Different forces acting in a typical welding arc zone

This chapter presents the different forces acting in a typical welding arc zone and their effect on welding. Further, influence of electrode polarity in welding has been described in respect of arc stability, heat generation and cleaning action on weld metal. Mechanism of arc blow and methods to overcome the same have also been discussed.

Keywords: Arc forces, pinch force, electrode polarity, heat generation, arc stability, cleanliness of weld, arc blow, electromagnetic forces,

7.1 Arc Forces and Their significance on Welding

All the forces acting in arc zone are termed as arc forces. In respect of welding, influence of these forces on resisting or facilitating the detachment of molten metal drop hanging at the electrode tip is important which in turn affect the mode of metal transfer and weld metal disposition efficiencies (Fig. 7.1 a-f). Metal transfer is basically detachment and movement of molten metal drops from tip of the electrode to the weld pool in work piece and is of great practical importance because two reasons (a) flight duration of molten metal drop in arc region affects the quality of weld metal and element transfer efficiency, and (b) arc forces affect the deposition efficiency.

7.1.1 Gravity Force

This is due to gravitational force acting on molten metal drop hanging at the tip of electrode. Gravitational force depends on the volume of the drop and density of metal. In case of down hand welding, gravitational force helps in detachment/transfer of molten metal drop from electrode tip (Fig. 7.1a). While in case of overhead welding it prevents the detachment.

Gravitational force (F_g)=ρVg ...7.1

Where ρ (kg/m)^{3}is the density of metal, V is volume of drop (m^3) and g is gravitational constant (m/s^2).

7.1.2 Surface Tension Force

This force is experienced by drop of the liquid metal hanging at the tip of electrode due to surface tension effect. Magnitude of the surface tension force (Equation 7.2) is influenced by the size of droplet, electrode diameter and surface tension coefficient. This force tends to resist the detachment of molten metal drop from electrode tip and usually acts against gravitational force. In case of vertical and overhead welding positions, high surface tension force helps in placing the molten weld metal at required position more effectively by reducing tendency of falling down of molten weld metal (Fig. 7.1b). Accordingly, flux/electrode composition for odd-position welding purpose must be designed to have viscous and high surface tension weld metal/slag.

Surface tension (F_s) = $(2\sigma \times \pi R_e^2)/4R$ ...(7.3)

Where σ is the surface tension coefficient, R is drop radius and R_e is the radius of electrode tip. An Increase in temperature of the molten weld metal reduces the surface tension coefficient (σ), hence this will reduce hindering effect of the surface tension force on detachment of the drop and so it will facilitate the detachment of drop from electrode tip.

7.1.3 Force Due to Impact of Charge Carriers

As per polarity charged particles (ions & electrons), move towards anode or cathode and eventually impact/collide with them. Force generated owing to impact of charged particles on to the molten metal drop hanging at the tip of electrode tends to hinder the detachment (Fig. 7.1c). This force is given by equation 7.4

Force due to impact of charged particles F_m= m(dV/dt) ...(7.4)

Where m is the mass of charge particles, V is the velocity and t is the time.

7.1.4 Force Due to Metal Vapours

Molten metal evaporating from bottom of drop and weld pool move in upward direction. Forces generated due to upward movement of metal vapours act against the molten metal drop hanging at the tip of the electrode. Thus, this force tends to hinder the detachment of droplet (Fig. 7.1d).

7.1.5 Force Due to Gas Eruption

Gases present in molten metal such as oxygen, hydrogen etc. may react with some of the elements (such as carbon) present in molten metal drop and form gaseous molecules (carbon dioxide). The growth of these gases in molten metal drop as a function of time ultimately leads to bursting of metal drops which in turn increases the spattering and reduces the control over handling of molten weld metal (Fig. 7.1 e1-e4).

7.1.6 Force Due to Electro Magnetic Field

Flow of current through the arc gap develops the electromagnetic field. Interaction of this electromagnetic field with that of charge carriers produces a force which tends to pinch the drop hanging at the tip of the electrode also called pinch force. The pinch force reduces the cross section for molten metal drop near the tip of the electrode and thus helps in detachment of the droplet from the electrode tip (Fig. 7.1 f1-f2). A component of pinch force acting in downward direction is generally held responsible for detachment of droplet and is given by:

Pinch force (F_p)= (μ X I^2)/8π ...(7.4)

Where μ is the magnetic permeability of metal, I is the welding current flowing through the arc gap.

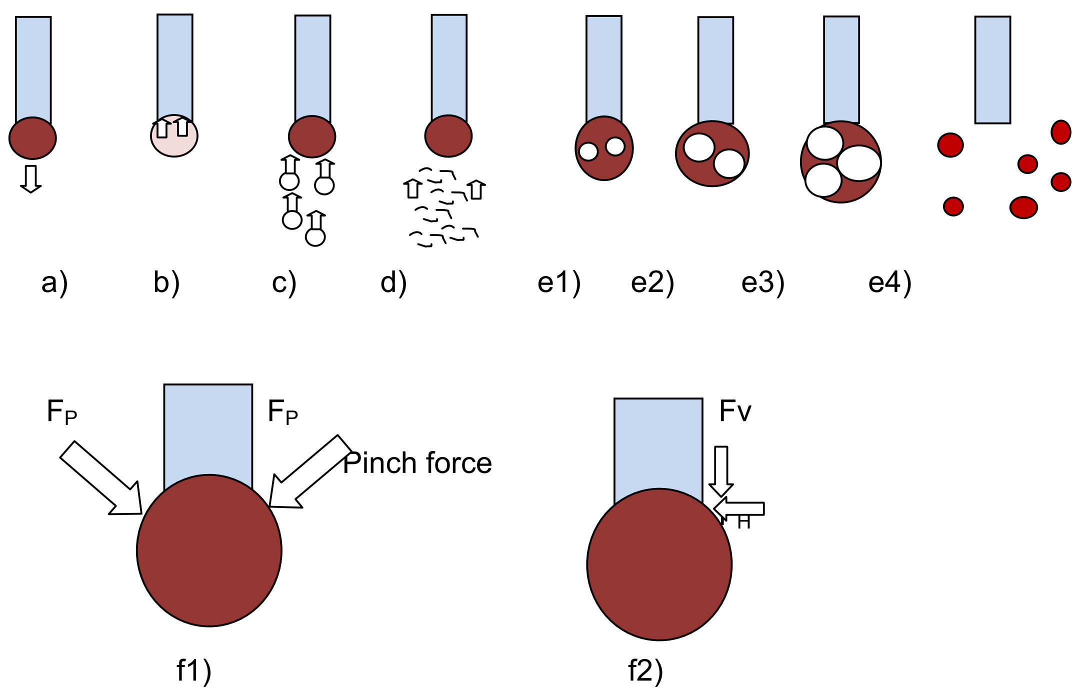


Fig. 7.1 Schematic diagram showing different arc forces a) gravitational force, b) surface tension force, c) force due to impact of charge particles, d) force due to metal vapours, e1 to e5) stages in force generation due to gas eruption and f1&f2) electromagnetic pinch force

7.2 Effect of Electrode Polarity

In case of D. C. welding, polarity depends on the way electrode is connected to the power source i.e. whether electrode is connected to positive or negative terminal of the power source. If electrode is connected to negative terminal of the power source, then it is called direct current electrode negative (DCEN) or straight polarity and if electrode is connected to positive terminal of the power source then it is called direct current electrode positive (DCEP) or reverse polarity. Polarity in case of A. C. welding doesn't remain constant as it changes in every half cycle of current. Selection of appropriate polarity is important for successful welding as it affects (Table 7.1):

1. distribution of heat generated by welding arc at anode and cathode,
2. stability of the arc and
3. cleanliness of weld

7.2.1 Heat Generation

In general, more heat is generated at the anode than the cathode. Of total DC welding arc heat, about two-third of heat is generated at the anode and one third at the cathode. The differential heat generation at the anode and cathode is due to the fact that impact of high velocity electrons with anode generates more heat than that of ions with cathode as electrons possess higher kinetic energy than the ions. Ion being heavier than electrons do not get accelerated much so move at low velocity in the arc region. Therefore, DCEN polarity is commonly used with non-consumable electrode welding processes so as to reduce the thermal degradation of the electrodes. Moreover, DCEP polarity facilitates higher melting rate deposition rate in case of consumable electrode welding process such as SAW and MIG etc.

7.2.2 Stability of Arc

All those welding processes (SMAW, PAW, GTAW) in which electrode is expected to emit free electrons required for easy arc initiation and their stability, selection of polarity affects the arc stability. Shielded metal arc welding using covered electrode having low ionization potential elements provide better stable arc stability with DCEN than DCEP. However, SMA welding with DCEP gives smoother metal transfer. Similarly, in case of GTAW welding, tungsten electrode is expected to emit electrons for providing stable arc and therefore DCEN is commonly used except when clearing action is receded in case of reactive metals e.g. Al, Mg, Ti.

7.3.3 Cleaning action

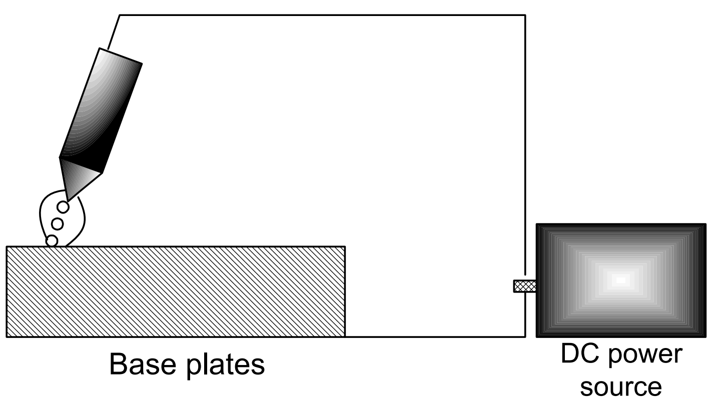
Good cleaning action is provided by mobile cathode spot because it loosens the tenacious refractory oxide layer during welding of aluminium and magnesium. Therefore, work piece is intentionally made cathode and electrode is connected to positive terminal of the power source. Thus, use of DCEP results in required cleaning action. Further, during TIG welding, a compromise is made between the electrode life and cleaning action by selecting the A.C..

Table 7.1 Comparison of AC and DC welding power sources

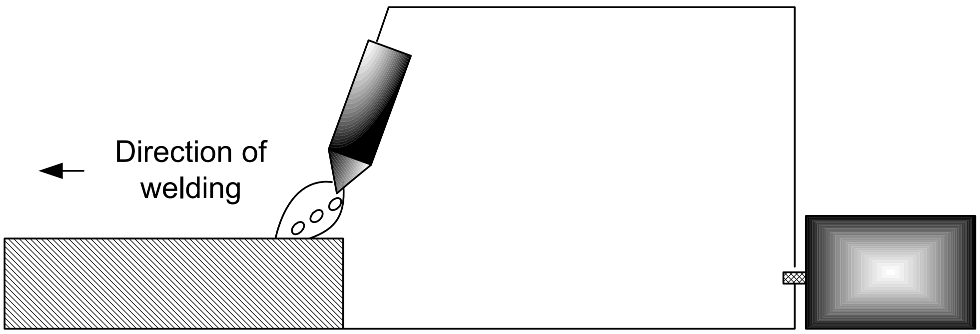
S. No.	Parameter	AC	DC
1	Arc stability	Poor	Good
2	Distribution of arc heat	Uniform	Provide better control of heat distribution
3	Efficiency	High	Low
4	Power factor	Low	High
5	Cleaning action	Good	Depends on polarity
6	Maintenance	Less	More
7	Cost	Less	More

7.3 Arc Blow

Arc blow is basically a deflection of a welding arc from its intended path i.e. axis of the electrode. Deflection of arc during welding reduces the control over the handling of molten metal by making it difficult to apply the molten metal at right place. A severe arc blow increases the spattering which in turn decreases the deposition efficiency of the welding process. According to the direction of deflection of arc with respect to welding direction, an arc blow may termed as be forward or backward arc blow. Deflection of arc ahead of the weld pool in direction of the welding is called forward arc blow and that in reverse direction is called backward arc blow (Fig. 7.2 a-c).



a)



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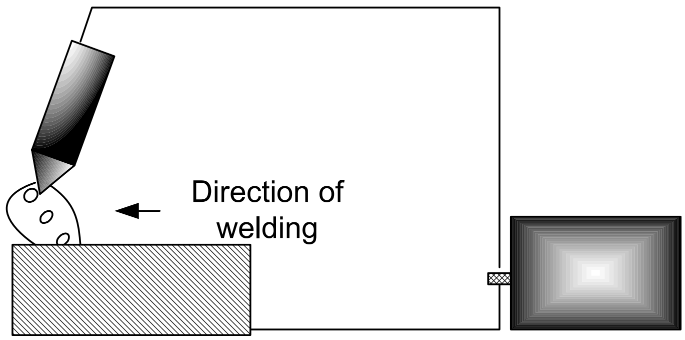

c)

Fig. 7.2 Schematic diagram showing welding a) without arc blow, b) with forward arc blow and c) with backward arc blow

7.3.1 Causes of arc blow

Arc blow is mainly encountered during DC arc welding due to interaction between different electromagnetic fields in and around the welding arc. Incidences of interaction between electromagnetic fields mainly occur in areas where these fields are localized. There are two common situations of interaction between electromagnetic fields that can lead to arc blow:

- interaction between electromagnetic field due to flow of current through the arc gap and that due to flow of current through plates being welded. Electromagnetic field is generated around the arc in arc gap. Any kind of interaction of this field with other electromagnetic fields leads to deflection of the arc from its intended path (Fig. 7.3a).
- interaction between electromagnetic field due to flow of current through the arc gap and that is localized while welding near the edge of the plates. The lines of electromagnetic fields are localized near the egde of the plates as these can flow easily through the metal than the air therefore distribution of lines of electromagnetic forces does not remain

uniform around the arc. These lines get concentrated near the edge of the plate (Fig. 7.3b).

7.3.2 Mechanism of arc blow

Electromagnetic field is generated in a plane perpendicular to the direction of current flow through a wire. Intensity of self induced magnetic field ($H= i/2\pi r$) due to flow of current depends upon the distance of point of interest from center of wire (r) and magnitude of current (i). In general, increase in current and decrease the distance of from the wire increase the intensity of electromagnetic field. Depending upon the direction of current flow through two wires, there can be two types of polarities namely like and unlike polarity, accordingly electromagnetic fields due to current flow interacts with each other (Fig. 7.3 a). In case of like polarity, the direction of flow of current is same in two conductors. Electromagnetic fields in case of like polarities repel each other while those of unlike polarities attract each other.

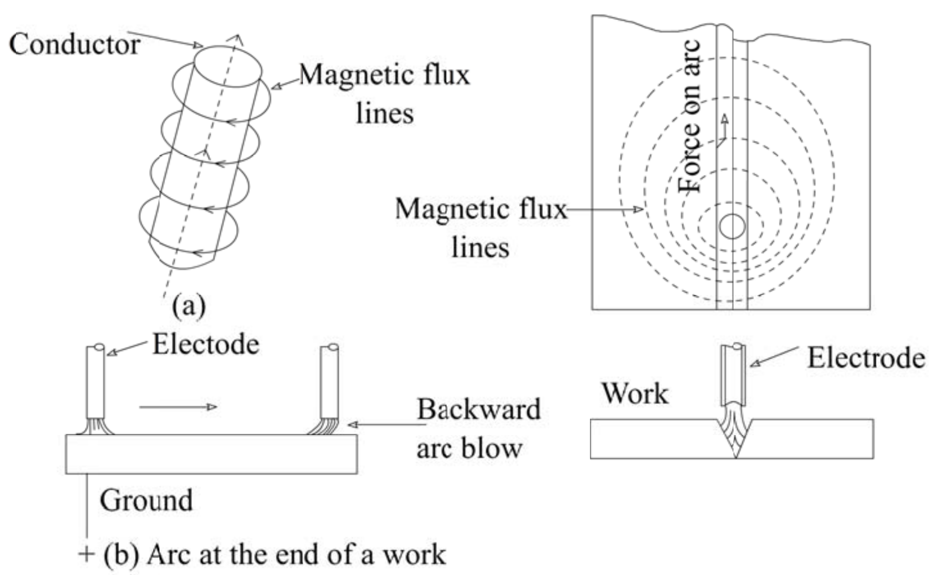

Fig. 7.3 Schematic diagrams showing generation of electromagnetic force around the welding arc & electrode causing arc blow

The welding arc tends to deflect away from area where electro-magnetic flux concentration exit. In practice, such kind of localization of electromagnetic fields and so deflection of arc depends on the position of ground connection as it affects the direction of current flow and related electro-magnetic field. Arc can blow towards or away from the earthing point depending upon the orientation of electromagnetic field around the welding arc. Effect of ground connection on arc blow is called ground effect. Ground effect may add or reduce the arc blow, depending upon the position of arc and ground connection. In general, ground effect causes the deflection of arc in the direction opposite to the ground connection.

Arc blow occurring due to interaction between electromagnetic field around the arc and that of localized electromagnetic field near the edge of the plates, always tends to deflect the arc away from the edge of the plate (Fig. 7.3 b-c). So the ground connection in opposite side of the edge experiencing deflection can help to reduce the arc blow.

Arc blow can be controlled by:

- Reduction of the arc length so as to reduce the extent of misplacement of molten metal
- Adjust the ground connection as per position of arc so as to use ground effect unfavorable manner from D.C. to
- Shifting to A. C. if possible so as to neutralize the arc blow occurring in each half
- Directing the tip of the electrode in direction opposite to the arc blow.

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