5. Arc Welding Processes

5.1. Introduction

Nearly all structural steel welding is undertaken using arc-welding processes. The important welding processes for steel structures; MMAW, SAW, FCAW, GMAW, ASW and GTAW are described in detail in this publication.

5.2. Arc Physics

An arc is a column of ionised gas (plasma) created by the passage of an electric current between two electrodes. The electrodes have to be quite close together (up to 6mm), and the gas in the space between them has to readily ionise for a stable arc to be created. Unstable arcs extinguish easily.

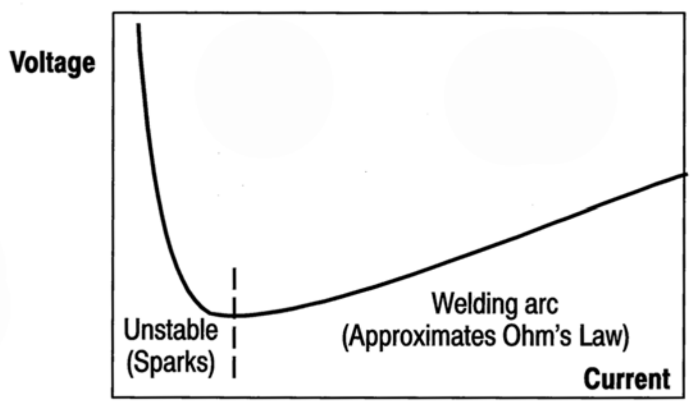

Figure 23 Arc Characteristic

Although the arc can be considered an electrical resistance or impedance, it only approximates Ohm's law at higher currents. At low current, arc voltage increases as current is reduced, and this is unstable. Welding arcs have a power of the order of 0.6 to 36 kW. This energy creates a column of hot plasma (ionised gas), which is quite stiff because of electromagnetic forces. It is these electromagnetic forces which cause transfer of material from the electrode to the workpiece, mould and shape the weld pool, and even in some cases hold the molten weld pool in place. A typical temperature of 6,000°C is generated in the arc. It is characterised in terms of its properties: stability, degree of ionisation, and stiffness. The main factors influencing arc properties are shape of the anode and cathode, emissivity of the cathode, composition of the ionised gas / vapour mixture and electrode material.

It is usual for the arc to be moved along the joint at a steady travel speed. The arc must generate enough energy to fuse the base and filler material. If it is moved too quickly, fusion does not occur. Even if fusion occurs, the weld bead may cool rapidly and crack. If it is moved too slowly the weld pool is large and may be uncontrollable, or other metallurgical problems may occur. In structural steel, excessively high arc energy may produce welds with low ductility and toughness. In quenched and tempered steel, weld strength may be low.

The arc energy, E is the arc power divided by the travel speed expressed in units of energy per unit length (kJ/mm). The arc energy, E is related to the welding current, A and arc voltage, V, and travel speed, S in mm/min by Equation 5.

$$E = 0.06 \times \frac{AV}{S} \quad \text{Equation 5}$$

Some of the energy is lost before it enters the weld pool, and this should be taken into account, but it rarely is. It is of relevance when comparing the heat inputs (HI) for different processes, particularly when looking at the effect of heat input on HAZ properties. The energy efficiency factor (η) can vary from 30 to 100% depending on process and is about 80% for MMAW.

$$HI = E \times \eta \quad \text{Equation 6}$$

Note heat input or arc energy is determined for individual weld runs. Adding heat input values for each individual run has no significance. Heat input is only one of the factors affecting distortion and residual stress.

5.3. Arc Welding Power Sources

Welding arcs typically operate at voltages of 10 to 80 volts for safety, but require high currents (50 to 2000 amps) in order to have sufficient power. Both alternating and direct current are used. The main requirements for a welding power source are the ability to supply power in the form it is required, and the ability to adjust the current and sometimes the voltage.

The simplest factor determining the type of power source required is its rated current output, which is determined by the capacity of the machine components. This determines the maximum size of electrode that can be welded and the deposition rate. High current machines are more productive, but sometimes at the expense of sensitivity of control, particularly at low current. Power source capacity is rated at a particular duty cycle, which is the arc-on time in a defined period, which is usually 10 minutes. A machine rated at 650A at a 40% duty cycle is used at this current for no more than 4 minutes in any 10-minute period. The duty cycle (T) and current (I) are related by Equation 7.

$$I_1 = I\sqrt{\frac{T}{T_1}} \quad \text{Equation 7}$$

Thus if the above rated power source is to be used at 100% duty cycle, the current should not exceed 410A.

Many different designs of welding power sources are available. Which type is best depends on a number of factors, including the range of welding processes and procedures it is required to undertake, capital cost and efficiency. Welding machines come with a variety of additional features. Machines for processes such as GTAW, GMAW and SAW require ancillary features, such as on-off contactors, gas solenoid valves, and ancillary power for wire feed motors.

The lowest cost welding power sources are simple transformers that have a tapped secondary coil for current adjustment. These machines only supply ac, current adjustment is in steps, and they are for MMAW only. Selecting different tapped positions varies both secondary impedance and open circuit voltage. These machines are for the minor maintenance, home or hobby welder.

More sophisticated ac welding machines need to have stepless adjustment. There are several different designs. Movable coil or movable shunt transformers allow adjustment by mechanical mechanisms. The addition of an adjustable reactor (inductance) in series in the secondary circuit also allows current to have stepless current adjustment. Moving the core of the reactor, or altering its impedance electrically, using a dc current (saturable reactor) is used to adjust current.

The lowest cost dc machines use a simple single-phase transformer with a single silicon diode as a rectifier. More often, a bridge rectifier is used to obtain full wave rectification. Adjustable reactors allow current control. These transformer-rectifiers can often supply both ac and dc. The thyristor is now replacing the adjustable reactor for control. It is also useful as an on-off contactor.

The rectified output from a single-phase transformer is not particularly smooth, but is satisfactory for many applications. In addition, these machines use the mains power in an unbalanced way, taking a high current from one or two of the supply phases, but leaving the other with no load. Three phase transformer-rectifiers provide a smoother output, are more efficient and take the same current from each phase of the supply. Generally the smoother the current, the easier striking and arc stability, leading to fewer welding defects. The thyristor controlled 3-phase transformer-rectifier provides smooth direct current efficiently and at a reasonable capital cost. However, it cannot supply ac.

The standard welding transformer or dc generator is a heavy device, weighing between 50kg and 900kg depending on its current output. In recent times the inverter welder has appeared. This power source rectifies the incoming supply electricity to dc, which is then converted to single-phase ac at 1 to 50 kHz by an inverter. The output from the inverter is transformed to welding voltage and rectified. The advantage of transforming high frequency is that smaller and lighter transformers are used, which means these welding machines are much more portable. They have a weight saving of up to 75% over conventional machines. These machines provide a crisp arc action because switching occurs at a much higher frequency. Their efficiency is much better, and they provide smooth, stable dc. There is a trend for the more sophisticated machines to use three-phase inverters. The small single-phase inverter machine, the size of a house brick is becoming popular for maintenance work. These can be carried on the shoulder, and operate from a 10 amp 250 V socket, but are capable of welding 3.2mm covered electrodes. Inverter machines capable of supplying square wave ac are now available.

Some welding machines are engine-driven or mains-powered dc generators that provide a smooth controllable current. Mains-powered DC generators are expensive, but are traditionally used where smoothest current is considered necessary, especially for vertical down stovepipe welding. They are now used much less, as the thyristor controlled or inverter machines are capable of providing comparable smoothness at lower cost, and with less noise. Engine-driven dc generators are popular for lower current MMAW applications. The larger engine-driven machines are usually alternators. As well as providing both alternating and direct welding current, these machines provide useful auxiliary ac power for other electrical equipment, such as power tools and lighting.

Welding machines should conform to AS 1966 or AS 3195 as appropriate. AS 1966 covers the majority of welding machines, those intended for industrial environments. AS 3195 is intended for machines that are connected to the 240-volt supply and used by the home handyman. Both standards are currently under review and are likely to be replaced by one based upon IEC 60974-1, an international standard.

It is important that welding machines are used which are suitable for the intended environment. All welding machines are constructed for use in the average fabrication workshop, but some are inadequately protected for use outdoors or in other hazardous environments. The current version of AS 1966 does not address this matter, but the new standard will ensure machines are marked with the degree of protection.

5.3.1. Welding Machine Current-voltage Characteristic

Welding machines have an output characteristic that must be matched to the welding process.

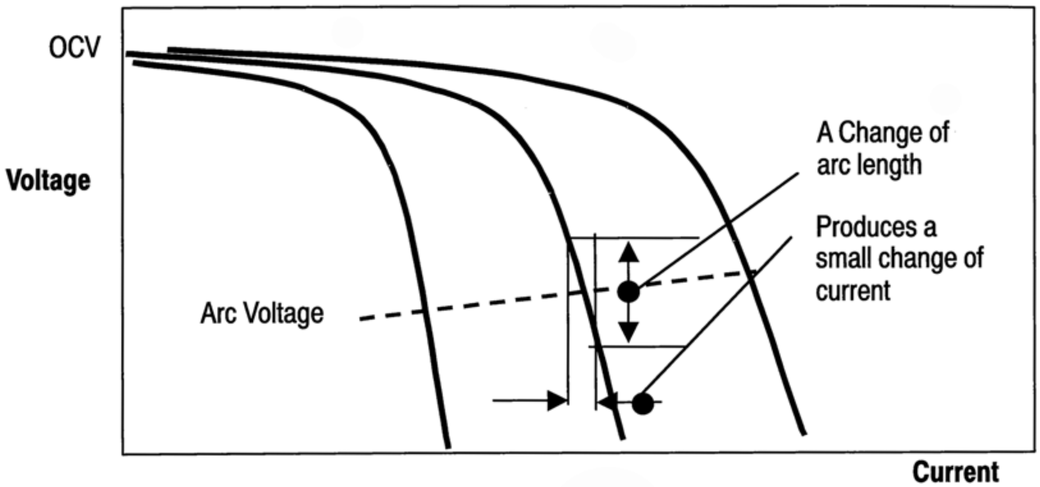

Figure 24 Drooping Characteristic Transformer (CC)

Welding machines for processes that have a non-consumable electrode, or which only consume the electrode slowly have a constant current, CC or drooping characteristic. As the current drawn is increased, the output voltage falls rapidly. This limits the current in case of a short circuit, and inadvertent changes in the arc length will give little variation in the arc power.

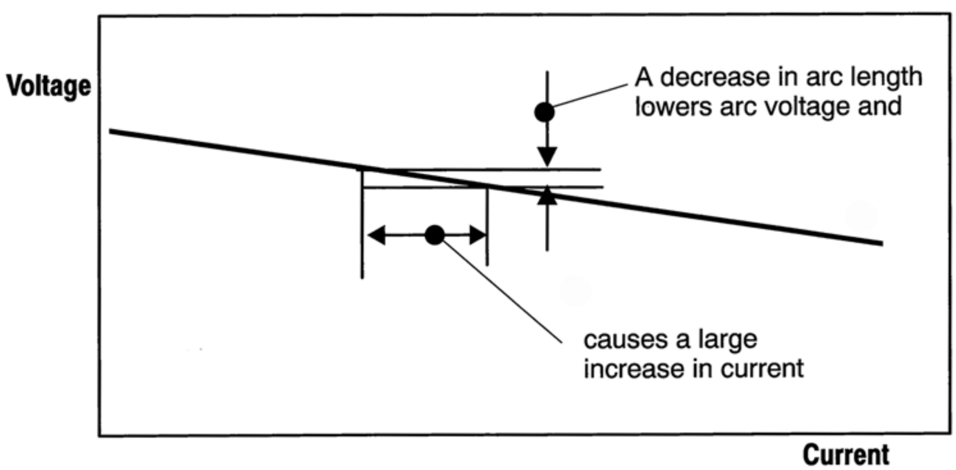

Figure 25 Constant Voltage (CV) Transformer

Welding machines for processes with a consumable electrode of small diameter (fed at high speed) usually use flat characteristic or constant voltage (CV) welding machine. Some processes (GMAW, FCAW or SAW with small wires) are characterised by the welding current being regulated by the wire feed speed. The wire feed rate is considerably faster than involuntary hand movement. If the torch-work distance is shortened, the

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