average pressure is calculated using one radius (R) by Eq. 19. The value of (R) radii can be calculated using Eq. 21 by the drop volume and bridge height. This modification considerably simplifies the calculations. In the spherical model, the computation of the principal radii was complex and expended a long simulation time.

The average pressure [38] on the cross-section of the bridge center is derived as follows:

$$P_{avg} = \frac{\mu_0 I^2}{8\pi^2 R^2} + \frac{\gamma}{R} \quad (19)$$

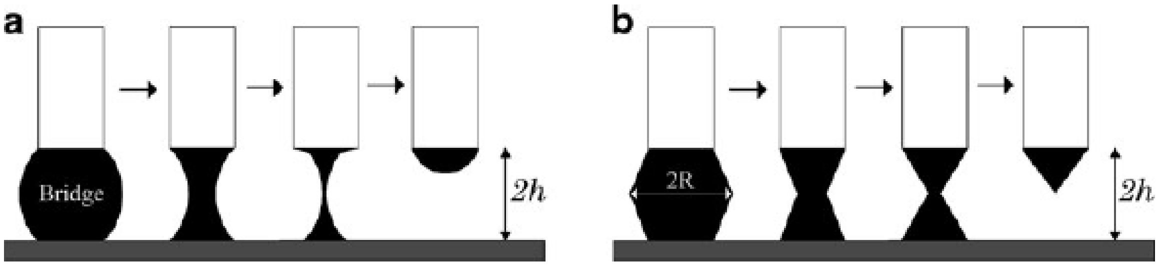

Figure. 3. 7-Spherical model (a) and simplified conical model (b) for the bridge shape. [40]

The switch condition to the arc period and the remaining mass at the neck of the electrode are:

If R =0 then :

$$x_5 = 0.5x_5 \tag{20}$$

$$R = \frac{1}{2}\left(-r_w + \sqrt{-r_w^2 + \frac{12}{h\pi}V_d}\right) \tag{21}$$

where V_d is the volume of the liquid material left on the electrode after detachment is calculated by Eq. 22 [31].

$$V_d = \frac{m}{2\rho_w}\left(\frac{1}{1+e^{-100V_d}} + 1\right) \tag{22}$$

Applying the Bernoulli equation with assumption 2, the flow velocity at the contact between the bridge and pool surface can be calculated using the average pressure and bridge height as:

$$v = \sqrt{\frac{2}{\rho_w}\left(P_{avg} + \rho_w g h\right)} \tag{23}$$

where h is the distance between the pool surface and bridge center. Finally, the state-space model corresponding to the metal transfer mode is given by

$$\dot{x}_1 = x_2 \tag{24}$$

$$\dot{x}_2 = \frac{1}{x_5}\left(F_g + F_{em} - F_S\right) \tag{25}$$

$$\dot{x}_3 = \frac{1}{L_S}\left[U_{oc} - R_S x_3 - \left[x_4 + x_1 + \left(\frac{3x_5}{4\pi\rho_w}\right)^{\frac{1}{3}}\right]\rho x_3\right] \tag{26}$$

$$\dot{x}_4 = S - \frac{C_2 \rho x_3^2 x_4}{\pi r_w^2} \tag{28}$$

$$\dot{x}_5 = \left(C_2 \rho x_3^2 x_4 - \sqrt{\frac{2}{\rho_w}\left(P_{avg} + \rho_w g h\right)} A_C\right)\rho_w \tag{29}$$

where A_C is the exchange surface between the liquid metal bridge and the weld pool.

3.1.4 Drop Detachment

During the welding process liquid metal is continuously added to the drop at the tip of the electrode, and at some point, the drop is detached from the electrode. Detachment happens when the surface tension of the drop is no longer able to support the drop attached to the electrode. Typically, drop detachment has been modelled by two different models: The static force balance model (SFBM) [27], and a model based on the pinch instability theory (PIT) [29, Chapter 3]. The SFBM predicts drop detachment by comparing the surface tension of the drop with the external forces exerted on the drop. Thus, in the SFBM the dynamics of the drop is not taken into account when predicting the occurrence of drop detachment. However, in [30], dynamics are taken into account by including the inertia force in the SFBM. This results in a dynamic model, which in [30] is called the dynamic force balance model (DFBM). Both the SFBM and the DFBM predicts drop detachment by evaluating forces affecting the drop against the surface tension supporting the drop. However, the pinch instability theory (PIT) results in a different detachment criterion. Based on the pinch instability theory, a detachment criterion can be derived that does not rely on balance of axial forces, but rather relies on radial forces.

The surface tension force, Fs, is in, for example, [31] expressed as the surface tension force in the zone in which the neck of the drop starts to form. The neck starts to form close to the electrode, and thus, the radius of the electrode, re, is used to derive the expression for the surface tension force.

The SFBM does not include any dynamics of the pendant drop. Hence, detachment occurs if the maximal surface tension force, Fs, is exceeded by the total force FT, affecting the drop.

SFBM, detachment if $F_T > F_s$

3.1.5 Implementation of the hybrid model

The hybrid model for MIG/MAG welding has been implemented in the MATLAB language. The simulation of the continuous state is performed by the Runge–Kutta solver and the main difficulty was to handle with the switching between the two continuous states. The values of the state variables obtained at the end of one continuous state are used as initial conditions for the other continuous state.

The switching from the droplet growth state to the metal transfer state is achieved when the distance between the drop and the weld pool equals zero. This consists in checking whether the sum of the stick-out ls (state variable x_4) and the drop height, obtained thanks to its mass and geometry (truncated sphere, see Figure 3.4), equals the contact tip to work-piece distance *CT*.

The switching from the metal transfer state to the droplet growth state is controlled by the molten metal bridge radius (R). It is obtained from the volume of the bridge using once again its geometry (see Figure 3.7 ab).

Table. 3. 1- List of parameters used for simulation. [40]

Constant	Value
System resistance, R_S	4 mΩ
System inductance, L_s	0.14 mH
Wire radius, r_w	0.5 mm
Linear resistivity, ρ	$8.64 \times 10^{-14}\ \Omega/m$
Mass density, ρ_w	7800 Kg / m^3
Wire feed speed, S	2 or 3 m/min
Contact tip to work-piece distance, CT	15 mm
Permeability, μ_0	$1,25\times 10^{-6}$ H/m
Surface tension, γ	1.2 N/m
U_0	16 V
R_a	0.036 Ω
E_a	1500 V/m
Arc hanging angle, θ	50°
Constant for arc heating, C_1	2.96×10^{-14} m^3 / As
Constant for Joule heating, C_2	0.0537 m^3/V As

3.1.6 Simulation

The figures bellow illustrates the events that occur during a complete MIG/MAG welding cycle in short-arc mode with Uoc=22 V and S=3 m/min. On each Figure the diagram of the physical phenomenon is shown on the left and the plots of the voltage at the top and the current at the bottom on the right. (Figure. 3.8) shows the beginning of an arc time so the beginning of the growth of a drop of molten metal at the end of the consumable electrode (Figure. 3.9) shows the growth of this drop with the voltage that is constant during the arc time. (Figure. 3.10) shows the physical contact between the molten metal drop and the weld bath, at this time the voltage cancels and the current begin to rise. Finally (Figure. 3.11) shows the process of transferring the liquid metal from the bridge to the weld bath. On this last figure located just before the breaking of the bridge and the ignition of a new arc, one notes the sharp tightening of the neck of the bridge and therefore the approach of the validation of the condition of guard number 2.

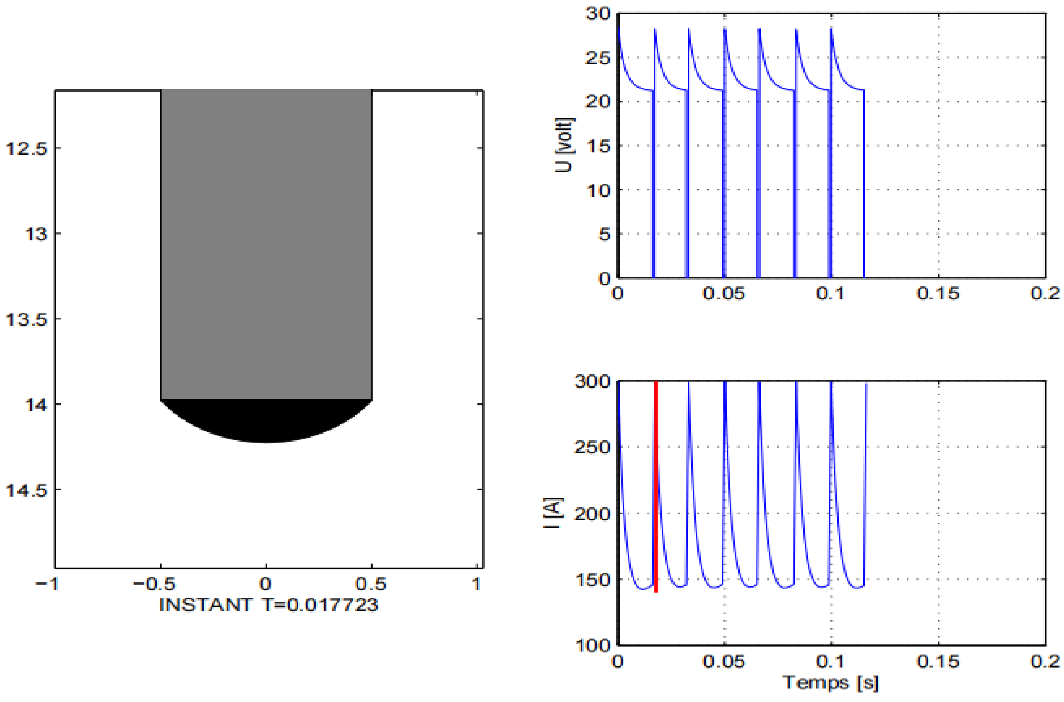

Figure. 3. 8 - Beginning of the arc. [21]

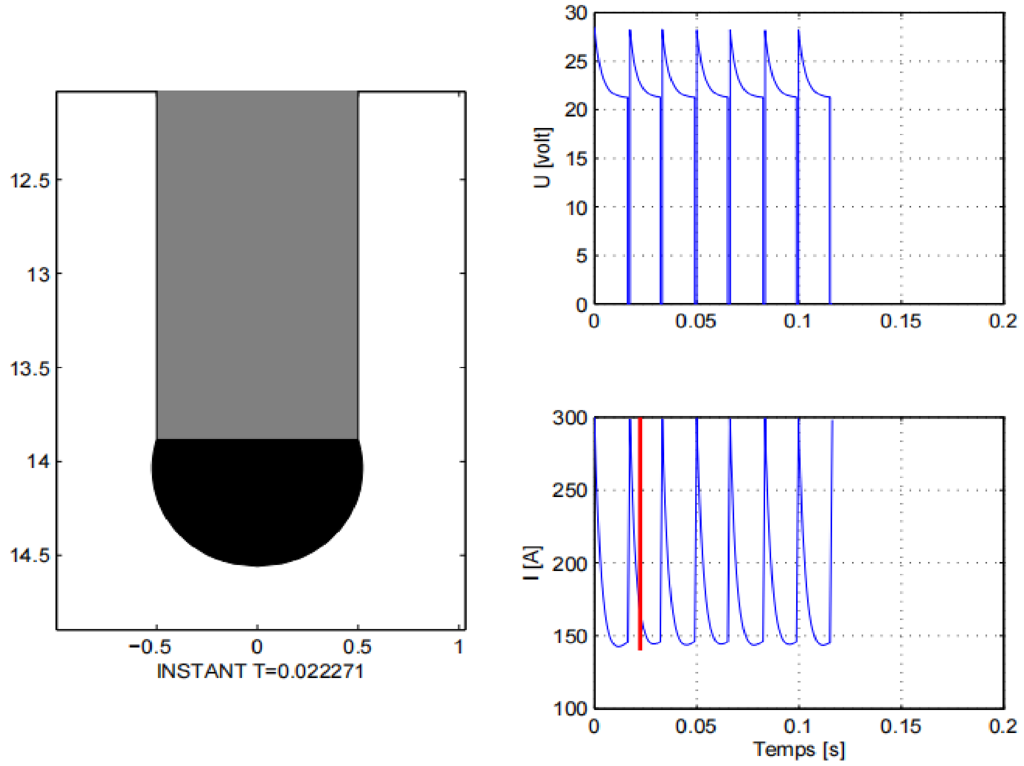

Figure.3. 9 - Droplet growth. [21]

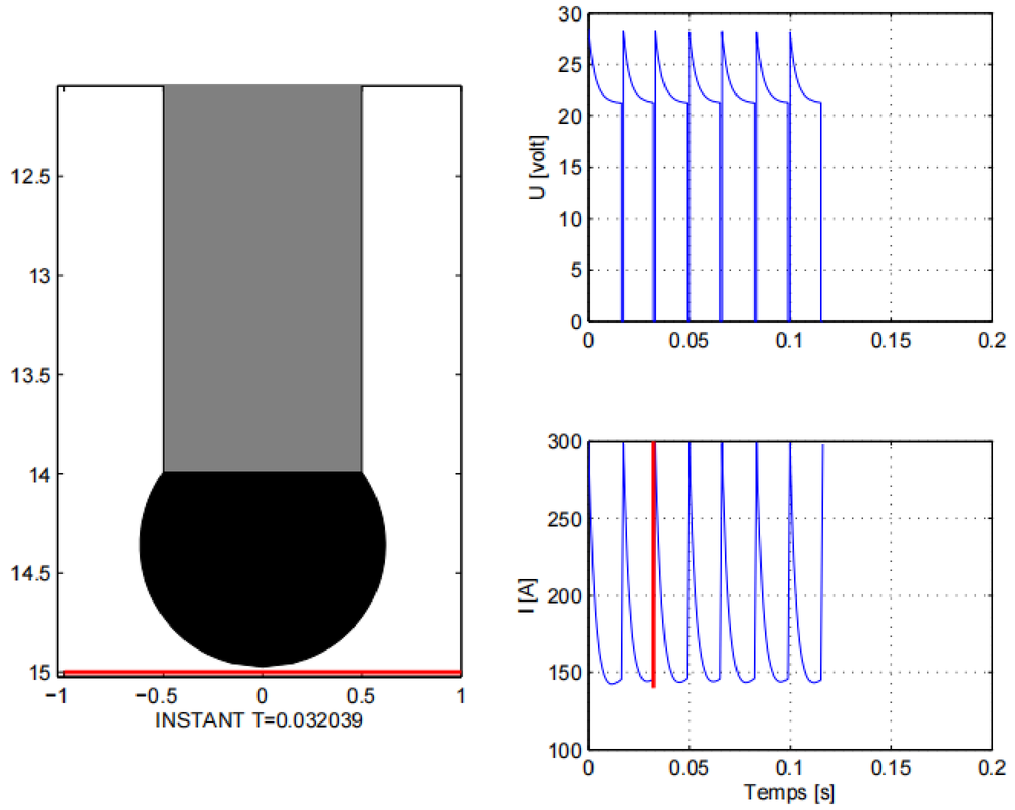

Figure. 3. 10 -Start of short circuit time. [21]

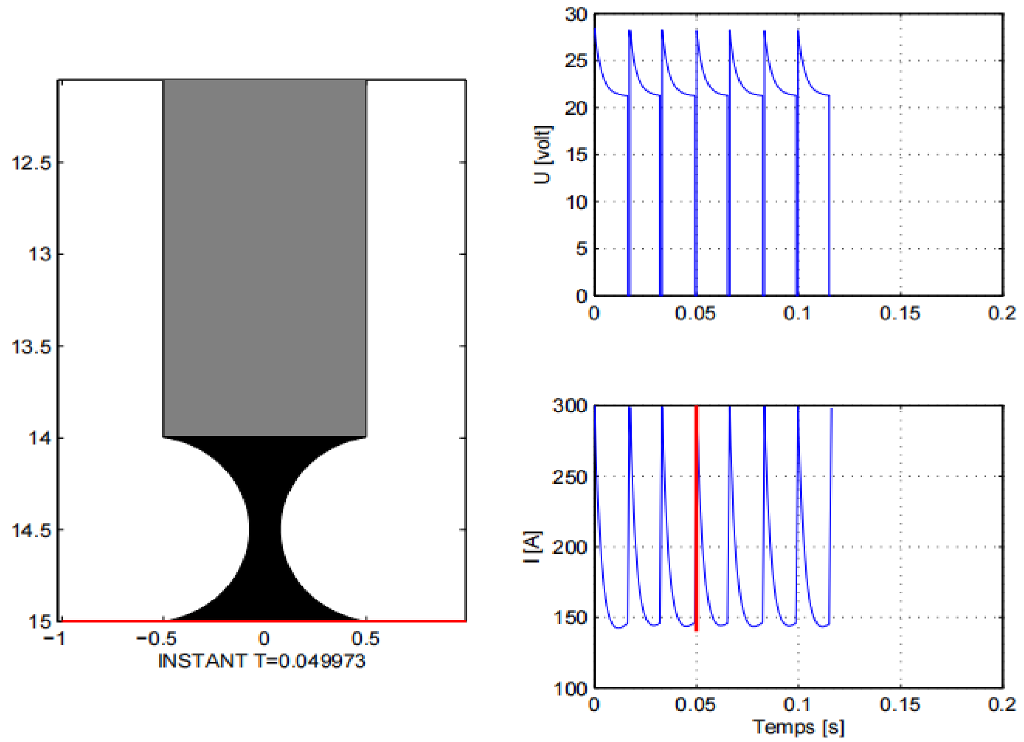

Figure. 3. 11 - Metal transfer. [21]

When the load changes to the output of a generator, the current takes a finite time to dye its new value. The circuit parameter responsible for this delay is inductance. The slope of current rise is determined by the inductance of the generator. Since the Lorentz force exerted at the end of the electrode on the molten metal increases with the current, the rate of increase of the amplitude of this force is also affected by the inductance of the circuit. For short arc welding, inductance can be added to control the slope of rising current to minimize projections. Increasing inductance will increase the duration of arc times and reduce the frequency of short circuits. The increase in arc time will produce a flatter and smoother weld seam. For each speed wire feed there is an inductance value to be preferred.

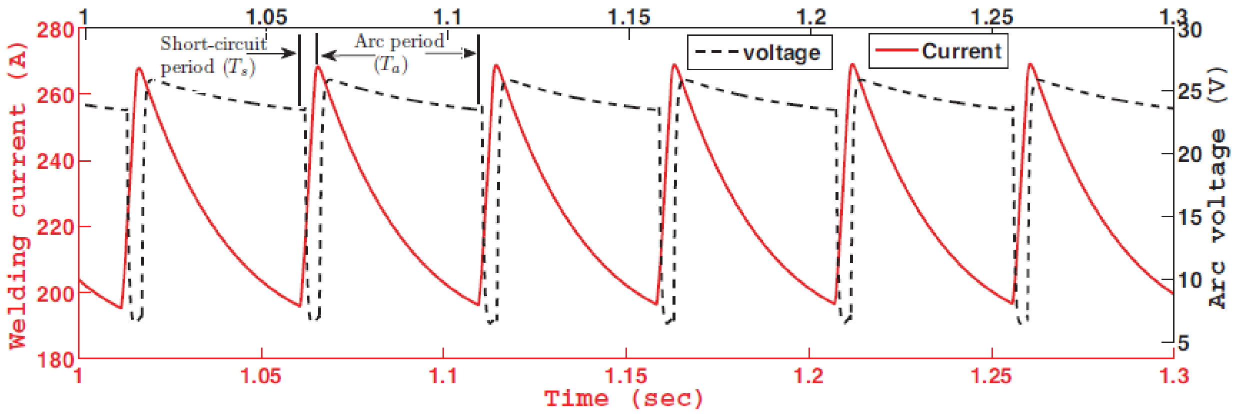

Figure.3. 12-Welding current and arc voltage in short-circuit transfer mode. [41]

Conclusion

In this chapter we presented the physical and the complete dynamic model for short arc MIG/MAG welding. The proposed hybrid models have two distinct continuous states: the arc state during which a, drop forms at the end of the electrode, and a short-circuit state when the liquid drop transfers to the weld, pool. the modifications were presented for short-circuit period, Conical bridge instead of spherical bridge shape for more simplification, Due to the complex physical interactions involved in the welding process, simplifications have been made to get a model accounting for the main physical contribution .

General conclusion

The study presented in this thesis represents a MIG/MAG electric arc welding application. Welding stations are used in varied and sometimes limited applications, but advances in electricity, chemistry and mechanics allow them today to be necessary in most industrial fields such as the construction of bridges, automobiles and welding of gas pipes, etc.

We have seen a history of welding with an electric arc, definition of a welding station as well as the characteristics of welding stations and the different types of welding.
And we saw the components of a welding station.

Then we saw the process principle of the GMAW and the arc and how the plasma generate, and the equipment of a MIG/MAG station (the power source, wire feeder, shielding gas supply, and welding gun,torches,control,.....etc) and some control parameters and we saw transfer modes (Short arc,Spray arc,Spray arc,Pulsed,arc,Rotating arc....etc) ,then we sit some Factors affecting on welding quality.

Finally, we presented the development and implementation of a hybrid model that describes the GMAW-S process, in short-circuit transfer mode. The model estimates the behavior of output parameters (X1–X5), from welding conditions given by input parameters. The approach of this model allows to identify two different stages involved in the phenomenon of short-circuit transfer; each of them has different physical and mathematical principles, which require proper study and treatment. The hybrid model was based on the continuous iteration of the two states, called arc period and short-circuit period, to roughly represent the mass transfer in GMAW-S welding.

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