RECENT ADVANCES IN ARC WELDING

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Keynote address at SEMINAR on APPLICATION OF WELDING IN STEEL
4th August 2001, C.M.E.R.L - Durgapur.

It's a great honour to have been invited to deliver the key-note address at this seminar on 'Application of Welding in Steel' organized by IIW CALCUTTA Branch and Regional Engineering College Durgapur. I personally and on behalf of my company BOC India Limited would like to thank the organizers for giving me an opportunity for sharing my thoughts with you on this very important occasion.

INTRODUCTION

Arc welding although invented around 100 years ago still remains the main means of fabrication for steel and other metallic materials. It has come to play a vital role in the growth and development of important sectors of the economy. Such as Power Generation, Steel, Heavy Engineering and Automobiles. Of the four major arc welding processes i.e. SMAW, GMAW, SAW, GTAW, Gas Metal Arc Welding (GMAW) has become the dominant welding process in the fabrication industry worldwide, because of the high levels of productivity and automation attainable with the process and ideally suited to manual, mechanized semi and fully automated and robotic welding applications. The table below gives the comparative use of the different welding processes in India and the developed countries.

Table 1

Welding Process	Percentage share in Weld metal deposited	
	INDIA	DEVELOPED COUNTRIES
Manual Metal Arc	77.5	20
Submerged Arc	7.5	8
Gas Metal Arc (MIG)	14.0	70 50-Solid Wire 20-Cored wire
Gas Tungsten Arc (TIG)	01.0	2

During the last decade even in India there has been a distinct change from SMAW to GMAW and the percentage of weld metal deposited by this process has grown from 6% to 14%. However the change has been mainly confined to the organized sector comprising of large and medium fabricators particularly in the automotive sector.

With globalization the competitive scene is becoming more intense and the switch to GMAW is expected to be more rapid to achieve improved quality at lower cost. Thus today we would like to take an overview of what have been the evolutionary advancements in this most important process.

ADVANCES IN GMAW

To cater to the demands of industry the GMAW method is undergoing continuous development and the following improvements and developments have been introduced over the last few years.

1. Solid Wire with Argon/Helium based gas mixtures.

2. Synergic Pulsed MIG process.
3. Rapid melt/Rapid Arc/T.I.M.E process
4. Tandem MIG process / Twin - wire GMAW.

However these developments in processes have been made possible by parallel developments in

1. Welding equipment and Power Sources.
2. Shielding gas mixtures.

Thus before we discuss the process improvements we will briefly examine the advances in Welding Equipment and Shielding Gas mixtures.

TRENDS IN WELDING EQUIPMENTS

Conventional power sources such as transformers, DC rectifiers, DC generators, etc., are quite bulky. These power sources are relatively energy inefficient and consume much higher power while welding. No-load losses of power are also quite substantial with these sources. New generation power sources are either thyristorised or are inverter type. Inverter type power sources are much smaller in size and weight, are portable and occupy much smaller floor space. Inverters are far more energy efficient than conventional power sources. Table 2 shows input KVA which actually determines the input current required and thus the size of the power sources.

Table 2

Sr No.	Output Welding Current	Input, KVA Required		Efficiency %	
		Conventional	Inverter	Conventional	Inverter
A	200A	15.59	<8.40	75.70	85
B	300A	20.98	<9.90	80.00	88
C	400A	26.00	<14.60	81.45	88.90
D	500A	30.80	<20.20	82.20	89.30

Table 3

Sr. No.	Electrode dia (E7018 type)	Power Consumption - KW per hr.	
		Motor Generator	IGBT Inverter
1.	2.50 mm	6.5	2.5
2.	3.15 mm	8.5	3.0
3.	4.00 mm	10.5	4.0

It would be noted that 200amps output inverter uses approx. half the KVA for a conventional power source. No-load losses for inverter power sources are also below 10 watts as compared to over 200 watts for conventional power sources.

Further the energy consumption for a particular size of electrode is much less in inverter power sources as shown in Table 3.

With inverter design, it is possible to build into a single unit multiple process applications such as MMW,GTAW, GMAW-P. A simple switch allows process selection. With inverter type power sources for TIG welding, it is possible to establish arc with 1 Amp setting. For MMAW welding inverter type power sources provide benefits such as hot start and arc force. Hot start benefit facilitates easier striking and restriking of the arc. This facility is especially useful for pipe welding in 5G/6G or 6 GR positions.

With an inverter, arc characteristics of GMAW can be designed into the power source and adjusted by the Operator. This technique overcomes many of the perceived disadvantages of short-circuit transfer. The development of invertor power source is one of the main reasons that GMAW-P use continues to grow. Inverter power sources allow the type of control required for effective GMAW-P welding. Synergic pulsed MIG power sources, which are advanced transistor controlled power sources are pre-programmed so that the correct pulse parameters are delivered automatically as the wire feed speed is varied. The power source can have pre-programmed pulse parameters for specific material.

Even though inverter type power sources are expensive welding industry has realized that the quality of the deposited weld-metal and the deposition rate can also be positively influenced by the power source and are opting for modern equipment.

Current welding process equipment developments relate to the use of microprocessor controlled inverter technology which is a minimum requirement for full real time adaptive process control based on fuzzy logic or neural network logic systems for automated and robotic applications. The inverters with switching frequencies of over 50 000 hertz's make real time process control a reality in combination with high speed sensing, monitoring and data processing technology. Fuzzy controlled inverter power sources currently on the market are able to adaptively change the voltage and wire feed speed in manual welding systems as welder's arc length changes from the ideal length. The self correcting adaptive responses take place at high speed providing constant welding penetration depths not attainable with other power source types.

SHIELDING GASES

In GMAW, the shielding gas plays a very important role in determining the quality and cost effectiveness of welded joints. In this context, the last few decades have seen development and increased use of different Argon-based gas mixtures for welding all types of materials from carbon-manganese steel to stainless steel, aluminum and non-ferrous alloys because of their enhanced performance characteristics, improved weld quality and productivity along with reduction in total welding costs.

Presently, in most of the western industrial economies, Argon-based mixtures are used for nearly 90% of all GMAW, using both solid and flux-cored wires. In India, till a few years back CO_2 was being extensively used as a shielding gas for GMAW of carbon-manganese/low-allow steel due to its ready availability and low cost. Argon, being a short-supply item, was only used for aluminum and stainless steel welding where there was no alternative. Today, however, the Argon availability position has dramatically changed leading to ready availability of a range of gas mixtures for various applications at economical prices. Already a number of industries have switched over to these mixtures with resultant improvement in weld quality, productivity and reduction in overall cost of welding.

WELDING ARC CHARACTERISTICS

A suitable gas would need to exhibit a low ionization potential; (the voltage needed to ionize the gas) so that the formation of the plasma can be easily accomplished. Low ionization voltages indicate that the gas is easily ionized. Arc starting and arc stability are influenced by this property.

The shielding gas also significantly affects the mode of metal transfer, particularly in the open arc process. With Argon & Helium it is possible to obtain fine axial spray transfer above a certain transient current. However, with CO2 globular metal transfer occurs due to the electromagnetic force with larger droplet size and high spatter.

Arc 'stiffness' is indicated by the force generated between the electrode and the workpiece. This is also affected by the shielding gas and it has been shown that helium-rich gas mixtures produce much lower arc forces than argon at the centre of the arc.

Oxygen added to Argon-based shielding gases in limited quantities has the effect of reducing the surface tension of the molten droplets, resulting in smaller droplets detaching from the end of the wire electrode during transfer through the arc and a flatter bead. The added oxygen also results in increased weld pool fluidity. The heat transfer is also improved with oxygen bearing shielding gases, which results in improved weld metal penetration.

CARBON DIOXIDE

Carbon dioxide (CO2) has a much higher density than air and makes a good shielding medium with high side wind resistance. It also exhibits high thermal conductivity giving a much broader arc plasma and weld profile. CO_2 is an active gas and has a very high oxidizing potential. The molten metal transfer modes applicable to the use of this gas are confined to dip transfer (short circuiting) and globular transfer.

PROBLEMS IN USING CO_2 AS SHIELDING GAS

- Unstable arc with high level of spatter
- High penetration with 'thumb' profile
- Undercut/sharp notch at the toe of weld
- High fume formation rate.
- Higher level of reinforcement.

WELDING SPEED AND DEPOSITION RATE

The more the welding speed is increased with CO_2 , the more convex the weld , while at the same time the transition between the weld metal and parent metal is poorer. This limits the welding speeds with CO_2 compared with Argon mixtures (Ref. Fig 1. below).

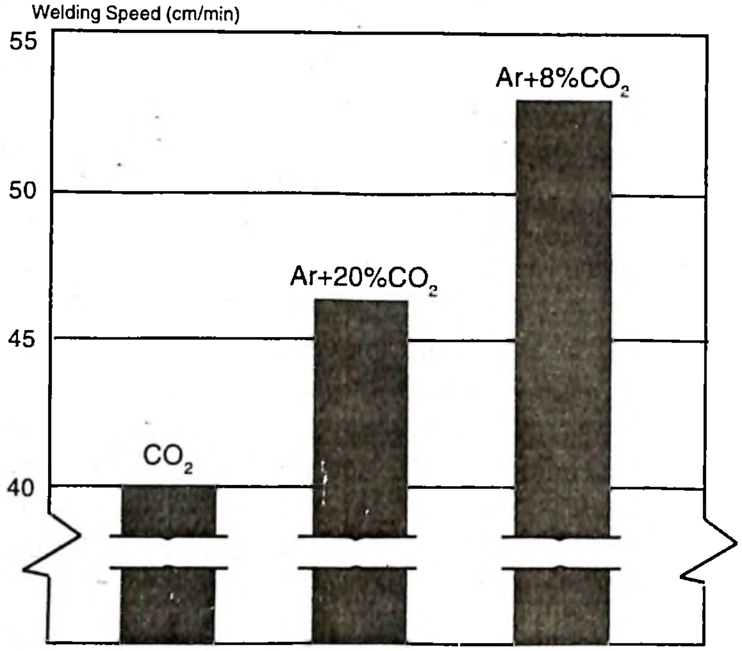


Fig. A : Max. welding speeds for fillet joints using different shielding gases. 4mm throat thickness, 6mm plate thickness, mild steel, wire dia 1.0mm, wire feed speed 12m/min.

In this experiment three different shielding gases were used for MAG welding of mild steel in a fillet joint. The wire speed was kept constant and the voltage was set to an optimum level for each gas . The wire speed was then increased until the weld bead was too convex. It can be seen that lower the CO2 content , the higher the welding speed.

PRODUCTIVITY, EFFICIENCY AND ECONOMY

The principal benefits of using Argon - based mixed shielding gases for GMAW are

1. The attainment of spray metal transfer mode, giving increased welding speeds and higher productivity leading to lower fabrication costs.
2. Significantly reduced oxidation leading to smoother, high quality, less oxidized weld surfaces, less elemental losses through the arc, resulting in improved mechanical properties.
3. Flatter fillet weld profiles with less weld metal wastage compared to convex CO_2 fillets.
4. Significantly lower spatter rates leading to reduced wastage and clean up time .
5. Environmentally friendlier process with significantly lower particulate fume formation rates and carbon monoxide emissions.

A judicious choice of gas can have a beneficial effect on the total cost of the welding operation. Often the use of a more expensive gas can result in cost savings in labour and wire usage leading to a total cost saving. The wire savings result from the flatter weld profile characteristics of Argon - based mixed gases and reduced spatter. A global perspective of costs of fillet welds shows that as the weld size increases the cost of wire and labour increases dramatically. The total cost of welding should not be confined to the cost of labour and welding consumables only. Factors such as overheads, plates preparation , NDT, back grinding/gouging, repair work, removal of spatter etc should be considered also.

ARC TYPES AND METAL TRANSFER

Conventional MIG/MAG welding involves working with either short arc welding or spray arc welding. The type of arc depends on how wire feed speed and voltage have been set in relation to the wire dimension and shielding gas used.

Short arc welding involves transfer of material from electrode to the weld pool in form of short circuiting droplets. There is low heat input to the work piece and this envelopes suitability of the process for relatively thin material, for root passes and for positional welding. The disadvantage is low deposition rate, which in turn results in a low welding speed.

In case of spray arc welding the transfer of material takes place in the form of a directed flow of small droplets which do not short-circuit between the electrode and melt. The deposition rate is high and therefore; spray arc welding is utilized for welding filling passes and in the welding of heavier material.

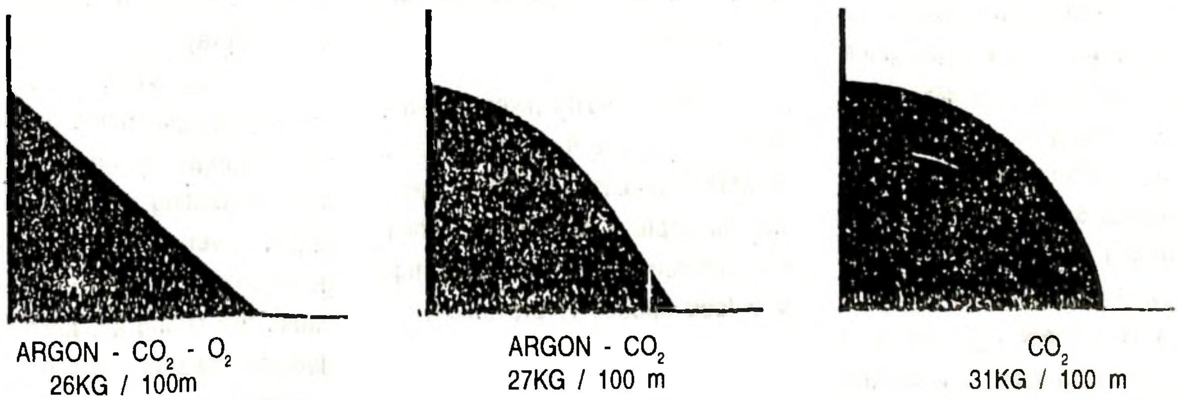
HIGH PRODUCTIVITY GMA WELDING

The most important single factor in increasing productivity is the deposition rate, The average rate in GMAW is about 2-6 kg/hour. If this rate can be increased to 7-10 kg/hour or even higher, a very high rate of productivity and cost advantage can be derived in GMAW. Basically two methods have been utilized for achieving higher deposition rates in GMAW.

a) Single wire with very high wire feed rates and increased stick out with varying voltages. These processes have been given various proprietary names such as - Rapid Arc, Rapid Melt and T.I.M.E.

b) Two wires, one behind the other, with two variants Twin GMA welding (also called Twin Arc , Twin Power, T.I.M.E. twin etc.) and Tandem MIG Welding. In Twin GMAW there are two equipotential contact tubes for both wires so that always the same voltage is applied for both the wires. In tandem MIG there is an electrical separation by an insulator between the contact tubes for the two wires and two independently controlled power

EFEECTS OF WELD BE.AD GEOMETRY ON WIRE CONSUMPTION



sources with individual user interfaces are used.

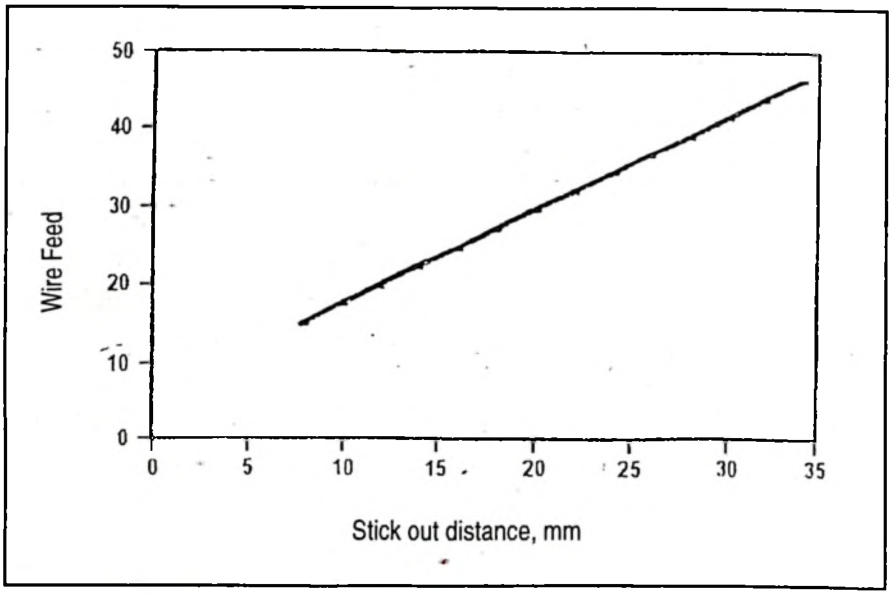
RAPID ARC / RAPID MELT OR T.I.M.E. PROCESS.

The concept comprises of two welding procedures: RAPID ARC, which aims at raising the welding speed in most plate thicknesses and RAPID MELT, which raises the deposition rate, primarily in the welding of heavier material.

The techniques are based on old and familiar observations e.g. that higher wire feed speed and preheated wire offer high deposition rates (Ref. Fig.4). However, one has to know how to combine the different parameters to make the arc as productive as possible, while remaining quite stable, and giving high weld quality. In combination with modern power sources and wire feed units, this process unites shielding gas technology and, this process know-how forms the whole secret behind RAPID ARC and RAPID MELT

RAPID ARC

The rapid arc welding process is designed to make it possible to increase the welding speed without the welding defects normally associated with high welding speed (undercut, high weld reinforcement). The process involves selecting a high wire speed and a longer wire stick out. Normally, a spray arc should be achieved when these high wire feed speeds are employed, but as the current is reduced as a result of the long electrode stick-out and the voltage is adjusted to a relatively low value, a forced short arc is instead obtained. A longer electrode stick-out results in increased resistance and hence reduced current in the case of constant voltage system.



The increased resistance also results in a certain amount of electrode preheating , which in turn increases the deposition rate . The forced arc is similar to the short arc as regards the metal transfer. However it is superior to both short arc and spray arc as regards deposition rate and welding speed.

RAPID ARC welding gives a better penetration profile than conventional MIG/MAG welding. The advantage is that incomplete penetration, which was previously a problem at high wire feed speeds is prevented.

RAPID MELT

Rapid Melt is a welding process which is primarily intended for increasing the deposition rate when welding heavier sections. A deposition rate of up to 25 kg per hour can be obtained although 10-20 kg per hour is a more realistic figure. Rapid Melt can be carried out using two different types of metal transfer, the Moderated spray arc and rotating arc. The wire feed speed is same in both cases. The desired arc type is set using the voltage: A higher voltage results in a rotating arc and lower voltage moderated spray arc. Moderated spray creates a narrow extremely deep penetration profile due to large droplet being forced down very strongly to the weld pool. In case of rotating arc, the penetration profile is very broad and gives very good side wall fusion. This is because the strong arc force which is directed towards the side wall. The transition between weld bead and base material is also extremely good.

IMPORTANCE OF SHIELDING GAS

The development of Rapid Arc and Rapid Melt has demonstrated that the optimum shielding gas for both methods is an argon-based shielding gas, contain about 8% CO_2. Thus optimum mixture is required to obtain the desired types of metal transfer needed for this method. In case of Rapid Arc welding this shielding gas increases the wettability of the weld pool and therefore improves the transition between weld bead and base material, as well as the bend shape which is flatter in spite of very high weld speeds. When it comes to Rapid Melt this type of shielding gas is required to get the regent types of metal transfer (rotating & moderated spray). The transition between weld bead and base material is also improved due to high wettability of the weld pool. For both methods the spatter level and amount of surface slag is minimized due to low CO2 content. The addition of helium to the argon/carbon-dioxide mixture is important for the properties of this process .In the T.I.M.E. process is not limited to the "ORIGINAL". T.I.M.E. gas composition is 0,5% O2, 8% C02, 26,5% He, 65% Ar but the process can also (depending on the application) be used with other gas mixtures.

TWO WIRE GMA WELDING PROCESS.

Whereas the high deposition rate processes with single wire could achieve maximum speeds of 2 mtrs per min and practical deposition rates 13 to 14 kgs per hour, further increase in deposition efficiency is limited by the unstable arc rotation. It is only by development of the 2 wire GMAW technology which is characterized by a second electrode feeding into a common gas nozzle, a distinct increase of deposition efficiency with a simultaneous increase in the weld speed has been made possible with tandem MIG speeds as high as 5 to 6 mtrs/min are achievable.

TWIN GMAW PROCESS

In this process there is a torch with common equipotential contact tubes for both wire electrodes so that the voltage between the contact tube and the work piece is same for both wires. As two equidirectional current carrying conductors exert a magnetic attraction to form for one another, one root migrates towards the other arc forming a common root depending on the electrode spacing. At a spacing of 4 to 7 mm (depending on wire size and current) the transferred drops meet in a common weld pool. If the distance is too small the common drop may form at the wire end and create process trouble and if the distance is too large separate weld pool forms resulting in heavy spatter. This process is limited to spray arc or preferably pulsed arc techniques.

TANDEM GMAW

For a separated control of the weld processes for both wire electrodes, in Tandem GMAW Technology two independently controllable power sources with individual user interfaces are applied. Moreover, a separated potential for both contact tubes is necessary. The electrical separation of both wire electrodes therefore is achieved by a V-shaped symmetrical inclination of the contact tubes at an angle of approx.10-11°. This, in comparison with the two-wire torch, leads to a somewhat larger design which entails a slightly higher gas consumption.

In general, Pulsed-Arc Welding is used, however for thicker plates,

The following mixtures are currently in use, having proved themselves suitable for various areas of application and welding tasks:

CORGON HE 30	MISON 8	T.I.M.E. II
30 % He 10 % CO_2 60 % AR	8 % Co_2 92 % AR 300 PPM Nitrogen Monoxide	2 % O_2 25 % CO_2 26.5 % He Remainder AR

Spray-Arc Welding is also applied. Modern tandem power sources are frequency-coupled. By the synchronization of master and slave power source a phase shift of the pulsed currents from wire electrode 1 and 2 can be achieved. In comparison with the Twin-Arc Technology, the advantage of the Tandem GMAW Technology is that by means of the separated set-up of both processes the arcs for both wire electrodes can be maintained very short. In principle, too long an arc leads to undercuts, so both arcs should be kept as short as possible. As the trailing wire, however, is burning-off into the weld pool of the leading wire, an equally long trailing second wire would lead to short circuits and the immersion of the wire end into the weld pool resulting in heavy spatter. Therefore it is preferable to keep the length of the trailing wire electrode shorter than that of the lead wire.

CONCLUSION

In the foregoing I have tried to give some idea of the recent developments for improving both quality and productivity in GMAW. Although adaptation of some of these processes may involve substantial initial investments in equipments, but in the long run they pay off in reduced overall welding costs.

In today's highly competitive scenario our fabricators will need to selectively adopt some of the relevant new technologies for their survival. ■