Surface Topography of MIG-CO_2 Welds (solid vs fluxcored wires)

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Abstract

Welding is a major fabrication process in various machine building, automobile and structural fabrication industries. Out of the wide range of welding processes available, CO_2 welding is finding increased applications, because of its versatality and economy. The recent development of flux-cored wires for MIG-CO_2 welding has increased their utility further. In this paper, results of the experiments carried out with solid as well as flux-cored wires are presented. For the first time, the surface topography of the weld beads has been quantitatively represented. It is shown that flux-cored welding process provides smoother metal transfer with less spatter and together with the slag cover available, results in a better bead topography than solid wire welding ; thereby requiring less post-weld cleaning and dressing.

Introduction

The aspects of productivity and economy have always been factors dictating the improvement of existing processes or the development of newer processes. Inherent disadvantages of low deposition rates and efficiency associated with manual metal arc welding processes led to the development of gas shielded arc welding processes with continuous bare metallic wire electrode. Since an inert gas has been used normally for shielding purposes, the process was termed Metal Inert Gas (MIG) welding process. The use of cheaper active gas like CO_2 was first adopted in 1953 and ever since the CO_2 welding (Metal Active Gas—MAG welding) has been popular for the welding of structural and low alloy steels. The application of CO_2 welding has since increased, resulting in the consumption of continuous wire exceeding that of stick electrodes, in Europe and USA around 1977-78. The versatality and economy of CO_2 welding is being presently exploited in India also.

The use of CO_2 welding increased further with the adaptation of flux-cored filler wires. Even though the flux-cored tubular electrodes were first made use of for hard surfacing as early as in 1920, the application to MIG welding was much later ; because of the limitations experienced in producing consistent quality continuous wires. There are two major variations in this process viz., one process using external shielding with CO_2 or a mixture of gases ; and the other a self-shielding type, obviating the necessity of using additional shielding gas.

Over the years, the advantages of bare metallic wire CO_2 welding has been discussed in many forums. Among them are ; the increased deposition rate, improved penetration, adjustability to a high degree of automation, applicability to thin as well as thick sections, high welding speeds, absence of stub end losses, low hydrogen in weld deposit, narrow HAZ and minimum heat spread with low distortion. But the inherent disadvantages of arc spatter because of arc and metal

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transfer characteristics limited its application at high currents and also often led to higher costs because of the necessity of using anti-spatter compounds and post-weld cleaning operations. All these disadvantages are supposed to be avoided by using flux-cored wires and this investigation mainly concerns with these factors.

The factors mentioned above assume significance because, in the engineering industry, CO_2 welding is advantageously used on account of its capability to automation and its economy. Any further measure to increase productivity and economy by cutting cleaning costs will also favour increased application. Further a better weld appearance improves 'customer-appeal' which is presently described as part of weld cosmetics. The manufacturers of earthmoving machinery, and automobile components, as well as structural fabricators will be interested in such a process, if improved surface quality and reduction in spatter are proven factors.

LITERATURE SURVEY

Arc and Metal Transfer Characteristics (1-5)

In consumable electrode processes like MIG/MAG welding, the arc characteristics as well as metal transfer characteristics are important. For technological reasons like good penetration and bead appearance and for economic reasons like post-weld clean up cost and higher welding speed, it is necessary that arc should be smoother and the metal transfer should occur more efficiently.

Fundamentally, there are three types of metal transfer mechanisms viz. dip transfer globular and spray transfer. The dip or short circuiting transfer has enabled thin section as well as out of position welding ; it occurs with CO_2 and also with the use of gas mixtures. The globular transfer occurs at such current densities that the drop forming at the tip of the electrode is transferred only by the force of gravity, i.e. in down hand position. This type of transfer again occurs with all types of gases, inert, active or mixed type. In spray transfer, the metal is transferred from the tip of the wire electrode in an axial stream of fine droplets. This transfer occurs at high current densities, and can be used for out of position welding as gravity is not the controlling force. In pulsed transfer, the peak and background currents are so designed that spray transfer is ensured with lower mean current levels.

The type of metal transfer is influenced by factors likethe magnitude and type of welding current, electrode diameter, electrode extension, deoxidisers and emissive coatings on the electrode, bare wire or flux-cored, shielding gas composition and the power supply characteristics.

Spatter (6-9)

Almost all the variables controlling metal transfer have been reported to influence the degree of spatter also. It is generally expected that all those parameters which lead to stable arc and efficient metal transfer mechanism will cause less spatter ; wheras the factors which result in arc instablity and poor metal transfer will lead to spatter.

The arc spatter in short circuit type CO_2 welding is influenced by the inductance in the circuit. In case of globular transfer, the non-axial type of transfer as influenced by the dissociable diatomic gas results in spatter. A true type of spray transfer is not attained in CO_2 welding. Operating in the sub-threshold range of current also leads to spatter. In bare metallic wire MIG welding, proper additions of reactive gases like CO_2 or O_2 is necessary to stablise the arc, if Argon is used. It is reported that in the case of flux-cored wire electrodes, the flux constituents ensure more arc stability and the slag formed also aids in more efficient globular transfer, reducing spatter.

Bead Topography (10-11)

Normally, bead topography means the bead reinforcement pattern, the penetration pattern and the surface roughness caused by weld ripples and arc spatter. CO_2 welding is characterised by a narrower and more convex weld contour and the penetration is broader and rounder in depth. Use of mixture of gases like Argon CO_2/O_2 in proper proportions promotes favourable penetration pattern and reduces undercutting by aiding the wetting and flow of metal along the fusion edges. In the case of flux-cored wires, the surface appearance is expected to improve because of arc stability and slag action.

Aim

Because of the wide variety of the variables involved, only two specific problems are investigated in this work. They are—

(i) Whether improved arc action/metal transfer is experienced with flux-cored welding, in comparison with solid wire ; and

(ii) Whether flux-cored welding provides better bead appearance and if so, can it be quantitatively expressed ?

EXPERIMENTAL DETAILS

Plates used

10mm thick structural steel plates corresponding to Indian Standard IS 2062 were used in this investigation. As per ISO recommendation, standard plates of 150mm ×300mm were used, for experiments. Weld beads were deposited as 'bead-on-plate' type. Later, confirmatory experiments were also made with V-type butt welds and 90° fillet welds.

Solid Wire CO_2 Welding

1.2 mm dia solid wire was used with CO_2 as shielding gas. Typical parameters were :

Voltage : 25, 30, 35V
Current : 130, 180, 230A ; DCRP
Speed : 30 and 60 cm/min
Gasflow : 16 lit/min ; CO_2

Beads were laid by varying one parameter at a given time.

Mixture of Gases

Experiments were also carried out with pure Argon and also a mixture of 80% Argon, 20% CO_2, again making use of solid wire only. The typical parameters were :

Voltage : 25, 30, 35V
Current : 130, 180, 230A ; DCRP
Speed : 30, 60 cm/min
Gas Mix : 100% Ar., 12 lit/min
80% Ar., 20% CO_2 ; 12 lit/min

The gas mixture was prepared using suitable mix-nozzles and using flow meters.

Flux-Cored CO_2 Welding

Indigenously available seamless type flux-cored wire of 1.6 mm dia. was used. The flux constituents were of rutile type and the wire has a filling ratio of about 30%. The current densities for both solid wire welding and flux-cored welding were matched to provide a better comparison.

The following parameters were used—

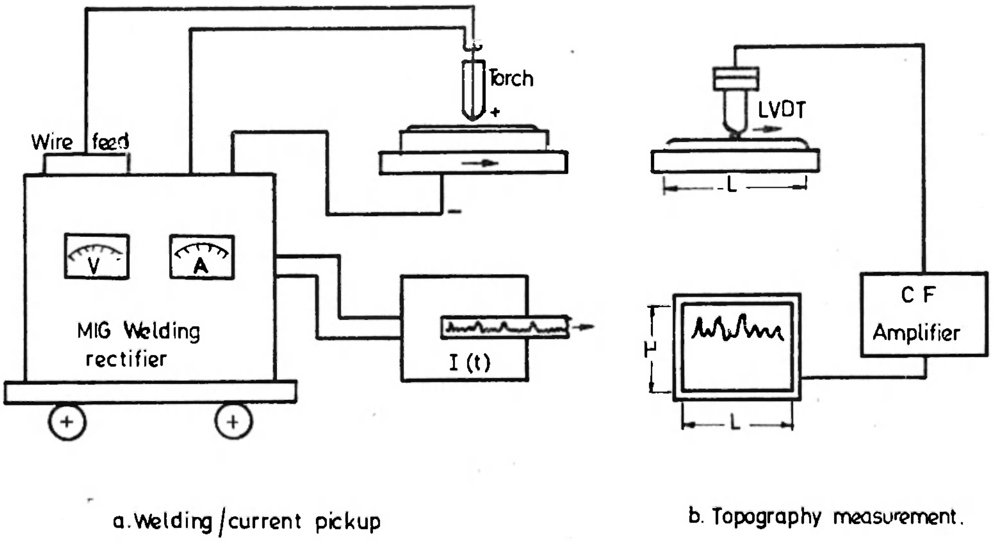
Voltage : 25, 30, 35V
Current : 180, 230, 280A ; DCRP
Speed : 30, 60 cm/min.
Gasflow : 12 lit/min CO_2

Arc and Metal Transfer Characteristics

To study these characteristics, the welding current variations experienced were recorded in a high speed X(t) recorder (Fig. 1a).

Surface Topography

The undulations on the surface caused by weld ripples and arc spatter were recorded using a spring loaded LVDT and traversing the same along the weld bead in the direction of welding. The LVDT signal is automatically recorded in an X-Y recorder Fig. 1(b). The recording sensitivity was of the order of ±5 μ but suppressed to a higher level of ±25 μ to yield a meaningful analysis.



a. Welding/current pickup

b. Topography measurement.

FIG. 1. EXPERIMENTAL SET-UP

Results and Discussion

Fig. (2) shows the weld current profile for solid wire CO_2 welding, whereas figs. (3) to (5) show the current profile for flux-cored process. In the case of solid wire process, the transient current variations are of a high order. There are large number of uncontrolled short circuits in the lower current range of 130A, which decreases with increasing the current to 230A. The observations during welding also indicated a high degree of spatter. In contrast, the current profiles for flux-cored welding are much smoother, showing neither uncontrolled short circuits nor arc spatter. It can be seen that this wire behaves optimally at a weld current level of 230A, showing least disturbances in the arc. Both in low (Fig. 3) and high (Fig. 4) weld speed ranges, as well as at different voltages (Fig. 5), the flux-cored arc welding gives smoother arc and metal transfer characteristics.

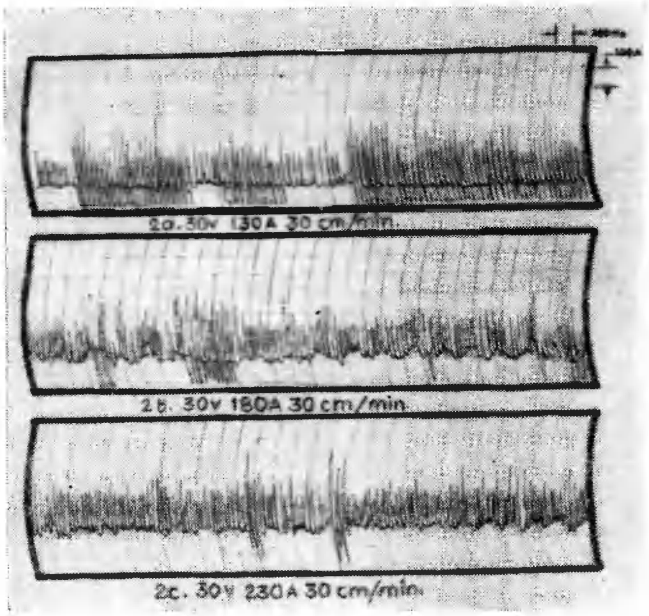


Fig 2. Weld current profile—solidwire Co_2—1.2 mm dia

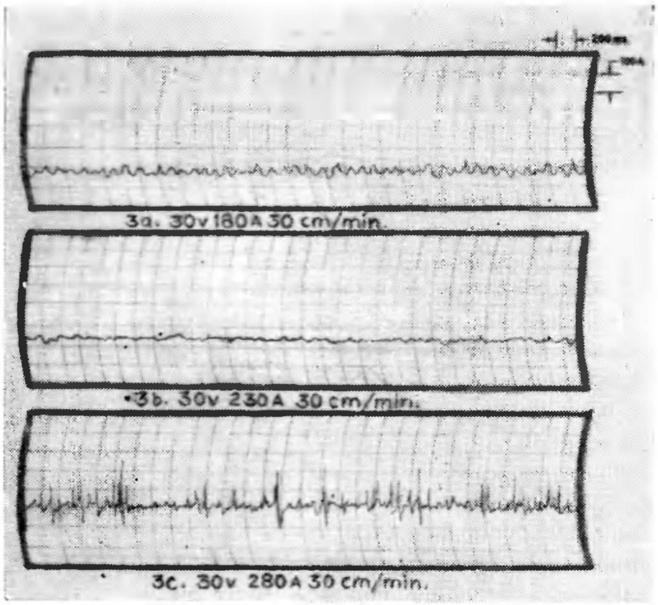


Fig 3. Weld current profile—fluxcored—1.6 mm dia

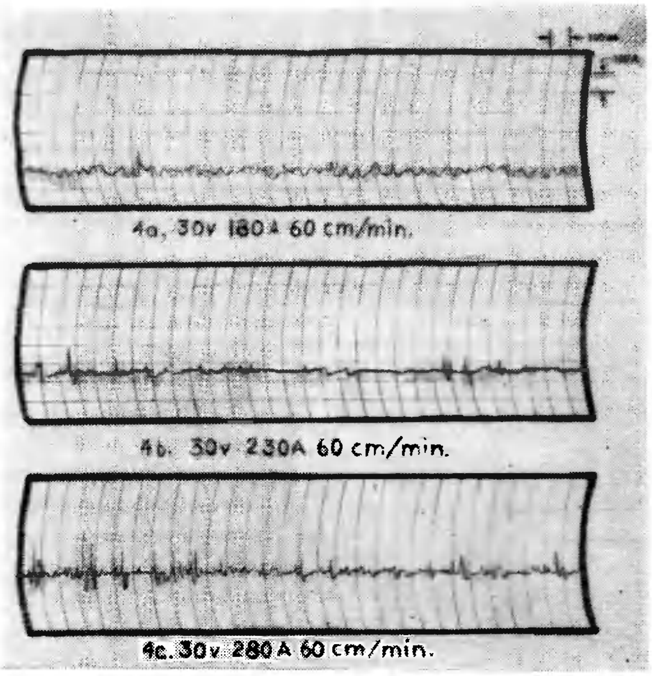


Fig 4. Weld current profile—fluxcored—1.6 mm dia

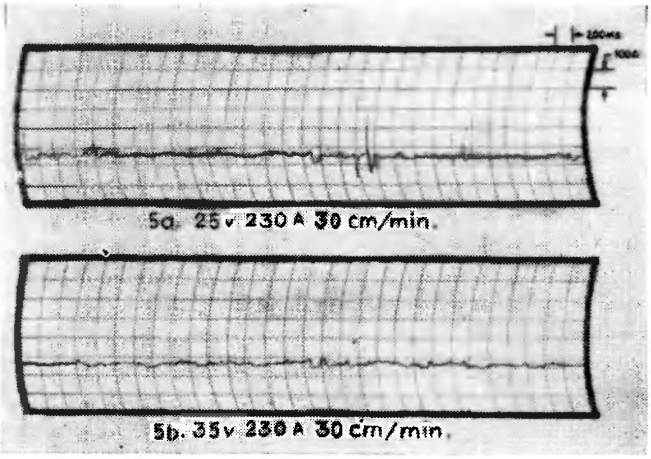
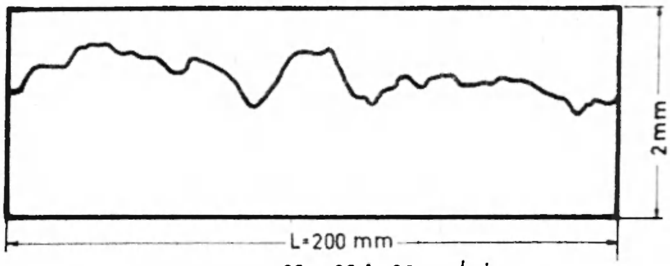


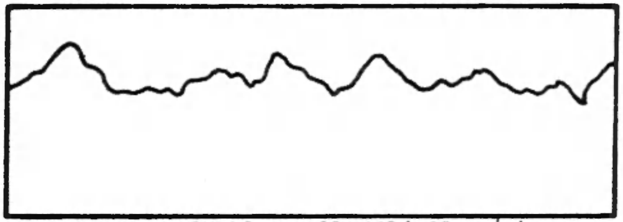
Fig 5. Weld current profile—fluxcored—1.6 mm dia

Surface Topography

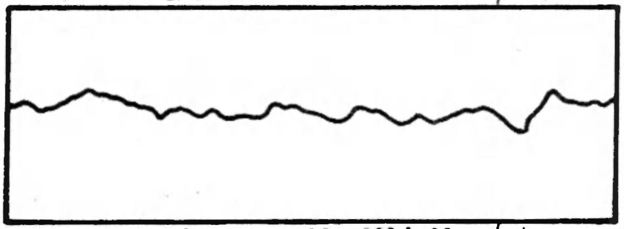
The surface topography of the weld bead as revealed by LVDT traverse are given in Figs. (6) to (11). For



a. SW 1.2mm 30v 130A 30 cm/min.

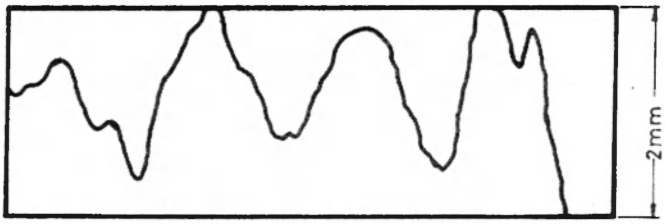


b. SW 1.2 mm 30v 180A 30 cm/min.

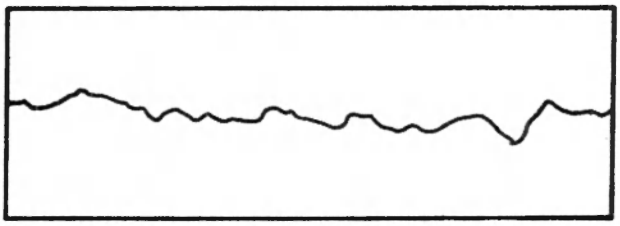


c. SW 1.2mm 30v. 230A 30 cm/min.

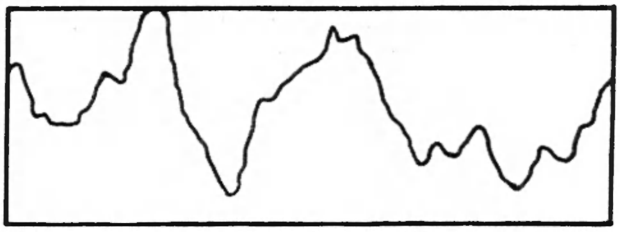
Fig 6. Effect of weld current—solidwire Co_2



a. SW 1.2mm 25v 180A 30 cm/min.

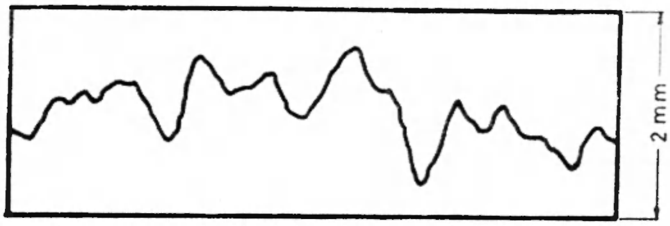


b. SW 1.2mm 30v 180A 30 cm/min.

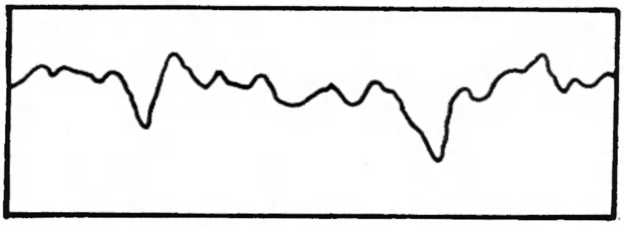


c. SW 1.2mm 35v 180A 30cm/min.

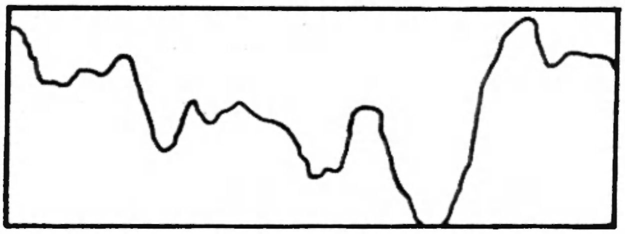
Fig 8. Effect of arc voltage—solidwire Co_2



a. SW 1.2 mm 30v 130A 60cm/min.

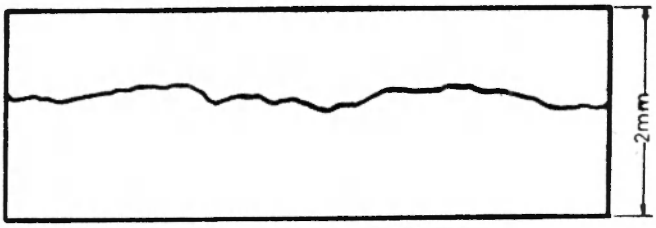


b. SW 1.2mm 30v 180 A 60 cm/min.

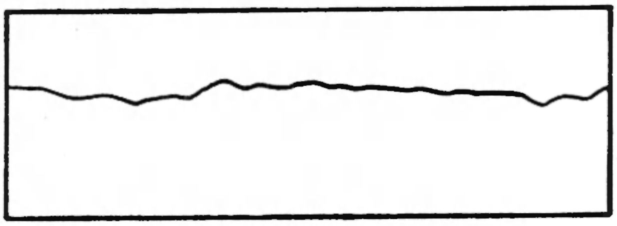


c. SW 1.2mm 30v 230A 60cm/min.

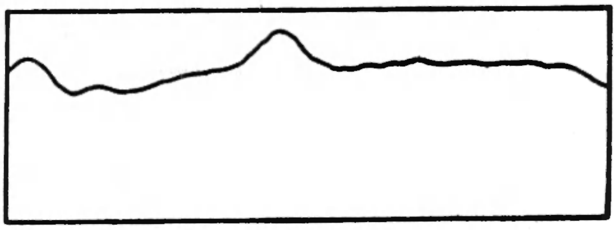
Fig 7. Effect of higher speed—solid wire Co_2



a. FC 1.6 mm 30 V 180 A 30 cm/min.

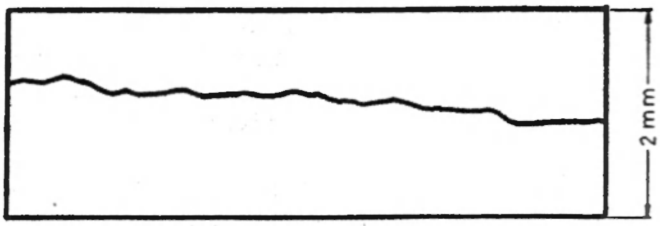


b. FC 1.6 mm 30V 230 A 30 cm/min.

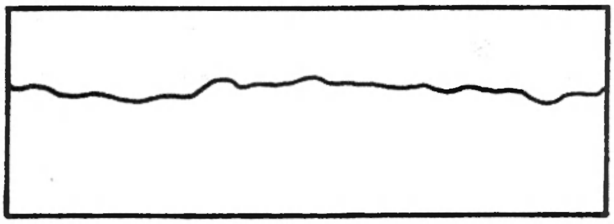


c. FC 1.6 mm 30V 280A 30 cm/min.

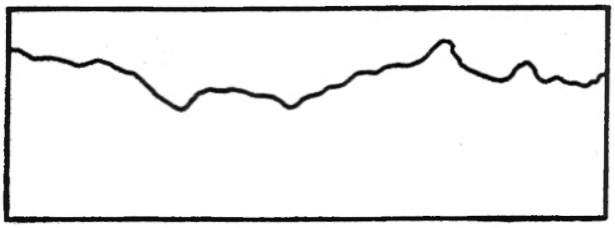
Fig 9. Effect of weld current—flux cored Co_2



a. FC 1·6mm 25v 230A 30cm/min.

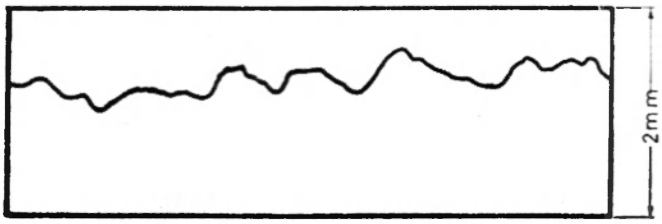


b. FC 1.6mm 30v 230A 30cm/min.

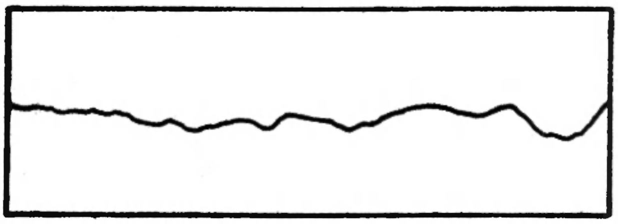


c. FC 1.6mm 35v 230A 30cm/min.

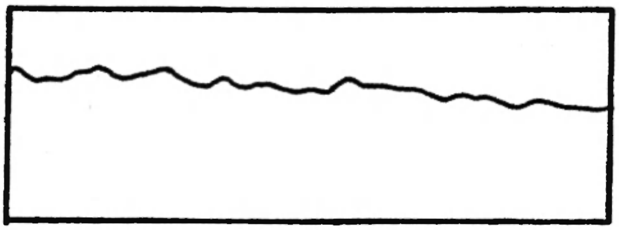
Fig 10. Effect of higher speed-flux cored Co_2



a. FC 1·6mm 30v 180A 60 cm/min.



b. FC 1.6mm 30v 230A 60cm/min.



c. FC 16mm 30v 280 A 60cm/min.

Fig 11. Effect of arc voltage-flux cored Co_2

Solid wire CO_2 welding, the effects of weld current (Fig. 6), welding speed (Fig. 7) and arc voltage (Fig. 8) are shown separately. Similar recordings are made for flux-cored welding also. (Fig. 9 to 11). To enable a statistical analysis of the same, the digital output of the recordings are used to arrive at statistical quantities like arithmetic mean, standard deviation and coefficient of variation. The data for various welding conditions are given in Table (I). Since the arithmetic mean as

Table-I

(Bead Topography—Statistical Analysis)

Sl. No.	Weld Bead	S.D.(σ) Microns	C.V. %
1	SW CO_2 30V 130A 30cm/min	175	0.13
2	,, 180A ,,	134	0.10
3	,, 230A ,,	82	0.08
4	SW CO_2 30V 130A 60cm/min	273	0.24
5	,, 180A ,,	186	0.16
6	,, 230A ,,	492	0.57
7	SW CO_2 25V 180A 30cm/min	481	0.39
8	,, 30V ,, ,,	134	0.10
9	,, 35V ,, ,,	468	0.49
10	SW AR 30V 130A 30cm/min	276	0.21
11	,, 180A ,,	379	0.33
12	,, 230A ,,	324	0.26
13	SW 80AR/20CO_2 30V 130A 30cm/min	317	0.27
14	,, 180A ,,	287	0.23
15	SW 80AR/20CO_2 30V 130A 60cm/min	386	0.40
16	,, 180A ,,	445	0.48
17	SW 80AR/20CO_2 30V 180A 30cm/min	287	0.23
18	,, 35V ,, ,,	278	0.16
19	FC CO_2 30V 180A 30cm/min	80	0.07
20	,, 230A ,,	63	0.05
21	,, 280A ,,	145	0.10
22	FC CO_2 30V 180A 60cm/min	132	0.11
23	,, 230A ,,	84	0.09
24	,, 280A ,,	92	0.07
25	FC CO_2 25V 230A 30cm/min	108	0.09
26	,, ,, ,,	63	0.05
27	,, ,, ,,	156	0.12

Note : SW—Solid wire
FC—Flux-cored wire

such has no significance here, as it depends on bead height, it is not given in the Table. The standard deviation (6) and the coefficient of variation (C.V) are taken as representative of undulations of the bead profile.

A general observation of all the results indicates that—

		S.D. $(\sigma)\mu$	C.V. (%)
Solid wire CO_2	:	82-492	0.08-0.57
Solid wire Ar	:	276-324	0.21-0.33
Solid wire Ar/CO_2	:	278-445	0.16-0.48
Flux cored CO_2	:	63-156	0.05-0.11

An analysis of the above results indicates that flux-cored welding provides much smoother beads than solid wire welding.

Further analysis indicates that for both solid wire and flux-cored wires, increase in heat input resulting from either increase in current or decrease in welding speed (Figs. 6, 7, 9, 10) provide relatively smoother weld beads. The investigations also show that there is an optimum voltage (Figs. 8, 11) where the bead appearance is in the optimum range.

A comparison of figs. (2 to 5) with figs (6 to 11) clearly indicates that smoother arc and metal transfer characteristics result in smoother weld beads. A further comparison, say fig. 3(c) with fig. 9(c) will also show that any minor variations in arc stability will also result in relatively less smooth bead appearance.

Conclusions

The following main conclusions can be drawn from the investigation.

(i) The weld current profiles for flux-cored arc welding are smoother, showing neither uncontrolled short circuits nor arc spatter. This indicates that an improved arc action and metal transfer characteristic is obtained with flux-cored welding, as contrasted with solid wire CO_2 welding.

(ii) The surface topography of flux-cored arc welding shows smoother bead appearance ; much better than solid wire welding either with CO_2 or Ar or Ar/CO_2 mixture, and

(iii) For a given welding process, there is an optimum range of weld parameters (V, I, S) to give an optimum bead topography.

The results reported in this paper are mainly based on the work carried out by the first author at I.I.T., Madras.

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