CHAPTER -3

CO₂ Welding Process

Introduction

The CO₂ welding process is commonly used for welding carbon and low alloy steels. CO₂ being an active gas, this process is therefore known as MAG (Metal Active Gas) process. CO₂ produces deeper penetration than argon or argon mixtures, with slightly more spatter. CO₂ welding overcomes the restriction of using small lengths of electrodes as in manual metal arc welding (SMAW) and over comes the inability of the submerged arc welding process to weld in various positions. CO₂ is basically a semi automatic process, in which the arc length and the feeding of the electrode wire into the arc are automatically controlled. Since the welder has simply to position the welding gun at a correct angle and move it along the joint (seam) at a controlled travel speed, a comparatively lesser skilled welder is sufficient as compared to one needed in TIG and SMAW processes [51]. CO₂ welding may also be used in mechanized and automatic forms where productivity is to be increased and consistent quality in welded objects is demanded. Advantages of CO₂ welding are

(1) Higher welding speeds. (2) Better deep joint penetration with good bead contour and little tendency to undercut as compared to argon. (3) Sound welds deposits that can be made consistently. (4) Good mechanical properties of weld metal. (5) Comparatively lower associated costs as CO₂ is relatively inexpensive as compared to argon or argon carbon-di-oxide combinations and (6) Despite the oxygen present in CO₂, porosity is not a problem when a suitably deoxidized wire (electrode) and a reasonably short arc are used [09].
3.1 Major Components of CO₂ Welding Machine

The major components of CO₂ Welding are Power source, Wire Feeder unit, welding torch assembly, shielding gas cylinder and control panel unit. The GMAW system consists of a power source with constant voltage characteristics and wire feeder with a constant feed speed. With this system, the arc length tends to change. The wire electrode is continuously fed into the arc by the wire feed unit at a speed preset by the operator.

The wire feed rate can be varied generally from 1 m / min. to 20 m / min. For given wire material and diameter, the arc current is determined by the wire feed rate. The required voltage is selected by adjusting the voltage control knobs provided at the power source. A wire feeder pulls the wire electrode from a spool and pushes it through the welding gun at a required speed.

A wire feed unit contains a

(i) DC motor

(ii) speed reducing gear box,

(iii) 2/4 roll drive

(iv) gas solenoid valve and

(v) Potentiometer for adjustment of wire feed speed.

The CO₂ shielding gas is supplied in cylinder at high pressure (140 kg/cm²). Therefore a pressure regulator and flow meter are connected to reduce the pressure to required level (2kg/cm²) and to control the flow rate of the shielding gas from the cylinder. A gas hose connects the flow meter to the solenoid valve. The solenoid valve, when actuated releases the shielding gas into the torch assembly.
The major components are show in fig. 3.1.1 to 3.1.6

Fig.3.1.1 Wire Feed Unit of GMAW
Fig.3.1.2 Wire Control Unit of GMAW

Fig.3.1.3 Wire speed selector Unit
Fig.3.1.4 Welding Gun of GMAW

Fig.3.1.5 Wire Electrode
Fig.3.1.6 CO₂ Cylinder with Heater
Power Source

Normally a power source with constant voltage characteristics is used for CO$_2$ welding as it has the ability to self regulate the welding arc. The positive polarity of the power source is always connected to the consumable wire electrode and the negative polarity is connected to the work piece. Transformer-Rectifier (T-R sets) types which were in use earlier are now being fast replaced by more advanced inverter power sources. The Transformer-Rectifier sets used to contain a variable inductance in series to limit the rate of rise of the short circuit current and thereby reduce the spatter loss. However, the advents of the thyristor and transistor power sources have obviated the need for inductance control the rate of rise of current is now controlled electronically [33]. The constant voltage power source Volt-Amp. A characteristic is shown in fig. 3.1.7.

![Fig.3.1.7 Volt-Amp characteristics of Constant Voltage Power source](image-url)
The welding voltages in these modern power sources can be adjusted both from the panel as well as from a remote pendant. Power sources incorporate output characteristics designed to optimize the arc performance for a given welding process.

### 3.2 Modes of Metal Transfer

The various types of metal transfers are shown in fig. 3.2.1 and have been classified into groups. The basic modes by which metal is transferred from the electrode to the weld pool are short circuiting transfer and free flight transfer. The type of transfer mode is affected by a number of parameters in the welding process of which welding current (magnitude and type), electrode diameter, electrode composition, electrode extension and shielding gas are the most important. Filler metal can be transferred from the electrode to the work in two ways: 1) The electrode contacts the molten weld pool, thereby establishing a short circuit, which is known as short circuiting transfer (short circuiting arc welding) and 2) Discrete drops are moved across the arc gap under the influence of gravity or electromagnetic forces.

![Fig. 3.2.1 Modes of Metal Transfer of GMAW](image_url)
Drop transfer can be either globular or spray type. Shape, size, direction of drops (axial or nonaxial), and type of transfer are determined by a number of factors. In free flight transfer an arc is maintained in between the electrode and work piece and the metal is transferred across the arc in the form of droplets. The common free flight modes are globular and spray [10,11].

**Short Circuiting Transfer**

It has the lowest range of welding currents and electrode diameters and is mostly used for thin sections and bridging large joint gaps or out of position welding. During short circuit transfer, the welding current increases when the wire contacts the weld metal. The molten metal at the wire tip pinches off which forms the actual metal transfer. An arc is initiated which heats and melts the tip and feed the wire down to the next short circuit.

The open circuit voltage of the power source must be low enough so that the drop of the molten metal of the wire tip cannot transfer until it touches the base metal. The number of short circuits is in general in the order of one to two hundred per second.

**Globular Metal Transfer**

It is characterized by a drop size with a diameter greater than that of the electrode. The large drop is mainly acted on by the gravity thus limiting the transfer to the flat position.

The average current is in general slightly higher than for short circuit and the arc (and voltage) must be long enough to ensure detachment of the drop before it contacts the weld pool. The number of drops is low down to a few per second. In general, globular transfer is characterized by lack of fusion and inefficient penetration.
Axial Spray Transfer

It is characterized as a spatter-free, stable spray which is possible to obtain in argon-rich shielding gas. The current should be DC with positive electrode and current level above a transition current where transfer occurs consisting of very small drops which are formed and detached at a rate of several hundred per second. The transition current is dependent on many parameters including the electrode diameter and composition, the shielding gas composition and the electrode extension. The drops are accelerated by arc forces to velocities that overcome the effect of gravity. Hence the process can be used in any position.

3.3 Process Control Variables of CO₂ Welding

In arc welding process a number of welding parameters exist that can affect the size, shape, quality and consistency of the weld. The major parameters that affect the weld include, Weld current, Arc voltage and Travel speed. The sizes and types of electrodes for shielded metal arc welding define the arc voltage requirements and the amperage requirements.

The current is DC and the power source must be able to control the current level in order to respond to the complex variables of the welding process itself. As direct current electrodes perform well at low amperage, they are often selected for welding thin sheets. Most covered electrodes operate best with electrode positive (reverse polarity), which produces the deepest penetration.

Negative electrode operation might produce a higher melting rate. The secondary variables include the angle of the electrode to the work, the angle of the work itself, the thickness of the flux layer, and the arc length.
The process control variables that affect the weld penetration and the bead geometry are Current density, Arc voltage, Welding speed, Electrode efficiencies, deposition rate, electrode extension, electrode size and gas flow rate [10].

(i) Amperage: Amperage for a certain electrode will depend on the size and classification of the electrode. Even the type of joint and welding position must be considered. The process requires sufficient electric current to melt both the electrode and a proper amount of base metal.

Higher the current, deeper is the penetration. Using high amperage may cause problems such as excessive spatter, electrode overheating and cracking of weldments. Welding current increases as the electrode wire feed speed increases, or the electrode size increases.

Within the usable range, as current increases, bead size, deposition rate, and penetration, all increase. Welding current is selected according to electrode size, base metal or work piece thickness, type of metal transfer and electrode feed speed.

(ii) Arc Voltage: The arc voltage is varied within narrower limits than welding current. It has an influence on the bead width and shape. Higher voltages will cause the bead to be wider and flatter. Extremely high arc voltage should be avoided, since it can cause cracking. The low arc voltage produces a stiffer arc that improves penetration. If the voltage is too low, a very narrow bead will result. As arc length increases, arc voltages increases and in turn weld width increases but penetration reduces. Arc voltage is important because it also determines the type of metal transfer. Arc voltage to be used depends upon work piece thickness, type of joint, electrode size and its composition, shielding gas, and welding position, etc.
The arc voltage is kept low for achieving short circuit or dip transfer whereas its value is higher for globular type of metal transfer. To reach a precise value of arc voltage, one should carry out trial runs, because no specific values are appropriate for all applications.

Arc voltage is dependent on the position of the welding electrode, size, shield gas composition and the type of the metal transfer. At any specific value of the arc voltage, increase in voltage tends to flatten the bead and increase the fusion zone width. Reduction in voltage results in a narrower weld bead with the high crown and deeper penetration. Excessive high voltage may cause porosity, spatter and undercutting.

Welding voltage provides the heat to melt off the wire. Most power sources used for robotic GMAW are of the Constant-Voltage (CV) type.

This means the voltage can be set to a constant value and also can be set for the desired wire feed speed. Then the machine automatically adjusts amperage to melt the wire off appropriately to maintain the set voltage. In spray mode, the metal from the welding wire is transferred to the part via small droplets sprayed across the arc.

An electric arc is established so the wire itself never touches the part. The arc voltage is proportional to this arc length. Higher voltage causes the arc to lengthen, which-taken to an extreme-can diminish weld quality. A too-low voltage value can cause the arc length to become so short that the process reverts to the low-energy short-circuiting mode [29].

**Factors to be considered for selection of arc voltage**

Factors to be considered for selection of arc voltage are current, mode of metal transfer, shielding gas and Stand-off-Distance [SOD is shown in fig. 3.4.1]
Empirical relationships:

\[ V = 14 + (0.04 \times I) \] For short arc

\[ V = 16 + (0.04 \times I) \] For spray arc

Standoff Distance [SOD] \( I < 180 \) A, SOD \( \approx \) 08 to 12 mm

Standoff Distance [SOD] \( I > 180 \) A, SOD \( \approx \) 14 to 18 mm

(iii) Travel Speed: The speed of the electrode when it travels along the joint has a direct influence on bead shape, depth of fusion, cosmetic appearance and heat input into the base metal. Faster travel speeds produce narrower beads that have less penetration.

This can be an advantage for sheet metal welding where small beads and minimum penetration are required. Travel speed also affects heat input, which in turn influences the metallurgical structure of the weld metal. The cooling rate increases or decreases proportionately with the travel speed. Also, the heat-affected zone will increase in size and the cooling rate decreases.

If travel speeds are too high, there is a tendency for undercut and porosity, since the weld freezes quicker. With all the parameters held constant, maximum penetration occurs only at a particular welding speed. When the welding speed is decreased beyond this, there is a drastic decrease in the penetration.

If the welding speed is increased to higher than the critical welding speed, then the penetration decreases and it may lead to undercutting.

(iv) Electrode Efficiency: Electrode efficiency is a term that is applied to the percentage of electrode that actually ends up in the weld deposit. Spatter levels, smoke, and slag formers affect the electrode efficiency. Globular transfer is associated with higher spatter levels that profoundly impact electrode efficiency. The efficiency of globular transfer can
vary from 85 to 88%, when shielded with 100% CO₂. The electrode efficiency is related
to the amount of electrode that actually ends up in the weld.

(v) **Arc Length:** Arc length refers to the distance from the molten tip of the electrode
core to the molten weld pool. Generally, arc length increases as the size of the electrode
and amperage increase. Limiting arc length to the diameter of the core rod of the
electrode is a good guideline.

(vi) **Contact Tip to Work Distance (CTWD):** Contact Tip to Work Distance (CTWD)
is a term that lends itself well to the electrode extension for mechanized or robotic
welding applications. It is measured from the end of the contact tip to the work piece.
In a Constant Voltage (CV) system the electrode extension or the CTWD acts as a
resistor. Varying the length of the electrode affects the current applied to the arc:
(a) Increasing electrode extension increases the resistance to the flow of current in the
electrode, and the current in the arc is decreased and
(b) decreasing the electrode extension decreases the resistance to the flow of current in
the electrode, and the current in the arc increases. Because the current can vary with an
increase or decrease in extension, the consistency of the extension is important to the
consistency of weld penetration. It is important to maintain a very steady hand during
semiautomatic welding.

(vii) **Electrode position:** The electrode may be perpendicular to the workpiece, sloping
in the direction of welding (i.e., forehand technique) or inclining opposite to the direction
of welding (i.e., backhand technique). The electrode (or gun) angle is usually maintained
within 10-20° on either side of the vertical/perpendicular position. Electrode position
affects depth of penetration and quality of the weld.
(viii) **Electrode size:** The choice of an electrode strongly influences the mechanical properties of the weld, making it a key factor in weld quality. In general, it is desirable that the welded metal have mechanical properties similar to those of the base material, and that there be no discontinuities, such as porosity, within the weld. To achieve these goals in different materials using different GMAW variations, a wide variety of electrodes exist. Deoxidizing metals such as silicon, manganese, titanium, and aluminum in small percentages to help prevent oxygen porosity, and some contain metals such as titanium and zirconium to avoid nitrogen porosity.

(ix) **Storage & Supply of CO₂:** The CO₂ shielding gas is supplied in cylinder at high pressure (140 kg/cm²), therefore a pressure regulator and flow meter are connected to reduce the pressure to required level (2kg/cm²) and to control the flow rate of the shielding gas from the cylinder. A gas hose connects the flow meter to the solenoid valve. The solenoid valve, when actuated releases the shielding gas into the torch assembly. When the cylinder is full, nearly 90% of the volume filled is CO₂ liquid and remaining is filled with gas.

The CO₂ gas and liquid phases are in equilibrium pressure. CO₂ cylinders must also be fitted with a heater near the gas regulator to avoid freezing around the regulator. The quality of the CO₂ gas used for welding must conform to BS4105:1967 or IS 307:1996.

As per the above standard the moisture in the CO₂ gas should be less than 10 ppm. Gas flow should be adequate to given necessary coverage filler wire tip and the weld pool.

Gas flow setting Outlet Pressure: 1.5 to 2.0 kg/cm². Flow rate: 15 to 20 L/m.
3.4 Welding Defects and their Causes

The importance of weld quality is increasingly felt in fabrication of sophisticated products using higher strength material combined with critical design consideration. The quality of a weld is a function of many factors: selecting satisfactory welding parameters, maintaining the same parameters in production, monitoring internal and external changes in the process and controlled manually [2].

Defects in weldments can be classified as follows:

(i) Defects involving Inadequate Bonding are Lack of fusion and Incomplete fusion
(ii) Foreign Inclusions are Slag, Oxide films and Tungsten,
(iii) Geometric Defects are Under cut, Excessive reinforcement, Burn through or excessive penetration, Distortion and Improper weld profile and
(iv) Metallurgical Defects are Cracks, Gas porosity, Arc strikes, Embrittlement and Structural notches. The reasons for defects are generally, lack of know-how and experience, welding process characteristics, base metal composition, defective welding filler metals, joint design and welding environment.

To reduce the dependence on manual inspection, in this work a welding signature analyzer is developed and the following defects are identified. Non destructive testing of weld joints comprises several methods, i.e. Visual Testing (VT), Penetrant Testing (PT), Magnetic particle Testing (MT), Radiographic Testing (RT) and Ultrasonic Testing (UT). The Visual Testing and Penetrant Testing methods are employed for the detection of surface imperfections or those reaching to the surface (cracks or lack of fusion). The Magnetic Particle Testing (MPT) methods are suitable for the detection of surface imperfections and UT and RT methods are employed for testing the interior of a weld.
(i) **Lack of Fusion:** LoF defects are planar defects in welds occurring when a parent metal cannot melt properly and, consequently, the filler material melted attaches itself to a previous weld bead or side walls because it can melt the parent material only partly, which means there is no mixing of the parent metal and the filler material. Lack of fusion is a hidden weld defect. The reasons for lack of fusion are improper manipulation of electrodes, incorrect position of electrodes, low welding current, too rapid arc advance, improper joint fit up and improper edge cleaning of slag after flame cutting.

(ii) **Incomplete Penetration:** A discontinuity characterized by unpenetrated and unfused area in a joint occurs when weld metal does not extend through the thickness of the joint. In CO2 welding Lack of Penetration (LoP) may be caused by improper joint preparation, improper welding parameters particularly current, incorrect electrode size, incorrect polarity where DC is used, slow travel speed and incorrect torch angle. Incomplete penetration can result from insufficient welding heat, improper joint, design, and improper lateral control of the welding arc.

(iii) **Burn through or Excessive Penetration:** The term burn through is described as a nonstandard term for excessive melt through or a hole. In the same standard the definition of excessive metal through is given as a hole through the weld metal usually occurring in the first pass [16]. The causes of burn through are improper manipulation of electrodes, high welding current, improper travel speed and incorrect torch angle.

(iv) **Lack of Shielding Gas:** The main causes of lack of shielding gas are an excessive wind in the welding area; this can blow away the gas shield, severely clogged gas nozzle, regulator failure, blockage in the nozzle and inadequate shielding gas, damages in gas supply system or empty cylinder.
3.5 Conclusion

In this chapter, CO₂ Process, major components, V-I characteristics of power source, mode of metal transfer, process variables of CO₂, and static and dynamic modeling of GMAW are explained. Welding defects and their main causes are also discussed.