Section 10

Introduction to Welding Processes

1 General

Common characteristics of the four main arc welding processes, MMA, TIG, MIG/MAG and SAW are:

- An arc is created when an electrical discharge occurs across the gap between an electrode and parent metal.
- The discharge causes a spark to form which causes the surrounding gas to ionise.
- The ionised gas enables a current to flow across the gap between electrode and base metal thereby creating an arc.
- The arc generates heat for fusion of the base metal.
- With the exception of TIG welding, the heat generated by the arc also causes the electrode surface to melt and molten droplets can transfer to the weld pool to form a weld bead or run.
- Heat input to the fusion zone depends on the voltage, arc current and welding/travel speed.

2 Productivity

With most welding processes, welding in the PA (flat or 1G) position will result in the greatest weld metal deposition rate and therefore highest productivity.

For consumable electrode welding processes, the rate of transfer of molten metal to the weld pool is directly related to the welding current density (the ratio of the current to the diameter of the electrode).

For TIG welding, the higher the current, the more energy there is for fusion and thus the higher the rate at which the filler wire can be added to the weld pool.

3 Heat Input

Arc energy is the amount of heat generated in the welding arc per unit length of weld, and is usually expressed in kilojoules per millimetre length of weld (kJ/mm) Heat input (HI) for arc welding is calculated from the following formula:

$$\text{Arc energy (kJ/mm)} = \frac{\text{Volts} \times \text{Amps}}{\text{Travel speed (mm/sec)} \times 1000}$$

Heat input is the energy supplied by the welding arc to the work piece and is expressed in terms of arc energy x *thermal efficiency factor*.

The *thermal efficiency factor* is the ratio of heat energy introduced into the welding arc to the electrical energy consumed by the arc.

Heat input values into the weld for various processes can be calculated from the arc energy by multiplying by the following *thermal efficiency factors*;

SAW (wire electrode)	1.0
MMA (covered electrode)	0.8
MIG/MAG	0.8
FCAW (with or without gas shield)	0.8
TIG	0.6
Plasma	0.6

Example

A weld is made using the MAG welding process and the following welding conditions were recorded;

Volts: 24
Amps: 240
Travel speed: 300mm per minute

$$\text{Arc energy (kJ/mm)} = \frac{\text{Volts} \times \text{Amps}}{\text{Travel speed (mm/sec)} \times 1000}$$

$$= \frac{24 \times 240 \times 60}{300 \times 1000}$$

$$= \frac{345{,}600}{300{,}000}$$

$$\text{Arc energy} = 1.152 \text{ or } 1.2\text{kJ/mm}$$

$$\text{HI (kJ/mm)} = \frac{\text{Volts} \times \text{Amps} \times 60 \times k}{\text{Travel speed (mm/sec)} \times 1000}$$

$$= \frac{24 \times 240 \times 60 \times 0.8}{300 \times 1000}$$

$$= \frac{276{,}480}{300{,}000}$$

$$= 9.9216\text{kJ/mm}$$

Units for formula: Travel speed in mm/sec
Heat input is given in kJ/mm

Heat input is mainly influenced by the travel speed.

Welding position and the process have a major influence on the travel speed that can be used.

For manual and semi-automatic welding the following are general principles:

- Vertical-up progression tends to give the highest heat input because there is a need to weave to get suitable profile and the forward travel speed is relatively slow.
- Vertical-down welding tends to give the lowest heat input because of the fast travel speed that can be used.
- Horizontal-vertical welding is a relatively low heat input welding position because the welder cannot weave in this position.
- Overhead welding tends to give low heat input because of the need to use low current and relatively fast travel speed.
- Welding in the flat position (downhand) can be a low or high heat input position because the welder has more flexibility about the travel speed that can be used.
- Of the arc welding processes, SAW has potential to give the highest heat input and the highest deposition rates and TIG and MIG/MAG can produce very low heat input.
- Typical heat input values for controlled heat input welding will tend to be in the range ~1.0 to ~3.5kJ/mm.

4 Welding Parameters

Arc voltage

Arc voltage is related to the arc length. For processes where the arc voltage is controlled by the power source (SAW, MIG/MAG and FCAW) and can be varied independently from the current, the voltage setting will affect the profile of the weld.

As welding current is raised, the voltage also needs to be raised to spread the weld metal and produce a wider and flatter deposit.
For MIG/MAG, arc voltage has a major influence on droplet transfer across the arc.

Welding current

Welding current has a major influence on the depth of fusion/penetration into the base metal and adjacent weld runs.

As a general rule, the higher the current the greater the depth of penetration.

Penetration depth affects dilution of the weld deposit by the parent metal and it is particularly important to control this when dissimilar metals are joined.

Polarity

Polarity determines whether most of the arc energy (the heat) is concentrated at the electrode surface or at the surface of the parent material.

The location of the heat with respect to polarity is not the same for all processes and the effects/options/benefits for each of the main arc welding processes are summarised below:

Process	Polarity		
	DC +ve	DC -ve	AC
MMA	Best penetration	Less penetration but higher deposition rate (used for root passes and weld overlaying)	Not suitable for some electrodes. Minimises arc blow.
TIG	Rarely used due to tungsten overheating	Used for all metals – except Al/Al alloys (and Mg/Mg alloys)	Required for Al/Al alloys to break-up the refractory oxide film
GMAW solid wires (MIG/MAG)	Used for all metals and virtually all situations	Rarely used	Not used
FCAW/MCAW gas-shielded and self-shielded cored wires	Most common	Some positional basic fluxed wires are designed to run on -ve; some metal cored wires may also be used on -ve particularly for positional welding	Not used
SAW	Best penetration	Less penetration but higher deposition rate (used for root passes and overlaying)	Used to avoid arc blow – particularly for multi-electrode systems

5 Power Source Characteristics

In order to strike an arc, a relatively high voltage is required to generate a spark between the electrode and base metal. This is known as the open circuit voltage (OCV) and it is typically in the range from ~50 to ~90V.

Once an arc has been struck and stabilised, there is a relationship between the arc voltage and the current flowing through the welding circuit that depends on the electrical characteristics of the power source.

This relationship is known as the power source static characteristic and power sources are manufactured to give a **constant current** or a **constant voltage** characteristic.

5.1 Constant current power source

This is the preferred type of power source for manual welding (MMA and manual TIG).

The Volt-Amp relationship for a constant current power source is shown in Figure 1. This shows the 'no current' position (the OCV) and from this point there are arc voltage/current curves that depend for the various current settings on the power source.

For manual welding (MMA and manual TIG) the welder sets the required current on the power source, but arc voltage is controlled by the arc length that the welder uses.

A welder has to work within a fairly narrow range of arc length for a particular current setting – if it is too long the arc will extinguish and if it is too short the electrode may stub into the weld pool and the arc will be extinguished.

For the operating principle of this type of power source see Figure 1.

The welder tries to hold a fairly constant arc length (B in Figure 1) for the current (Y) that has been set. However, he cannot keep the arc length constant and it will vary over a small working range (A to C in Figure 1) due to normal hand movement during welding.

The power source is designed to ensure that these small changes in arc voltage during normal welding will give only small changes in current (X to Z). Thus, the current can be considered to be essentially constant and this ensures that the welder is able to maintain control of fusion.

The drooping shape of the Volt-Amp curves has led to constant current power sources sometimes being referred to as having a '**drooping' characteristic**.

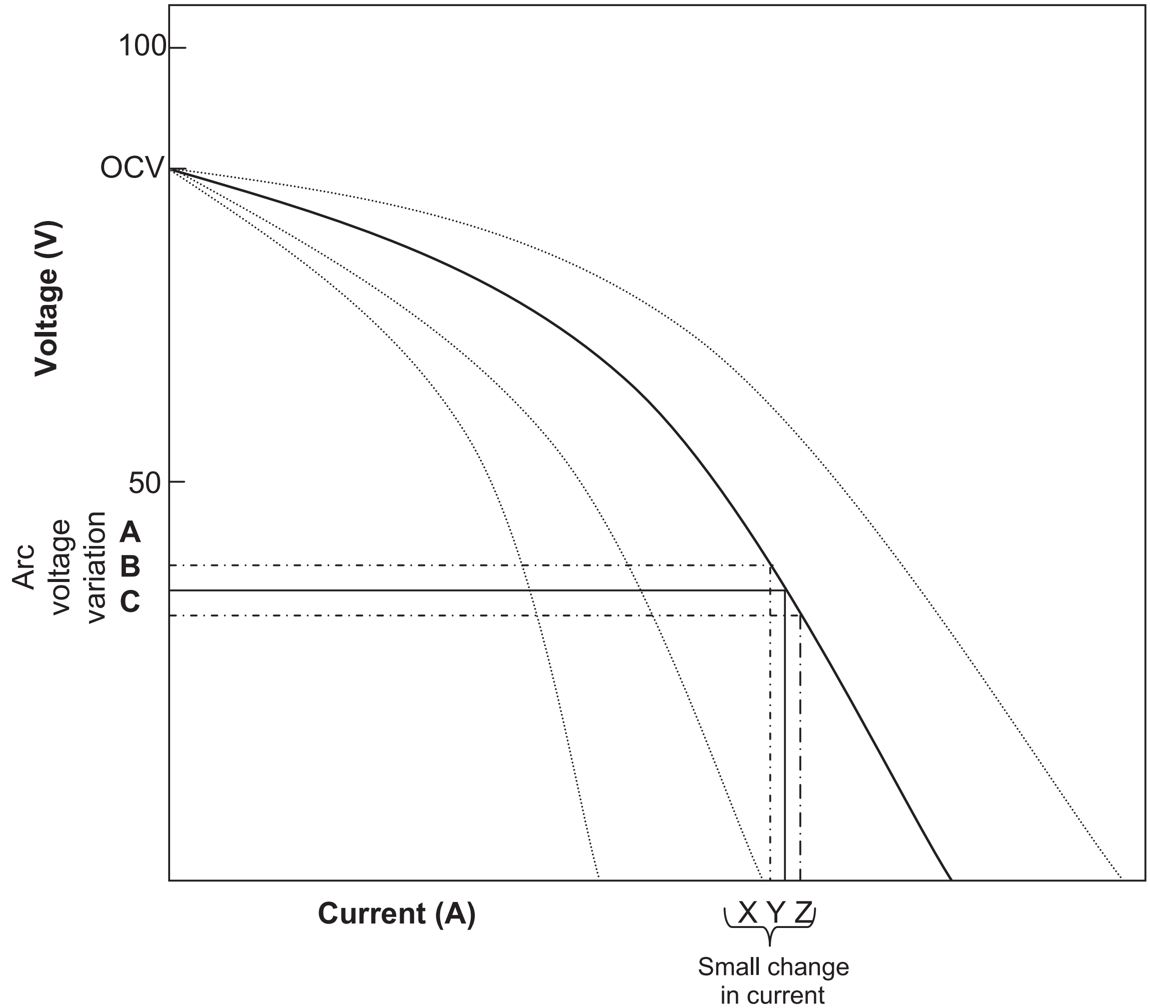

Figure 1 *Typical Volt-Amp curves for a constant current power source.*

5.2 Constant voltage power source

This is the preferred type of power source for welding processes that have a wire feeder (MIG/MAG, FCAW and SAW).

Wire feed speed and current are directly related so that as the current is increased, the feed speed increases and there is a corresponding increase in the burn-off rate to maintain the arc length/ voltage.

The operating principle of this type of power source is shown in Figure 2

A welder sets the voltage B and the current Y on the power source. If the arc length is decreased to C (due to a variation in weld profile or as the welder's hand moves up and down during semi-automatic welding) there will be a momentary increase in welding current to Z. The higher current Z, gives a higher burn-off rate and this brings the arc length (and arc voltage) back to the pre-set value.

Similarly, if the arc length increases the current quickly falls to X and the burn-off rate is reduced so that the arc length is brought back to the pre-set level B.

Thus, although the arc voltage does vary a little during welding the changes in current that restore the voltage to the pre-set value happen extremely quickly so that the voltage can be considered to remain constant.

The straight-line relationship between voltage and current and the relatively small gradient is the reason why this type of power source is often referred to as having a **'flat characteristic'**.

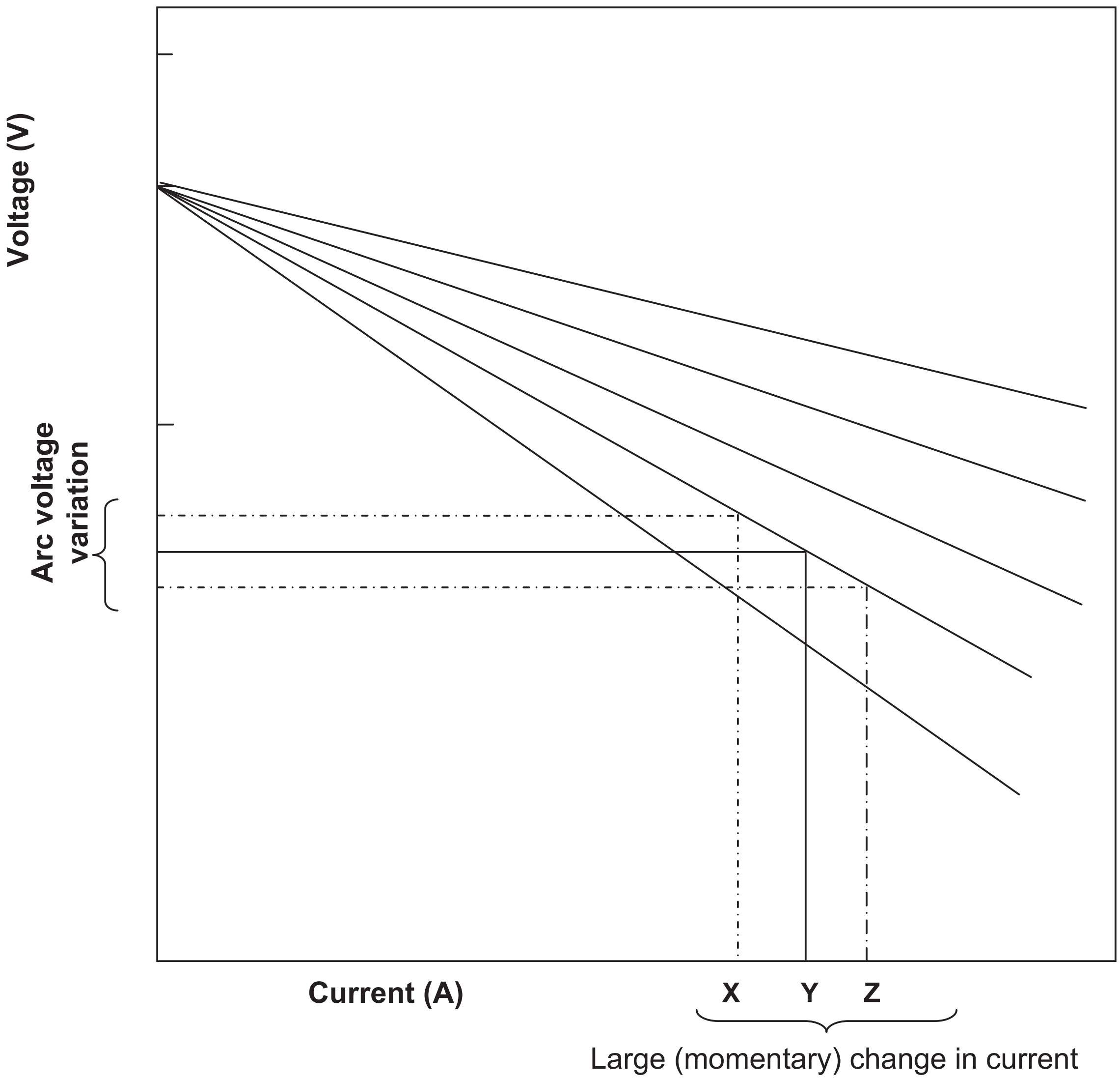

Figure 2 *Typical Volt-Amp curves for a constant voltage power source.*