Fundamentals of welding arc

This chapter presents fundamentals of welding arc, mechanisms of electron emission, different zones in welding arc, electrical aspects related with welding arc and their significance in welding.
Keywords: Welding arc, electron emission, thermo-ionic emission, field emission, cathode and anode spot, arc power

5.1 Introduction

A welding arc is an electric discharge that develops primarily due to flow of current from cathode to anode. Flow of current through the gap between electrode and work piece needs column of charged particles for having reasonably good electrical-conductivity. These charged particles are generated by various mechanisms such as thermal emission, field emission secondary emission etc. Density of charged particles in gap governs the electrical conductivity of gaseous column. In an electric arc, electrons released from cathode (due to electric field or thermo-ionic emission) are accelerated towards the anode because of potential difference between work piece and electrode. These high velocity electrons moving from cathode toward anode collide with gaseous molecules and decompose them into charged particles i.e. electrons and ions. These charged particles move towards electrode and work piece as per polarity and form a part of welding current. Ion current becomes only about 1% of electron current as ions become heavier than the electrons so they move slowly. Eventually electrons merge into anode. Arc gap between electrode and work piece acts as pure resistance load. Heat generated in a welding arc depends on arc voltage and welding current.

5.2 Emission of Free electrons

Free electrons and charged particles are needed between the electrode and work for initiating the arc and their maintenance. Ease of emitting electrons by a material assessed on the basis of two parameters work function and ionization potential. Emission of electrons from the cathode metal depends on the work function. The work function is the energy (ev or J) required to get one electron released from the surface of material. Ionization potential is another measure of ability of a metal to emit the electrons and is defined as energy/unit charge (v) required for removing an electron from an atom. Ionization potential is found different for different metal. For example, Ca, K, and Na have very low ionization potential (2.1-2.3ev), while that for Al and Fe is on the higher side with values of 4 and 4.5 ev respectively. Common mechanisms through which free electrons are emitted during arc welding are described below:

5.2.1 Thermo-ionic emission

Increase in temperature of metal increases the kinetic energy of free electrons and as it goes beyond certain limit, electrons are ejected from the metal surface. This mechanism of emission of electron due to heating of metal is called thermo ionic emission. The temperature at which thermo-ionic emission takes place, most of the metals melt. Hence, refractory materials like tungsten and carbon, having high melting point exhibit thermo ionic electron emission tendency.

5.2.2 Field emission:

In this approach, free electrons are pulled out of the metal surface by developing high strength electro-magnetic field. High potential difference (10^7 V/cm) between the work piece and electrode is established for the field emission purpose.

5.2.3 Secondary emission

High velocity electrons moving from cathode to anode in the arc gap collide with other gaseous molecules. This collision results in decomposition of gaseuous molecules into atoms and charged particles (electrons and ions).

5.3 Zones in Arc Gap

On establishing the welding arc, drop in arc voltage is observed across the arc gap. However, rate of drop in arc voltage varies with distance from the electrode tip to the weld pool (Fig. 5.1). Generally, five different zones are observed in the arc gap namely cathode spot, cathode drop zone, plasma, anode drop zone and anode spot (Fig. 5.2).

5.3.1 Cathode spot

This is a region of cathode wherefrom electrons are emitted. Three types of cathode spots are generally found namely mobile, pointed, and normal. There can be one or more than one cathode spots moving at high speed ranging from 5-10 m/sec. Mobile cathode spot is usually produced at current density 100-1000 A/mm^2. Mobile cathode spot is generally found during the welding of aluminium and magnesium. This type of cathode spot loosens the oxide layer on reactive metal like aluminium, Mg and stainless steel. Therefore, mobile cathode spot helps in cleaning action when reverse polarity is used i.e. work piece is cathode. Pointed cathode spot is formed at a point only mostly in case of tungsten inert gas welding at about 100A/mm^2. Pointed tungsten electrode forms the pointed cathode-spot. Ball shaped tip of coated steel electrode forms normal cathode spot.

5.3.2 Cathode drop region:

This region is very close to the cathode and a very sharp drop of voltage takes place in this zone due to cooling effect of cathode. Voltage drop in this region directly affects the heat generation near the cathode which in turn governs melting rate of the electrode in case of the consumable arc welding process with straight polarity (electrode is cathode).

5.3.3 Plasma:

Plasma is the region between electrode and work where mostly flow of charged particles namely free electrons and positive ions takes place. In this region, uniform voltage drop takes place. Heat generated in this region has minor effect on melting of the work piece and electrode.

5.3.4 Anode drop region:

Like cathode drop region, anode drop region is also very close to the anode and a very sharp drop in voltage takes place in this region due to cooling effect of the anode. Voltage drop in this region affects the heat generation near the anode & so melting of anode. In case of direct current electrode negative (DCEN), voltage drop in this zone affects melting of the work piece.

5.3.5 Anode spot:

Anode spot is the region of a anode where electrons get merged and their impact generates heat for melting. However, no fixed anode spot is generally noticed on the anode like cathode spot.

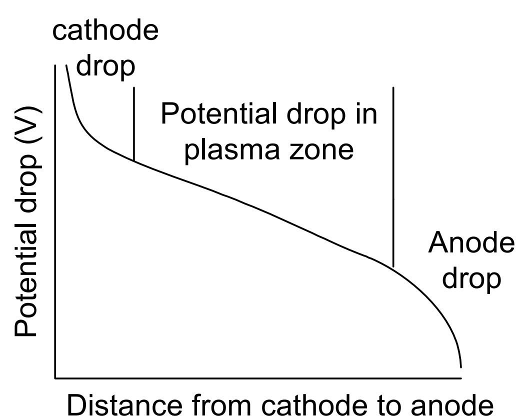

Fig. 5.1 Potential drop as function of distance form the cathode to anode

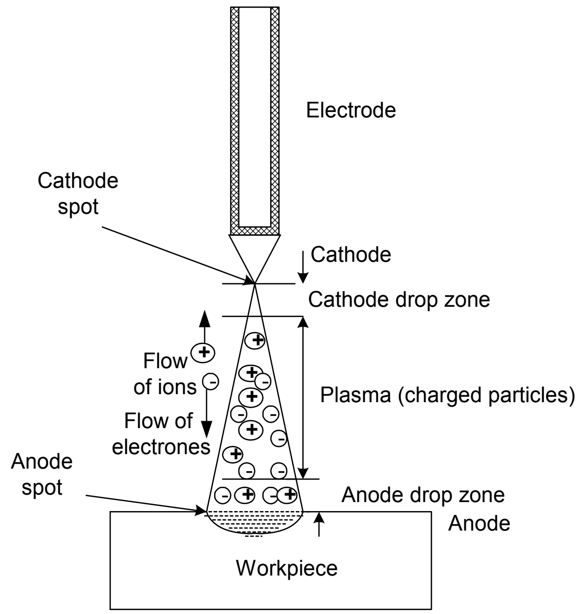

Fig. 5.2 Zones in arc gap of a welding arc

5.4 Electrical Fundamentals of Welding Arc

The welding arc acts as impedance for flow of current like an electric conductor. The impedance of arc is usually found a function of temperature and becomes inversely proportional to the density of charge particles and their mobility. Therefore, distribution of charged particles in radial and axial direction in the arc affects the total impedance of the arc. Three major regions have been noticed in arc gap that accounts for total potential drop in the arc i.e. cathode drop region, plasma and anode drop region. Product of potential difference across the arc (V) and current (I) gives the power of the arc indicating the heat generation per unit time. Arc voltage (V) is taken as sum of potential drop across the cathode drop region (V_c), potential drop across the plasma region (V_p), and potential drop across the anode drop region (V_a) as shown in Fig. 5.3.

Power of the arc (P) = $(V_c + V_p + V_a)\, I$……………………….(5.1)

Potential drop in different zones is expressed in terms of volt (V), welding current in ampere (A) and power of arc P is in watt (W). Equation 5.1 suggests that the distribution of heat in three zones namely cathode, anode and arc plasma can be changed. Variation of arc length mainly affects plasma heat while shielding gas influences the heat generation in the cathode and anode drop zones. Addition of low ionization potential materials (namely potassium and sodium) reduces the arc voltage because of increased ionization in arc gap so increased electrical conductivity which in turn reduces the heat generation in plasma region. Heat generation at the anode and cathode drop zones is primarily governed by type of welding process and polarity associated with welding arc. In case of direct current (DC) welding, when electrode is connected to the negative terminal and workpiece is connected with positive terminal of the power source then it is termed as direct current electrode negative polarity (DCEN) or straight polarity and when electrode is connected to the positive terminal of the power source and workpiece is connected with negative terminal then it is termed as direct current electrode positive polarity (DCEP) or reverse polarity. TIG welding with argon as shielding gas shows 8-10 time higher current carrying capacity (without melting) than DCEP. The submerged arc welding with DCEP generates larger amount of heat at cathode than anode as indicated by high melting rate of consumable electrode.

Increase in spacing between the electrode and work-piece generally increases the potential of the arc because of increased losses of the charge carriers by radial migration to cool boundary of the plasma. Increase in the length of the arc column (by bulging) exposes more surface area of arc column to the low temperature atmospheric gas which in turn imposes the requirement of more number of charge carriers to maintain the flow of current. Therefore, these losses of charged particles must be accommodated to stabilize the arc by increasing the applied voltage. The most of the heat generated in consumable arc welding process goes to weld pool which in turn results in higher thermal efficiencies. This is more evident from the fact that the thermal efficiency of metal arc welding processes is found in range of 70-80% whereas that for non-consumable arc welding processes is found in range of 40-60%.

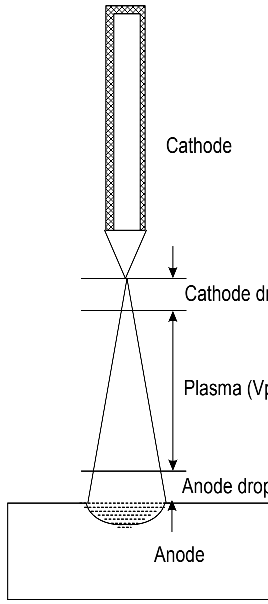

Fig. 5.3 Three different zone in which voltage drop takes place

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