Influence of welding parameters and Shielding Gas on Arc characteristics and behavior of Metal Transfer in GMA Welding of Mild Steel

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ABSTRACT

The effects of welding parameters under Ar+18%CO2 and argon gas shielding on arc characteristics and behaviour of metal transfer in GMAW using mild steel filler wire have been studied by video-graphy of arc environment. The measured root diameter, projected diameter, length and deflection of arc as well as the transferred droplet diameter at the time of detachment along with the estimated arc stiffness have been measured and correlated to the welding parameters under different gas shielding. It has been observed that the arc characteristics with respect to its shape, stiffness and spreading over the weld characteristics significantly vary with welding current and arc voltage giving due consideration to the shielding environment. The use of argon gas shielding appreciably reduces the arc deflection and enhances the DR, DP and L with respect to that observed under Ar+18%CO2 gas shielding.

Keywords : GMAW, arc voltage, welding current, arc profile, arc pressure, arc deflection and metal transfer

INTRODUCTION

Gas metal arc welding (GMAW) is largely used in industries for welding wide variety of ferrous and non-ferrous materials. During GMAW process, the consumable electrode wire is melted and the molten metal is transferred across the arc into the weld pool. But it is often pointed out that the quality of GMA weld very much depends upon arc characteristics and behaviour of metal transfer dictated by the welding parameters and shielding environment affecting the energy transferred to the weld. The thermal behaviour of weld governed by the arc characteristics and the behaviour of metal transfer significantly influences the geometry, chemistry, microstructure and stresses of the weld [1, 2]. The effect of welding parameters and shielding environment on the arc characteristics and the behaviour of metal transfer in GMAW process is qualitatively well known. But, hardly any correlations amongst them is readily available in reported literatures which can be analytically used to control the welding process for desired weld characteristics, especially under mechanized and automatic weld fabrication.

In view of the above the effect of arc voltage (V) and welding current (I) under different gas shielding on variation in arc characteristics and behaviour of metal transfer have been studied by video-graphy of arc environment during GMA weld deposition of mild steel filler wire. The characteristics of arc have been studied by its root diameter, projected diameter, length, deflection and stiffness and the behaviour of metal transfer has been noted by the droplet diameter at the time of detachment. All these measured or estimated aspects of GMAW of mild steel are correlated to the arc voltage and welding current at different gas shielding. The study provides a basic understanding to analyze the mechanism of variation in weld characteristics with respect to variation in welding parameters under different shielding environment which, may be beneficial in using GMAW to produce desired weld quality and also may form a basis of improved automation of this process.

EXPERIMENTAL

Welding

Studies on arc characteristics and behaviour of metal transfer were carried out by bead on plate weld deposition on 10 mm thick mild steel plate by conventional GMAW processes using direct current electrode positive (DCEP). The weld deposition was made by employing 1.2 mm diameter mild steel

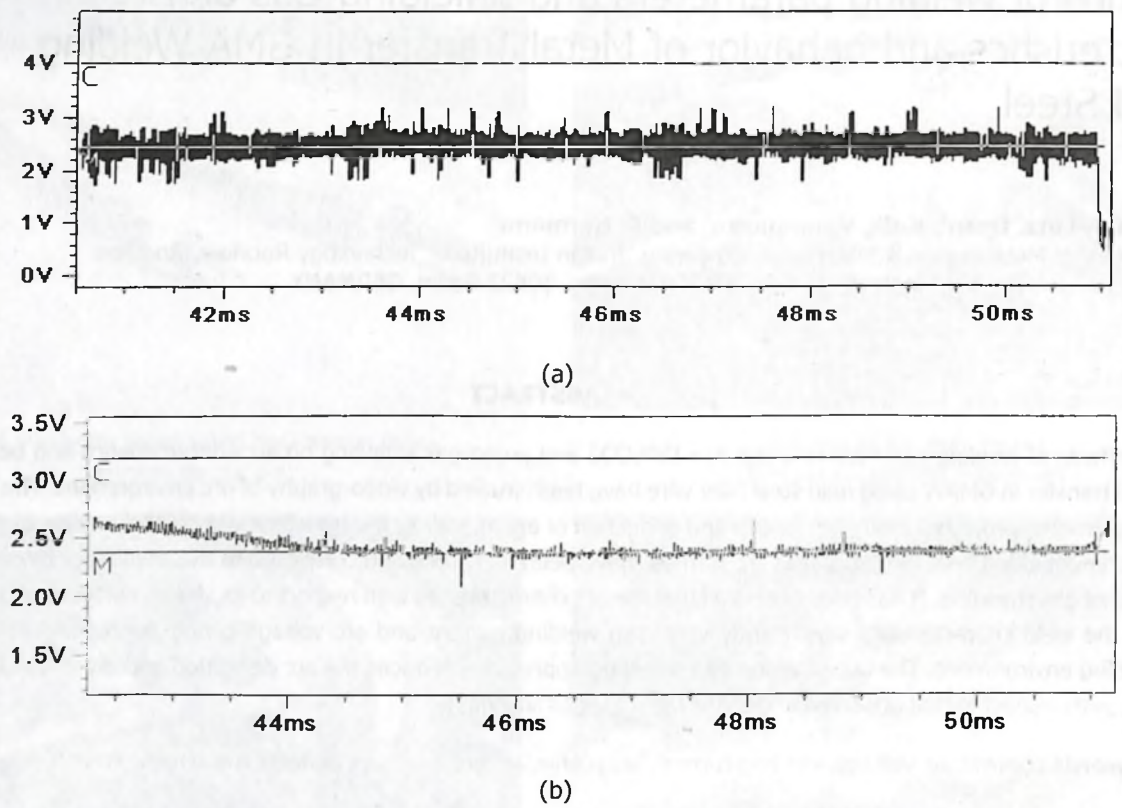

Fig.1.The variation in (a) arc voltage and (b) welding current recorded during welding.

filler wire of specification AWS/SFA 5.18ER-70S-6 at electrode extension of 15mm. Welding was carried out by using Ar+18%CO2 and commercial pure argon as shielding gas at a flow rate of 18 l/min. Some typical values of measured arc voltage (V) and welding current (I) under different shielding environments considered in this work are presented in Table-I. In order to compare the arc characteristics under different shielding environments the studies were carried out by keeping the welding parameters practically similar with respect to the wire feed speed, welding current and arc voltage. The arc voltage and welding current were measured with the help of a transient recorder (maximum resolution of 1 MHz) fitted with the electrical circuit of the welding set up the captured V and I by the transient recorder as typically shown in Fig. 1 (a) and (b) respectively. In consideration of its importance as a most commonly used gas shielding in GMAW with mild steel filler wire, the arc characteristics under Ar+18%CO2 gas shielding was thoroughly studied by video-graphy with the help of a high speed camera operated at a speed of 104 frames per second. The camera was placed on a rigid fixture in front of the arc along the line of welding. However, for a comparative study of academic interest, the arc characteristics under argon gas shielding giving relatively more stable arc were also studied by video-graphy using an automatic camera rapid shooting at an interval of 0.33 second. The video graphs were suitably analyzed in sequence with respect to the welding parameters by classifying the welding current (I) in to two stages of about 185±2 and 230±2A wherein the globular and spray modes of metal transfer respectively exist at the arc voltages of 24, 30 and 33V.

Measurements of arc characteristics and metal transfer

The nature of variation in arc characteristics with respect to its profile and pressure and the behaviour of metal transfer with the change in welding parameters of GMAW have been studied on the video graphs of the welding arc environment. The arc profile defined by its root diameter (DR), projected diameter (DP) and length (L) was suitably measured by computerized scaling technique applied on the relevant photographs taken at each welding parameter as schematically shown in Fig. 2 (a) and (b) respectively. Whereas, the observed deviation of arc from the electrode axis (appeared to be arc blow) was measured by a similar computerized scaling technique as schematically shown in Fig. 3. The measurement was carried out in reference to the known size of filler metal appeared in the photographs. In reference to variation in arc profile the arc stiffness visa-vis arc pressure was also estimated as stated latter. The behaviour of metal transfer was also studied by measurement of diameter (D) of the droplets using the similar computerized scaling technique. The droplets occasionally revealed in the background of the glair of arc during their transfer to the weld pool at different welding parameters.

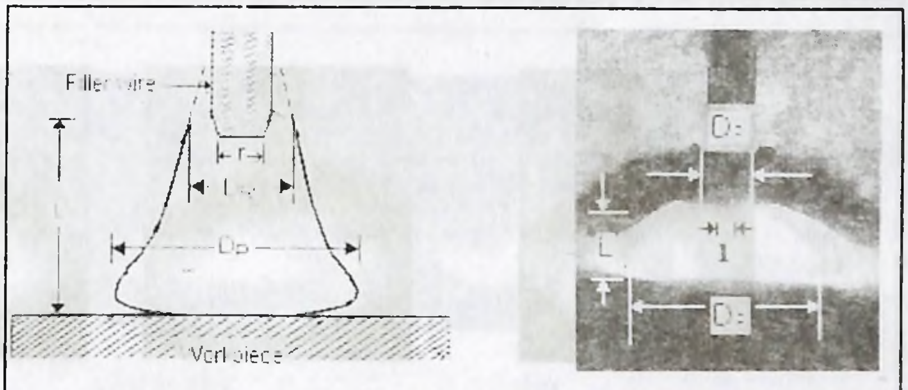

Fig.2. (a) The schematic diagram showing measurement technique of arc characteristics and (b) typical nature of electrode tip.

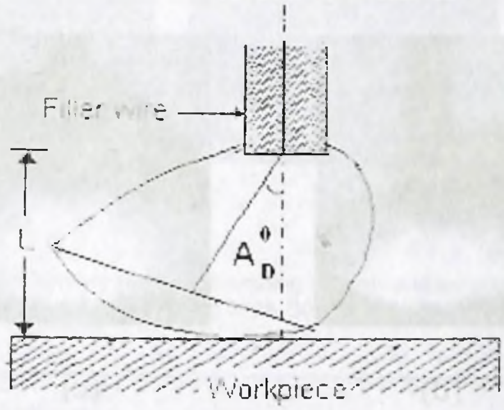

Fig.3.The schematic diagram of measurement of arc blow in terms of arc deflection from electrode axis.

RESULTS AND DISCUSSION

The arc characteristics primarily understood by its profile, stiffness and stability as well as behaviour of metal transfer affecting the weld quality is largely dictated by the welding parameters and the type of shielding gas of GMAW process. The arc profile defined by its root diameter (DR), projected diameter (DP) and length (L) largely denotes the degree of constriction and stiffness of arc influencing the weld characteristics. Although the arc profile observed in video-graphs may not be a true profile of the arc arising out of over estimation in measurement due to covering by glare of plasmatic part of shielding gas around it, but its nature of response to welding parameters can be a matter of great interest to understand its influence on weld quality.

Arc profile under Ar+18%CO2 gas shielding

During GMA welding under Ar+18%CO2 gas shielding the typical change in arc profile with respect to its shape and size at different welding currents of about 185 and 230A under varying arc voltage of 24, 30 and 33V has been shown in the photographs presented in Fig. 4 (a-f). The photographs reveal that at a given welding current the increase of arc voltage from 24 to 33V significantly influences the arc profile. The nature of variation of arc profile with the change in welding parameters has been discussed below.

At different welding currents of about 185A and 230A the effect of arc voltage on arc root diameter (DR), projected arc diameter (DP) and arc length (L) has been shown in Fig. 5 (a-c) respectively. The Fig. 5(a) shows that at a given welding current the DR decreases significantly with the increase of arc voltage and at a given arc voltage especially at a lower one it reduces more prominently with a increase in welding current. This may be primarily happened because at a given welding current an increase of arc voltage enhances the arc pressure and thus tends to constrict the arc roots [3, 4, 5]. At different currents the empirical correlation of DR with the arc voltage has been worked out as follows.

$$D_{R185\,A} = 2.53 - 0.036\,V \quad \ldots i$$

$$D_{R230\,A} = 2.59 - 0.046V \quad \ldots ii$$

The Fig. 5 (b) shows that the increase of arc voltage up to 30V marginally reduces the DP but, a further increase of arc voltage to 33V enhances it significantly. However, at a given arc voltage the increase of welding current (I) relatively reduces the DP. At different currents the empirical correlation of DP with the arc

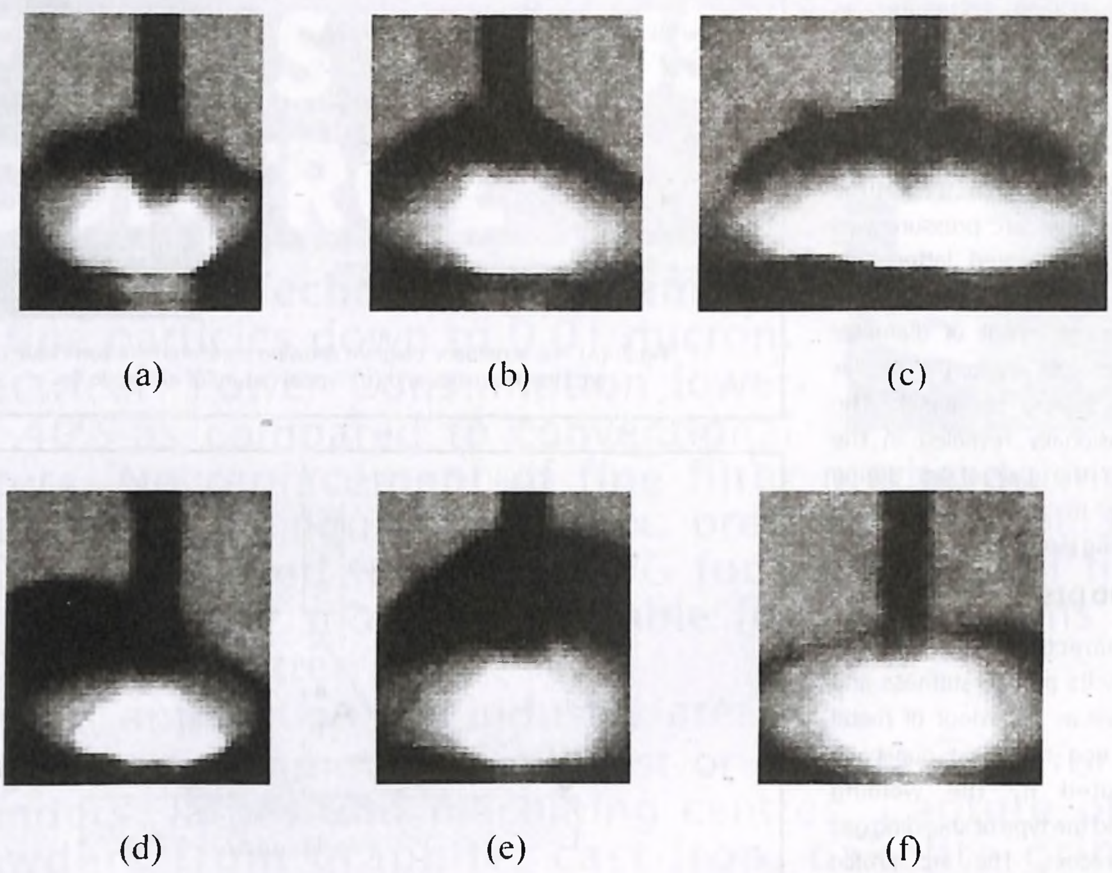

Fig.4. The typical change in arc characteristics under Ar+18%CO_2 gas shielding at different welding currents and arc voltages of (a) 186A, 24V, (b) 188A, 30V, (c) 187A, 33V, (d) 233A, 24V, (e) 232A, 30V and (f) 234A, 33V.

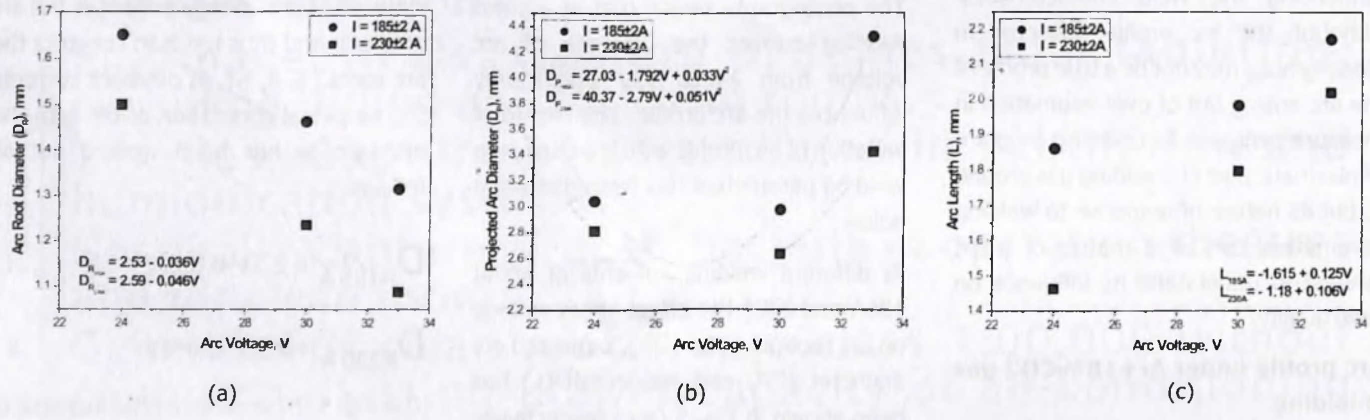

Fig. 5 Under Ar+18%CO_2 gas shielding at different welding current the effect of arc voltage on (a) arc root diameter (b) projected arc diameter and (c) arc length

voltage has been estimated as follows.

$$D_{P\,185\,A} = 27.03 - 1.792V + 0.033V^2$$

$$D_{P\,230\,A} = 40.37 - 2.79V + 0.051V^2$$

The Fig. 5 (c) shows that at a lower and higher welding current of about 185 and 230A, where a globular and spray mode of metal transfer exists, the increase of arc voltage enhances the arc length (L). This may have primarily happened because arc length is proportional to arc voltage, where a longer arc at higher arc

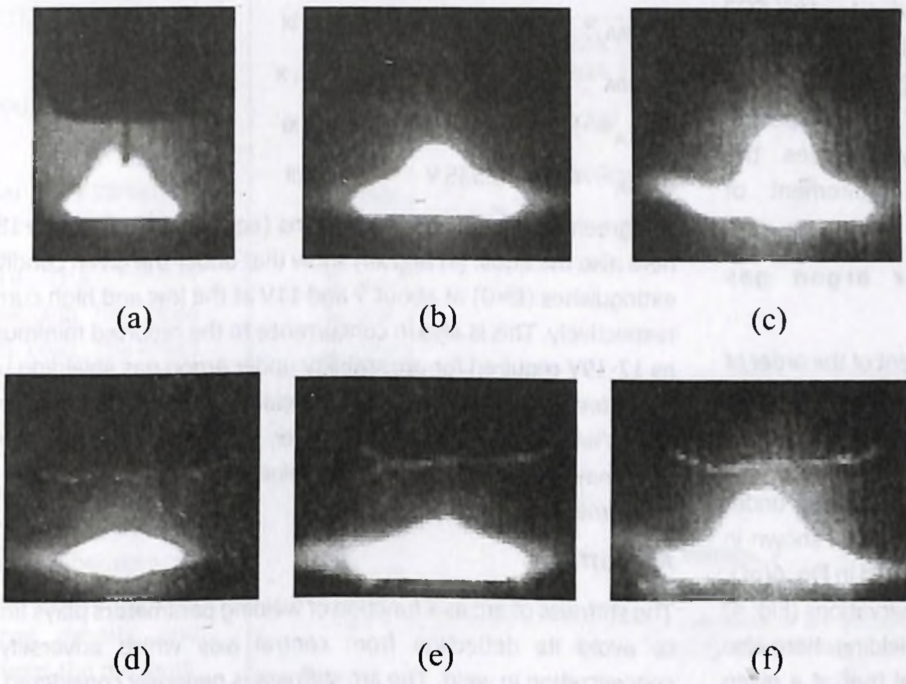

Fig.6. Typical arc characteristics under argon gas shielding at different welding currents and arc voltages of (a) 182A, 24V, (b) 183A, 30V, (c) 187A, 33V, (d) 231A, 24V, (e) 229A, 30V and (f) 230A, 33V.

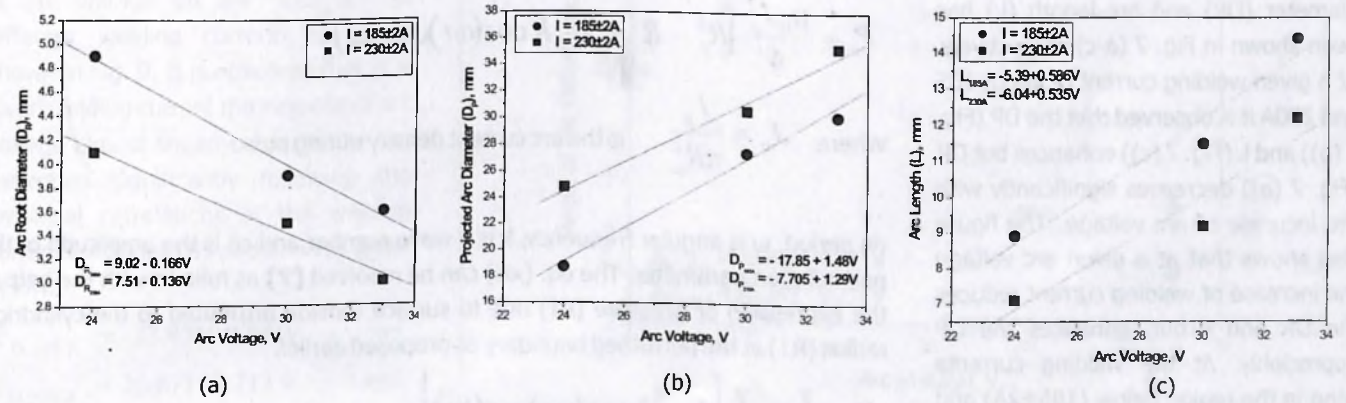

Fig.7. Under argon gas shielding at different welding currents the effect of arc voltage on (a) arc root diameter (b) projected arc diameter and (c) arc length.

voltage consumes more energy under a given current [1, 5]. However, at a given arc voltage the increase of welding current relatively reduces the L following the empirical correlations as given below.

$$L_{185\,A} = 1.615 + 0.125\,V \qquad \ldots v$$

$$L_{230A} = -1.18 + 0.106\,V \qquad \ldots vi$$

The above equs. (v and vi) show that under the given condition of welding the arc extinguishes (L=0) at about 13 and 11V under the relatively lower and higher currents of 185 and 230A respectively with respect to the transition current (220±5 A) [1]. The minimum arc voltage required for arc stability largely depends also upon type of power source and the welding current. In consideration of the minimum arc voltage required as 21-22V for arc stability under Ar+18%CO2 gas shielding using 1.2mm diameter mild steel filler wire [1], the outcome of the equs. (v and vi) for L with respect to arc voltage broadly satisfies the prescribed general requirement of GMAW of mild steel.

Arc profile under argon gas shielding

At a given welding current of the order of about 185 and 230A the typical change in characteristics of arc in reference to its shape and size with varying arc voltage to about 24, 30 and 33V under argon gas shielding has been shown in the photographs presented in Fig. 6(af). In the line of earlier observations (Fig. 4) of Ar+18%CO2 gas shielding, here also the photographs reveal that at a given welding current the increase of arc voltage from 24 to 33V (Fig.6) significantly influences the arc characteristics. At different welding currents the effect of arc voltage on the root diameter (DR), projected arc diameter (DP) and arc length (L) has been shown in Fig. 7 (a-c) respectively. At a given welding current of about 185 and 230A it is observed that the DP (Fig. 7 (b)) and L (Fig. 7 (c)) enhances but DR (Fig. 7 (a)) decreases significantly with the increase of arc voltage. The figure also shows that at a given arc voltage the increase of welding current reduces the DR and L but, enhances the DP appreciably. At the welding currents lying in the region below (185±2A) and above (230±2A) the transition current (215±5A) [1] of the filler wire with respect to the drop and spray transfer mode of metal respectively the influence of arc voltage on the various characteristics of the arc can be estimated by the following the empirical correlations.

$D_{R185A} = 9.02 - 0.166\,V$ ... vii

$D_{R230A} = 7.51 - 0.136\,V$ ... viii

$D_{P185A} = 17.85 + 1.48\,V$ ... ix

$D_{P230A} = -7.705 + 1.29\,V$ ... x

$L_{185\,A} = -5.39 + 0.586\,V$ ... xi

$L_{230A} = -6.04 + 0.535\,V$ ... xii

In agreement to earlier observations (equs. v and vi) of Ar+18%CO2 gas shielding, here also the equs. (xi and xii) show that under the given condition of welding the arc extinguishes (L=0) at about 9 and 11V at the low and high currents of 185 and 230A respectively. This is also in concurrence to the reported minimum value of arc voltage as 17-19V required for arc stability under argon gas shielding using 1.2mm diameter mild steel filler wire [1], which is relatively lower than that reported in case of the Ar+18%CO2 gas shielding. However, in spite of the agreed trend of the equations they may be further modified by minimizing scattering with the help of using more experimental data in this regard.

Arc stiffness

The stiffness of arc as a function of welding parameters plays an important role largely to avoid its deflection from central axis which adversely affects the energy concentration in weld. The arc stiffness is generally considered as a direct function of arc pressure. The arc pressure (Pa) can be estimated [6,7] with the help of an equation derived from total pressure distribution at the perturbed boundary of solid-liquid interface by assuming arc as a hollow conducting fluid cylinder of inner and outer radius equal to equilibrium radius of the molten metal (R) and arc root radius (Ra) respectively. The Pa is expressed as follows.

$$P_a = \frac{\mu_0 J_a^2}{4}\left[R_a^2 - R^2 - 2\varepsilon_o R\cos(\omega t)\cos(kz)\right] \quad \text{.... xiii}$$

Where $J_a = \dfrac{I_p}{\pi R_a^2}$ is the arc current density during pulse

on period, ω is angular frequency, k is a wave number and εo is the amplitude of the perturbation parameter. The eq. (xiii) can be resolved **[7]** as follows with the help of the expression of pressure (P1) due to surface tension attributed to the cylindrical radius (R1) at the perturbed boundary as proposed earlier.

$$P_1 = \frac{\gamma}{R_1} = \frac{\gamma}{R}\left[1 - \frac{\varepsilon_0}{R}\cos(\omega t)\cos(kz)\right] \quad \text{... xiv}$$

$$\varepsilon_0\cos(\omega t)\cos(kz) = R - \frac{R^2}{R_1} \quad \text{... xv}$$

Considering the eqs. (xiv) and (xv) the expressions for estimation of arc pressure Pa in GMAW is finally derived as follows.

$$P_a = \frac{\mu_0 I_P^2}{4\pi^2 R_a^4}\left[R_a^2 - 3R^2 + \frac{2R^3}{R_1}\right] \quad \text{....xvi}$$

Where, the R and R1 are assumed as the size of droplet radius (D/2) and effective radius (r) of

tapering of electrode respectively (Table-II).

Arc stiffness under Ar+18%CO2 gas shielding

The arc pressure (Pa) under Ar+18%CO2 gas shielding has been estimated by using eq. (xvi). The effect of arc voltage and welding current on arc pressure has been shown in Fig. 8. The figure depicts that at any welding current the arc pressure enhances with the increase of arc voltage. This may have primarily happened because an increase of arc voltage at a given current enhances the energy density and consequently strengthens the magnetic field at the arc root [8]. As the arc pressure is directly related to the arc blow, the occurrence of such behaviour of arc may cause variation in heat distribution and related thermal characteristics of weld joint. The effect of arc voltage on arc deflection at different welding current has been shown in Fig. 9. It is observed that at a given welding current the increase of arc voltage almost linearly reduces the arc deflection significantly following the empirical correlations at the welding currents of about 185 and 230A as given below.

$$A^{o}_{D\ 185\ A} = 32.436 - 0.841V \quad \text{... xvii}$$

$$A^{o}_{D\ 230\ A} = 26.371 - 0.717\ V \quad \text{... xviii}$$

The equs (xvii and xviii) also reveals that at a given arc voltage the increase of welding current further reduces the arc deflection due to comparatively higher arc pressure (Fig. 8) and thus lowers the possibility of arc blow. At different welding current the measured angle of arc deflection has been further compared with their corresponding estimated values of arc pressure as shown in Fig. 10 (a) and (b). The figure

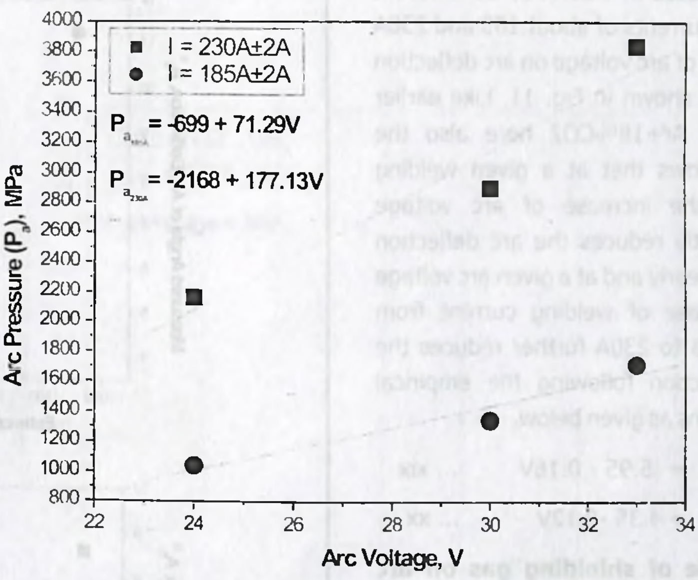

Fig.8 : At different welding current the effect of arc voltage on arc pressure under Ar+18%CO_2 gas shielding

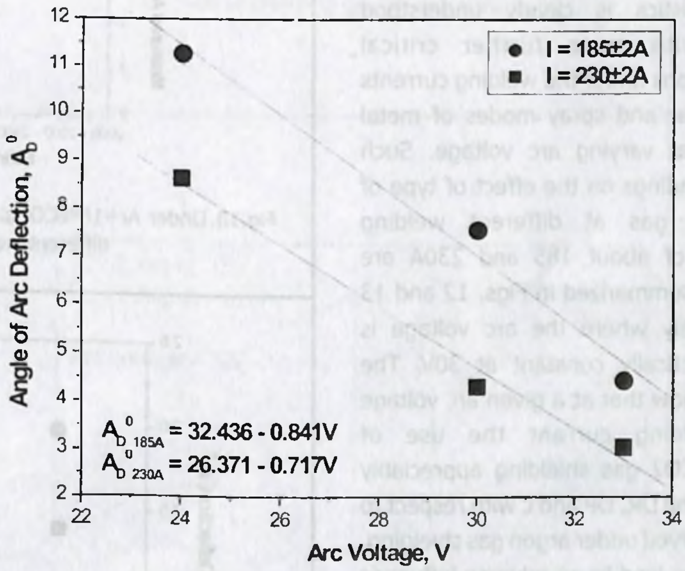

Fig.9 : At different welding current the effect of arc voltage on arc deflection under Ar+18%CO_2 gas shielding.

shows that at any welding current the arc deflection reduces with the increase of arc pressure.

Arc stiffness under argon gas shielding

The arc pressure (Pa) is estimated on the basis of arc root radius, tapering of electrode and radius of transferring droplet. Under argon gas shielding the invisibility droplets due to excessive glare of arc arising out of its comparatively lower ionization potential (40ev) than that (55ev) of Ar+18%CO_2 [6] did not allow the measurement of droplet size and subsequent estimation of arc pressure. However, at different welding currents of about 185 and 230A the effect of arc voltage on arc deflection has been shown in Fig. 11. Like earlier cases of Ar+18%CO2 here also the figure shows that at a given welding current the increase of arc voltage significantly reduces the arc deflection almost linearly and at a given arc voltage the increase of welding current from about 185 to 230A further reduces the arc deflection following the empirical correlations as given below.

$AO_{D185\ A} = 5.95 - 0.16V$ ... xix

$AO_{D230\ A} = 4.35 - 0.12V$ ... xx

Influence of shielding gas on arc characteristics

In view of the results depicted in Figs. 4-11 the well known facts of significant role of type of shielding gas on arc characteristics is clearly understood along with some further critical observations under the welding currents of globular and spray modes of metal transfer at varying arc voltage. Such understandings on the effect of type of shielding gas at different welding currents of about 185 and 230A are typically summarized in Figs. 12 and 13 respectively where the arc voltage is kept practically constant at 30V. The figures show that at a given arc voltage and welding current the use of Ar+18%CO2 gas shielding appreciably reduces the DR, DP and L with respect to that observed under argon gas shielding, which may lead to an adverse influence of arc stability. This may be primarily attributed in agreement to the well known fact of higher heat flow associated with the Ar gas mixtures containing significant amount of CO2 primarily due to its comparatively higher thermal conductivity of 1.265W/mK as compared to that of argon as 0.625W/mK [9, 10]. A relatively higher thermal conductivity of CO_2 gives rise to more heat loses by conduction causing a

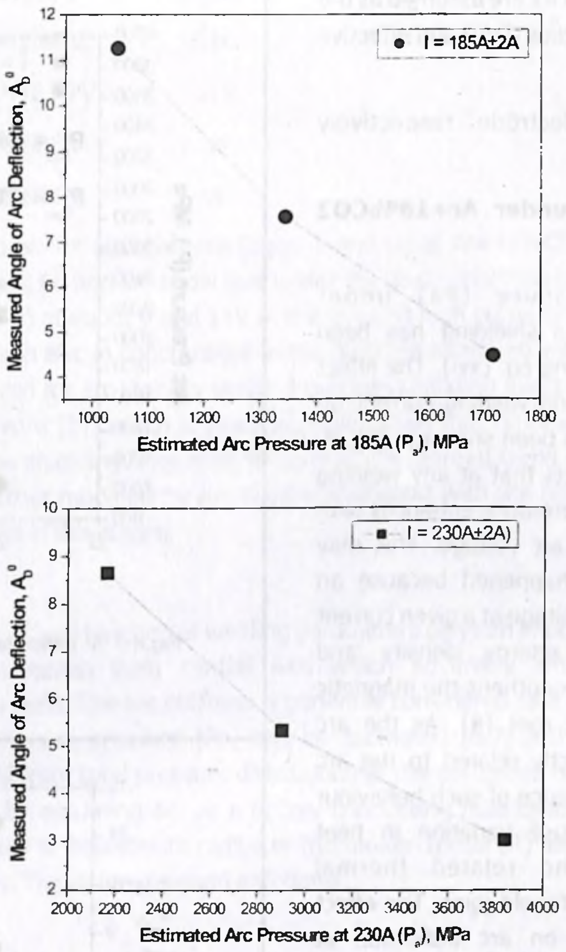

Fig.10. Under Ar+18%CO_2 gas shielding the effect of arc pressure on arc deflection at different welding current of (a) 185A and (b) 230A.

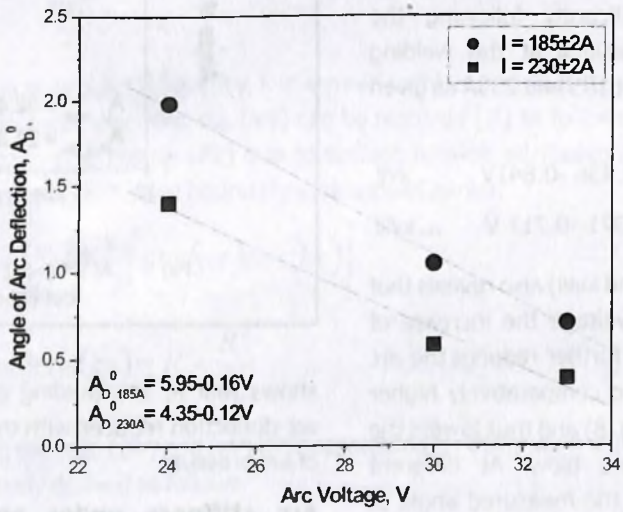

Fig.11. At different welding current the effect of arc voltage on arc deflection under argon gas shielding.

uniform radial distribution of arc temperature [9]. On the contrary, pure argon gas shielding has an inner zone that is comparatively hotter than the peripheral zone [11]. This indicates that the arc stability decreases with the addition of carbon dioxide content in the mixture. However an increase of arc voltage at a given current intensity improves the arc stability. But, it is found that at a given welding current and arc voltage the magnitude of arc deflection is considerably lower under the argon gas shielding (Fig.11) than that observed in case of the Ar+18%CO_2 gas shielding (Fig.9). This may have primarily occurred due to differences in thermal conductivity of shielding gases which produce a variation in arc shape. However, to have more clear understanding of this phenomenon the influence of welding parameter on arc stiffness under argon gas shielding in GMAW process should be studied further in detail at higher speed video-graphy with better resolution and clarity

Behaviour of metal transfer

Although the studies on behaviour of metal transfer by video-graphy is to a large extent handicapped due to glair of the arc. However, in certain cases it became possible to reveal some salient features of the mode of metal transfer on the video-graphs taken at various stages of welding parameters. Accordingly the droplet diameter (D) was suitably measured. The diameter of droplet (D) under Ar+18%CO2 gas shielding as observed in the video graphy of welding with varying arc voltage of 24V, 30V and 33V at given welding currents of 185A and 230A has been typically shown in the photographs presented in Fig. 14, while the measured droplet diameter has been given in Fig. 15. The figure shows that at a given welding current the increase of arc voltage from 24 to 33V as well as at a

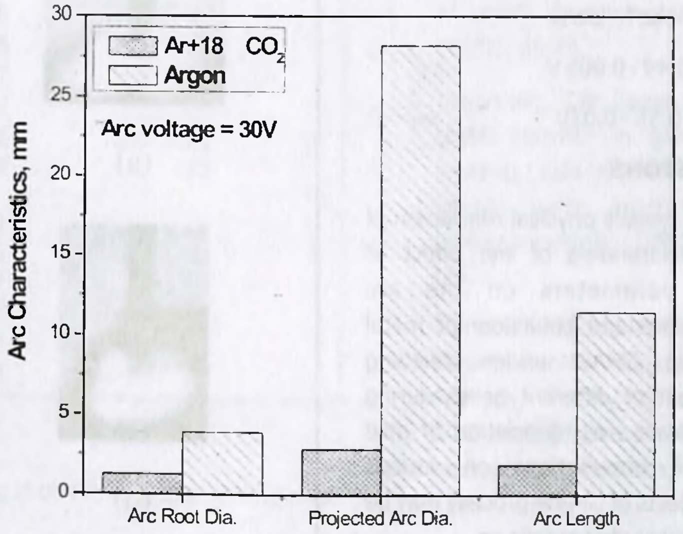

Fig.12. At given arc voltage and welding current of 30V and 185±2A respectively the effect of shielding gas on arc characteristics.

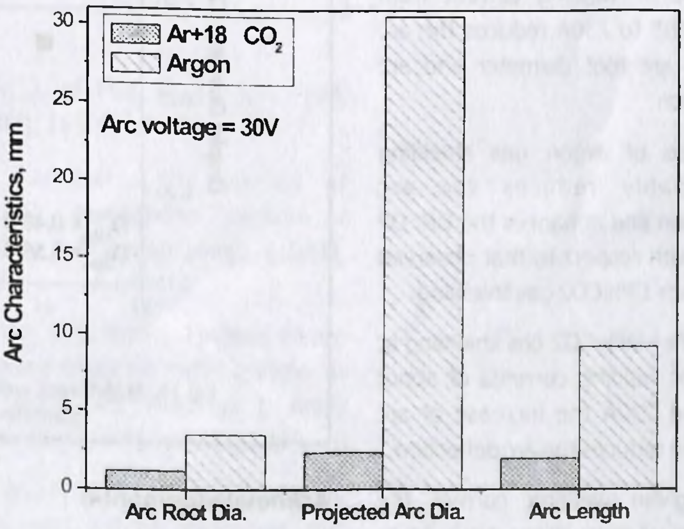

Fig.13. At given arc voltage and welding current of 30V and 230±2A respectively, the effect of shielding gas on arc characteristics.

given arc voltage the increase of welding current from about 185 to 230A relatively reduces the D following the correlations as follows.

$$D_{185\,A} = 0.49 - 0.005\,V \quad \ldots xxi$$

$$D_{230\,A} = 0.55 - 0.01V \quad \ldots xxii$$

CONCLUSIONS

The study reveals physical realisation of basic understanding of the effect of welding parameters on the arc characteristics and behaviour of metal transfer in GMAW under shielding environment of different gases during bead on plate weld deposition of mild steel. The observations on various critical aspects of GMAW process may be primarily concluded as follows.

1. The increase in arc voltage from 24 to 33V enhances the projected arc diameter and arc length but reduces the arc root diameter and arc deflection under both the gas shielding of Ar+18%CO2 and argon.
2. Under Ar+18%CO2 and argon gas shielding at a given arc voltage an increase of welding current from about 185 to 230A reduces the arc length, arc root diameter and arc deflection.
3. The use of argon gas shielding appreciably reduces the arc deflection and enhances the DR, DP and L with respect to that observed under Ar+18%CO2 gas shielding.
4. Under Ar+18%CO2 gas shielding at different welding currents of about 185 and 230A the increase of arc pressure reduces the arc deflection.
5. At a given welding current the increase of arc voltage from 24 to 33V as well as at a given arc voltage the increase of welding current from about 185 to 230A relatively reduces the droplet diameter under Ar+18%CO2 gas shielding.

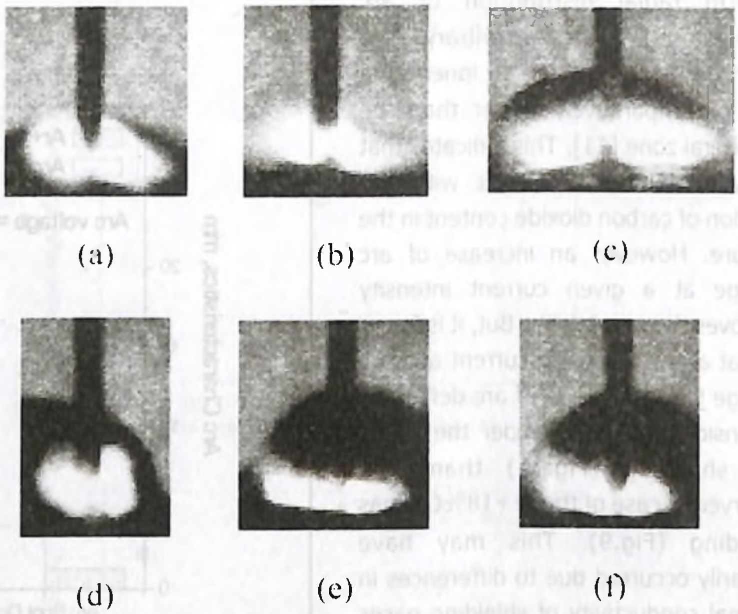

Fig.14. The typical change in metal transfer of GMAW under Ar+18%CO_2 gas shielding at different welding current and arc voltage of (a) 186A, 24V, (b) 188A, 30V, (c) 187A, 33V, (d) 233A, 24V, (e) 232A, 30V, (f) 234A, 33V.

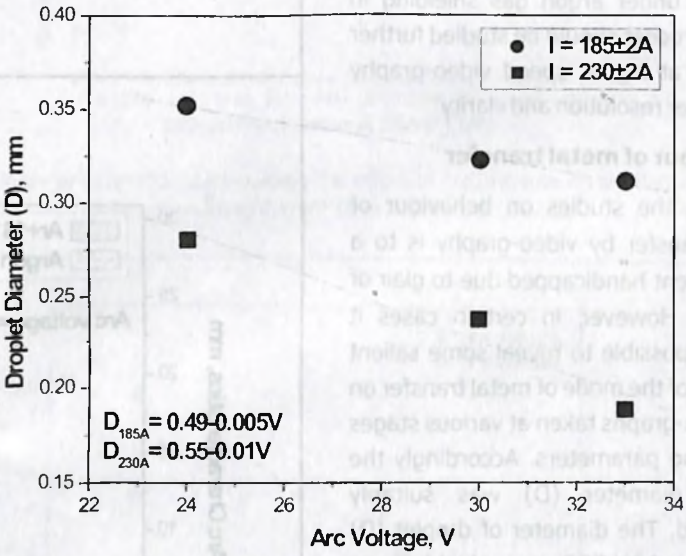

Fig.15. At different welding current the effect of arc voltage on droplet diameter under Ar+18%CO_2 gas shielding.

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Table I : Welding parameters used under different shielding gases

Shielding gas	WFS (m/min)	Welding Current, A	Arc Voltage, V
Ar+18% CO_2	6	186	24
	6	188	30
	6	187	33
	8	233	24
	8	232	30
	8	234	33
Argon	6	182	24
	6	183	30
	6	187	33
	8	231	24
	8	229	30
	8	230	33

Table II Measured droplet diameter and electrode tapering at different welding parameters of GMAW process under Ar+18%CO2 gas shielding

Welding Current A	Arc Voltage V	Measured D, mm	Electrode Tapering (r), mm
185±2	24	0.352	1
	30	0.321	0.92
	33	0.310	0.87
230±2	24	0.279	0.80
	30	0.258	0.77
	33	0.189	0.64

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