Technological advances in Inert gas shielded arc welding processes —an over view

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ABSTRACT

Inert-gas-shielded arc welding processes widely used for quality welds comprise MIG, TIG and Plasma. The technological advances which have taken place since their introduction, can be broadly classified in terms of process-design and process-parameters.

The general developments in process-design encompass the pulsification of the arc current and magnetic control of arc. The advances in MIG cover narrow gap welding, welding in thermally ionized gas, synergic pulse mode and spot welding. Hot-wire, orbital and multi-electrode techniques are some of the process-design developments in TIG. Another recent modification is the SERIES MIG-TIG welding. The above technological advancements contribute to the superiority of the welded structure from the view point of metallurgical and mechanical properties, higher degree of automation, ease of accessability, in-situ operation, reliability and economy.

The developments in process-parameters include combined effect of anode/cathode geometry and type of shielding gas on the penetration characteristics in TIG, and high deposition rate with electrode negative polarity in MIG. Arc stability and achievability of keyhole weld with intermediate plasma and potentiality of microplasma in the field of precision fabrication have been highlighted by the authors with due emphasis.

1. INTRODUCTION

The difficulties posed by the usage of powerful fluxes needed to form a truely protective fluid slag on the easily oxidised magnesium during fusion joining gave rise to the technique of protecting the welding arc and molten pool by argon or helium gases (1). These gases being chemically inert provide very effective protection against pick-up of oxygen, nitrogen and other atmospheric impurities. The inert gas-shielded arc welding processes recognised for producing quality welds comprise TIG (tungsten inert gas), MIG (metal inert gas) and Plasma.

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TIG is basically a non-consumable electrode process employing tungsten electrode. In MIG, the consumable electrode serves the purpose of electrode as well as filler wire. Plasma process is characterised by a constricted plasma colunm. Since their introduction, these welding processess have conceived a new generation inherting the fruits of advancement. The present paper highlights the various technological advances in inert-gas-shielded arc welding processes and their respective advantages over the conventional practices.

2. CLASSIFICATION

The technological advances which have taken place can be classified in two categories namely, process-design and process-parameter. The process-design encompasses the developments in the hardware of the process and modifications in the variables of the process technology fall under process-parameter. The various advances in inert-gas-shielded arc welding processes are summarised in Fig.1 based on the above classification scheme. It is evident from the figure, that the developments viz. pulsification of arc-current and magnetic control of arc are the common to TIG, MIG and Plasma.

TIG Hot Wire Technique

This technique is characterized with the heating of filler wire by resistance or induction means prior to deposition. In resistance heating, the wire always remains in contact with the weld puddle in order to make the electrical circuit complete (Fig.2).

Higher deposition at a lower dilution level is the main feature of the hot wire process and thus makes it very effective for surfacing application. Additionally, due to preheating, the volatile surface contaminants of the filler wire get evaporated, leading to total elimination of the entrapped porosities. Even for applications which do not call for high deposition, this technique can be readily used with increased welding speed resulting higher production rates (3 to 4 times).

Orbital TIG

Orbital TIG welding is a recent development

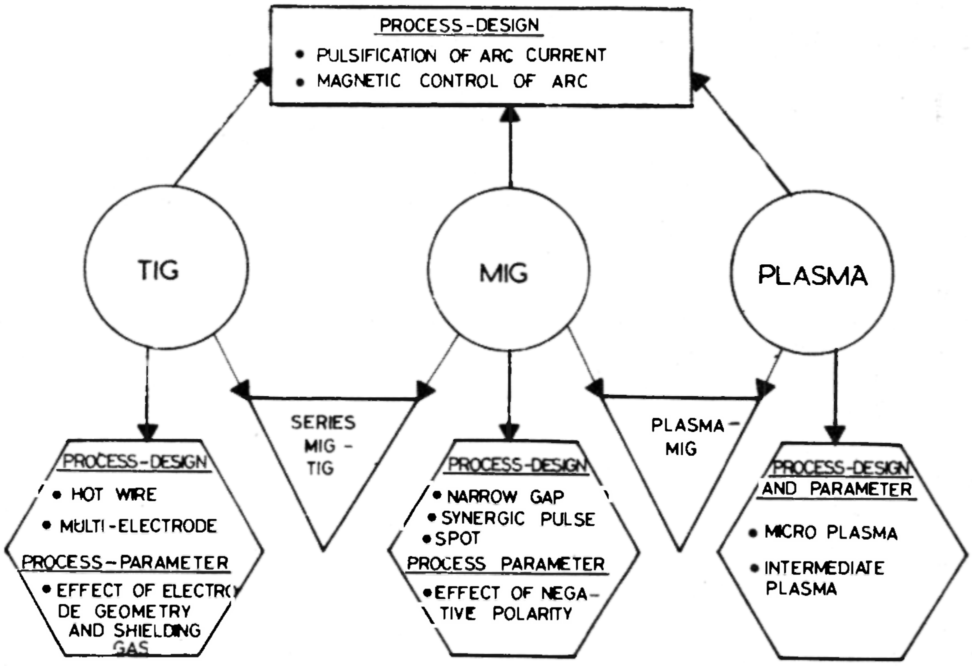


Fig.1 - Various Advances In Inert-Gas-Shielded Arc Welding Process

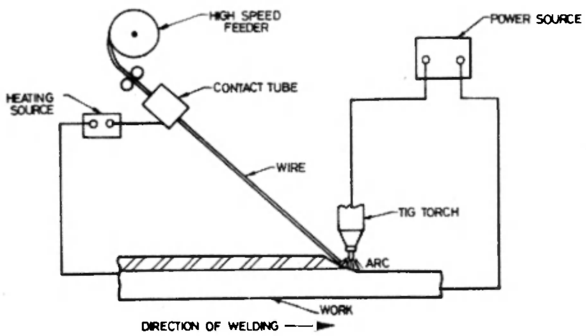


Fig.2 - Set-Up For Hot Wire Tig

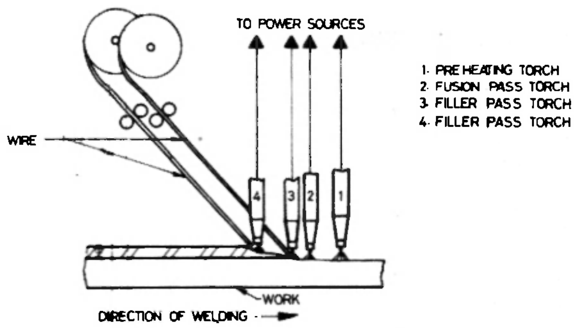


Fig.3 - Multi-Electrode Tig Employing Four Electrodes

to carry out semi-automatic circumferential seam welding of pipes and tubes. The same is acquired by close tolerance control in pipe preparation, head positioning accuracy in in-situ operation, oscillation of torch, weld speed programmer and weld current programmer in order to take care of variations in weld position (2).

The process finds extensive application in the welding aircraft external fuel tanks (3) and CANDU type nuclear reactors (2). Naval ship repair facilities employ extensively the automatic orbital welding process to weld pipes and tubes (4). Consumable inserts of different shapes can be successfully used to get a reliable pattern of penetration in pipe and tube welding.

Multielectrode Technique

This process employs more than one electrode. In two electrode process, the first electrode imparts the preheating to the basemetal. This in turn, reduces the residual stresses, hot cracking tendency and gives deeper penetration and higher welding speeds. Another recent development adopts four electrodes. The first electrode provides the necessary preheat, the second one makes the fusion-pass and the last two electrodes which are accompanied by filler wire complete the filler passes (Fig.3). Application of this technique yields higher production-rates (5).

Electrode Geometry and Shielding Gas

Contrary to the accepted practice, Savage et al (6) reported that the weld depth/width ratio increased as the electrode vertex angle was changed from 30° to 120°. Spiller et al (7) carried out a series of experiments on stainless steel plates of 6.4 and 3.2 mm thickness to provide better understanding of the above conflicting evidence and practice. They reported that it was more appropriate to consider three classes of plate thickness : 'thin' (penetration between 70 and 100%), 'intermediate' (30 to 70%) and 'thick' (lesser than 30%) and found that bead width is a linear function of vertex angle and decreases as the angle increases. However, depth of penetration depends on vertex angle and thickness of the plate. Increased vertex angle yields lesser penetration in case of 'thin' plates and vice-versa for 'thick' plates (Fig.4).

This is explained on the basis that bell shaped envelope is formed by the plasma jet striking the pool surface and being reflected by it. The vortex angle of 120° shows a complete absence of plasma jet. The pool surface on 'thin' plates is more easily depressed. The significant depression with pronounced cathode plasma jet tends to trap the plasma and thereby increases the efficiency of heat transfer in the vertical axis in the 'thin' plate case (Fig.5).

The results of the studies carried out by Key (8) show that shielding gas mixtures containing high ionization potential helium gas improve penetration by increasing the overall volume of the fusion zone without having strong effect on depth/width ratio.

MIG Narrow Gap Welding

This process is designed for the welding of heavy and very thick plates and primarily calls for the usage of a square butt joint with a narrow gap (6 to 9 mm) regardless of the thickness and welding position (9). The various narrow gap welding techniques aimed towards ensuring complete fusion on both the sides and high diffusion rates, are schematically shown in Fig.6.

Economy, reliability and possibility of in-situ operation are the other attractive features of this process. It finds extensive applications in ship-building and pressure-vessel industries.

Synergic Pulse MIG

In this system, the unit pulse principle has been adopted to produce a fully automated control system. The WAVE unit pulsed current would detach one droplet of metal for each pulse. In order to ensure material transfer with each pulse, the pulse must have a minimum duration. Villeminot et al (10) reported that this threshold level decreased slightly as the pulse amplitude was increased.

In practice there is a range of unit pulses which is determined by material composition and the wire diameter to detach droplet of specific volume (11). Once the range is fixed the power source is pre-programmed.

Spot Welding

MIG spot welding process is attractive both as a fabrication technique and for cladding structural materials for corrosion resistance. The process uses a standard MIG torch with a special nozzle fitted with legs to maintain it at a preset distance from the work-piece. Jordan et al (12) investigated the effects of the MIG spot welding parameters on weld dimension, shape and soundness and reported that increased weld time resulted in lesser porosity.

This technique has an advantage over resistance welding technique for the fabrication and cladding of structures and vessels, in the sense that it requires accessability only from one side of the joint and can be used for similar as well as dissimilar joints. The cladding 1.2 mm thick 90/10 copper-nickel sheet to mild steel water boxes of 25 mm or more thick plates for sea water distillation plant application is a

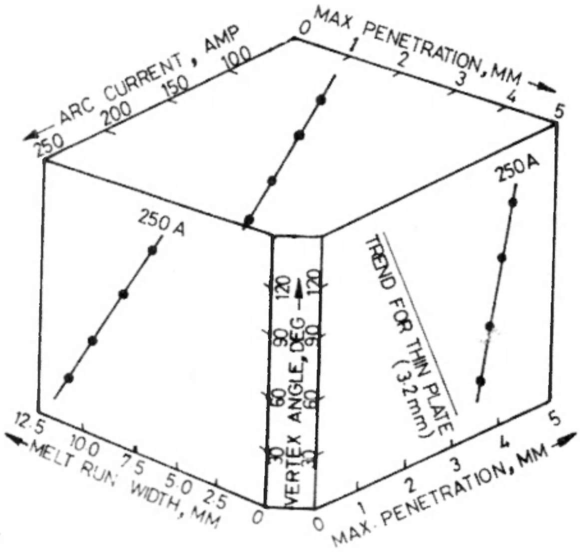


Fig.4 - Relationship Between Various Parameters For 6.4 mm Stainless Steel Plate With Travel Speed Of 150 mm/min (Vortex Angle Of Electrode With Conical Tip)

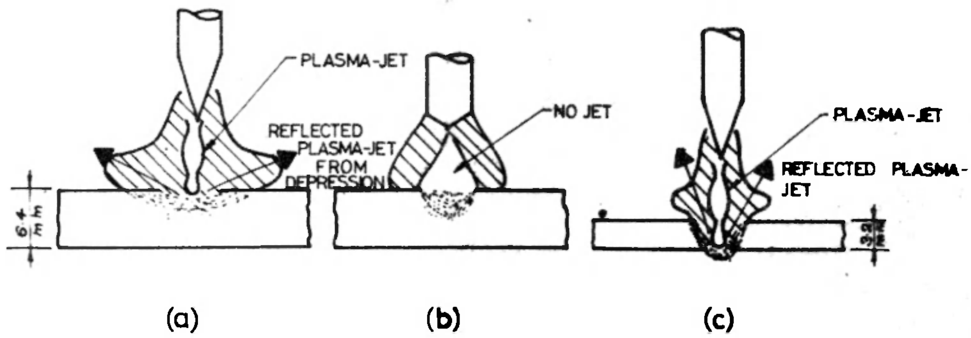


Fig.5 - Diagrammatic Representation Of Tig Arc Configuration
(Note : Suggested modes of operation on thick and thin plate at same nominal current with extremes of vortex angles)
Vortex Angles (a) 30° (b) 120° and (c) 30°

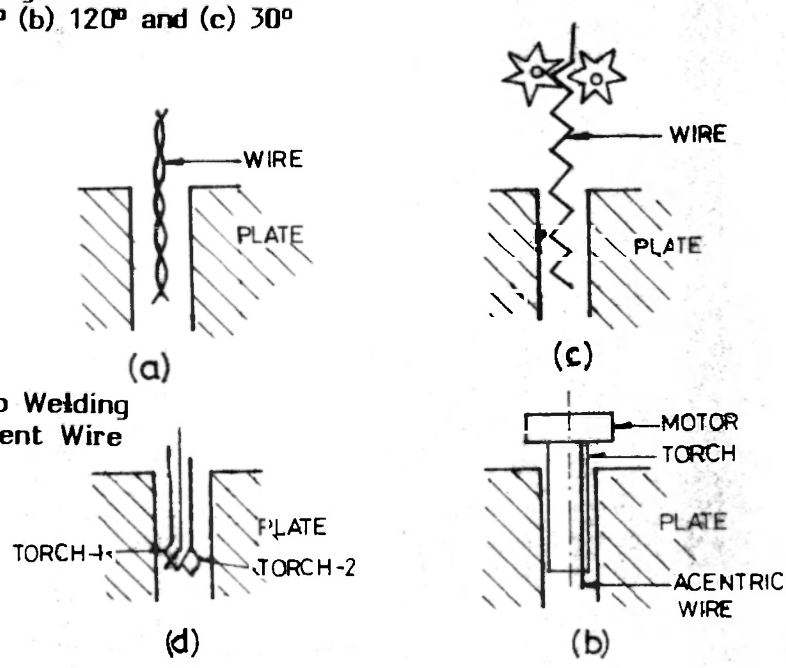


Fig.6 - Various Techniques Of Narrow Gap Welding
(a) Twisted Wire (b) Wire Weaving (c) Bent Wire
(d) Double-Torch Bent Contact-Tube

common example of welding the dissimilar materials by MIG spot technique.

Electrode Negative Polarity & Shielding Gas Composition

Electrode negative operation (13) in MIG welding yields high deposition rates (Fig.7). But the deterrant factor with the process is that it results in fairly high spatter levels and finger-type penetration with the possible risk of lack of fusion (14). Norrish (15) carried out some experiments to study the effect of various shielding-gas combinations on the stability of arc and regularity of metal transfer with electrode negative arcs. He reported that mixtures of argon with '2 to 10% O2 and 10% CO2' or '0 to 5% O2 and 12% CO2' provided stable arcs.

3. SERIES MIG-TIG WELDING

Normal MIG welding process generally results in lack of fusion, if not used with high current spray technique. To overcome this limitation, two alternatives exist : (a) to increase the current to work without increasing the amount of wire feed and (b) to preheat the weldment suitably. First alternative is not possible, as in consumable electrode process, the wire feed rate controls the current level. To preheat a large amount of parent plate is not cost-effective.

An alternative method of increasing the effective heat-input for a given amount of wire is to operate a TIG arc ahead of MIG arc. Once both the arcs are established, it is not necessary for work-piece to have any connection with the power source (Fig.8).

Carter et al (16) studied the welding characteristics of SERIES MIG-TIG process and reported that arc current with respect to MIG arc in the MIG-TIG process was the same as that of the MIG process alone.

4. PLASMA

Microplasma

Due to constriction of arc in the plasma process, the resultant heat-source takes the form of a stable, unidirectional, high energy-density jet (17). It provides good tolerance to stand-off distance from torch to the work. A change of arc length of 1.2 mm for Plasma welding is equivalent to a 0.12 mm change in TIG arc length (Fig.9). At low currents (0.1 to 10A) it is extremely difficult to weld with a TIG arc due to instability with very short arc with the variations in the torch-to-work distance. Another difficulty with short TIG arc is the tungsten inclusion in the weld pool. These are overcome in the microplasma process by virtue of the long and stiff arc column and the fact that the electrode is contained within the body.

Precision welding of very thin materials falls in the range of microplasma applications which include the welding of pressure tight metal bellows and diaphragms, filters for aero-space industry, platinum-rhodium probes from 1/2 mm hypodermic tubing and encapsulation of electronic components.

Intermediate Plasma

The practical advantages obtained with plasma at both low and high currents led to the developments of power sources which operate at currents upto 100A. In addition to good tolerance to torch stand-off distance, arc stability and lack of tungsten contamination, this current range provides the ability to weld with keyhole technique. The keyhole effect is achieved by increasing the plasma flow until a hole is punched through the plate. As the welding progresses, surface tension forces cause the molten metal to flow in behind the keyhole to form the weld bead (18). This technique finds application where high joint integrity with respect to certainty of full penetration and the higher depth to width ratio in the resultant weld are sought.

5. PLASMA-MIG WELDING

In MIG welding there is a possibility of varying the temperature of the shielding gas. Thermally ionized gas, i.e. a plasma generated by a separate arc discharge provides very high ambient temperature around the wire. Initial designs for the process intended as a low penetration technique for joining and overlaying were given by Taver and Shorshorov (4). The design by Mac Nary (24) maintains a TIG arc between the work and a cylindrical tungsten electrode and feeds the filler wire through the axis. In the set-up reported by Essers et al (21) the filler wire is introduced axially through a copper nozzle into the arc plasma which is maintained between an off-set tungsten electrode and the work (Fig.10). It can be used for deep penetration joining as well as for low penetration surfacing application (22).

When the thermally ionized gas, which has high electrical conductivity is brought around a wire which is at a suitable potential, the flow of the electrical current from the wire is no longer dependent on its own arc discharge. This offer advantages like spontaneous start, increased stability and better control over metal transfer and heat-input (23).

Pulsification of Arc Current

The magnitude of the current is modulated

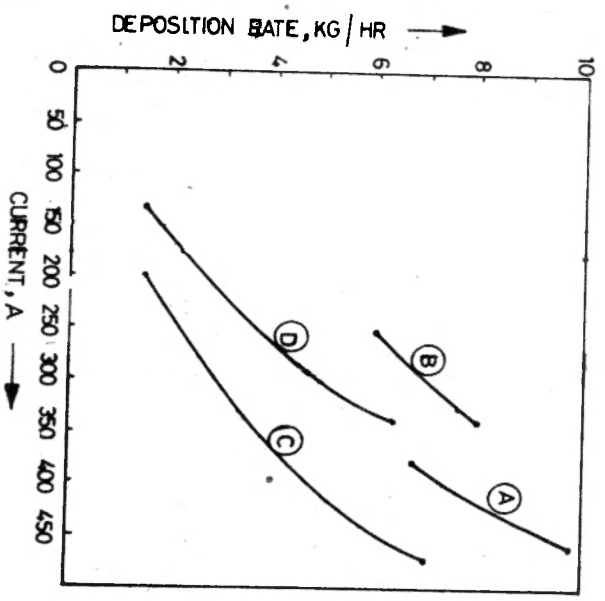


Fig.7 - Comparative Deposition Rates For Mig With Different Electrode Polarity :
(A) 1.6 mm Electrode -ve ; (B) 1.2 mm Electrode -ve ; (C) 1.6 mm Electrode +ve ; (D) 1.2 mm Electrode +ve

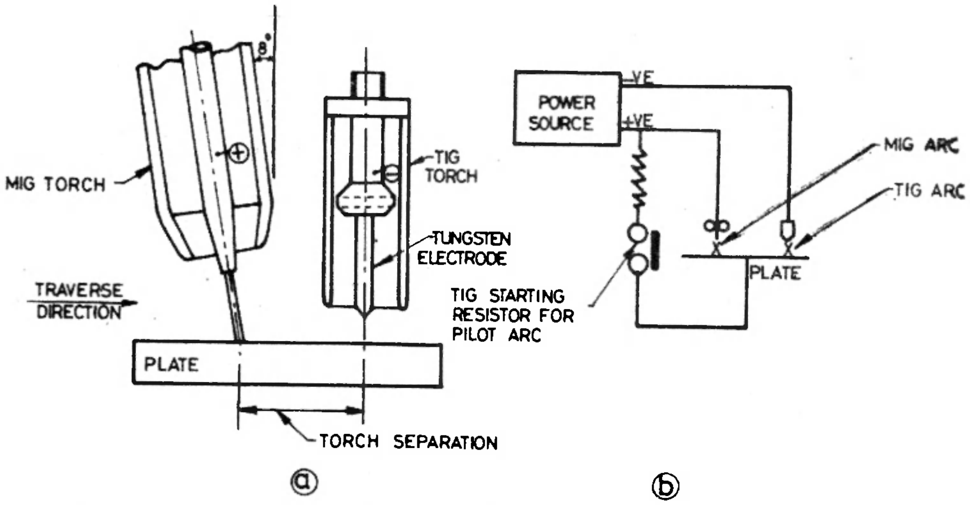
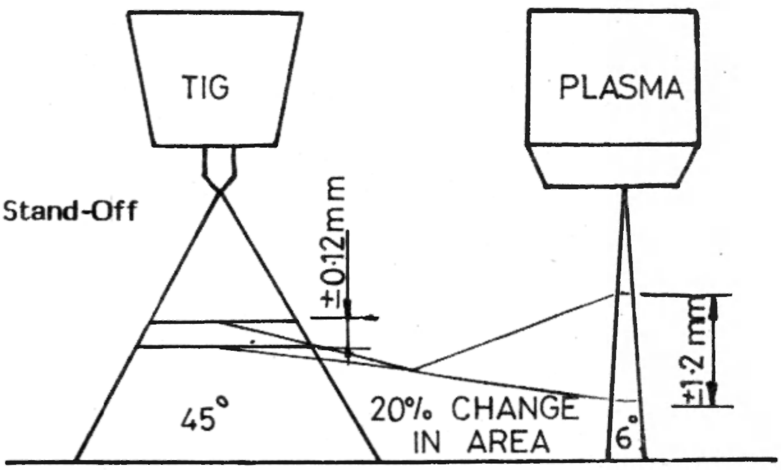


Fig.8 - Series MIG-TIG Arc System :
(a) Arrangement of MIG-TIG torch heads (b) Basic electrical circuit

Fig.9 - Variation In Heat Input With Stand-Off



between a 'high' level and 'low' level (Fig.11). At 'high' position of thus pulsed current, welding takes place. During 'low' period the torch is manipulated. Parameters are so adjusted that electrode is kept sufficiently hot and the ionized column is retained so that the arc is not extinguished during low level of current. The weld bead so obtained is in the shape of overlapping nuggets having a regular pitch. Compared with a continuous arc, the pulsed arc increases the penetration with lesser heat input and minimizes porosity (5).

Villeminot et al (10) brought out in their studies on pulsed current MIG process that apart from being equivalent to a low heat-input steady current process, it yields axial spray made of metal transfer instead of slow and irregular large drops. Use of pulsed TIG process for joining windings to commutator bars in traction motor armature eliminated the building up over and under penetration conditions (24). Pulsed micro-plasma obviates the heat build-up problem which makes the process particularly suitable for automatic orbital pipe welding applications (17).

Magnetic Control of Arc

Keeping in view, the formation of a natural magnetic field in the case of multi-arc A.C. welding, Mandel' berg et al (25) conducted some experiments to study the effects of an extraneous travelling magnetic field on the distribution of welding pool metal and joint formation. As shown in the Fig.3, this field can be generated in two ways. They found that rate of displacement of the pool and weld shape could be controlled by varying the strength of the controlling magnetic field. Successful trials were also performed for using the controlling magnetic field to hold liquid metal in the welding of joints on inclined and cylindrical surfaces.

Keyhole technique (26) which is widely adopted for plasma arc welding of medium thick plate (6 mm) does not posses the stability of keyhole formation being fairly sensitive to any change of welding conditions like arc current, working gas flow rate, travelling velocity and so on. Imposition of cusp magnetic field to the plasma results in marked broadening of feasible range of welding operation by keyhole technique. Also, narrow deep penetrated weld bead was obtained as an outcome of magnetic deformation of arc.

6. CONCLUSION

By virtue of superiority of metallurgical and mechanical properties of the welded structure, higher degree of automation, ease of accessability and possibility of in-situ operation, these advancements are bringing about a rapid change in the hardware and software of the conventional inert-gas-shielded arc welding processes. They also result in more reliability and contribute directly or indirectly to economy. To epitomise, the technological advances which have taken place in inert-gas-shielded arc welding processes are finding ever increasing application in the areas of industrial and special structural welding.

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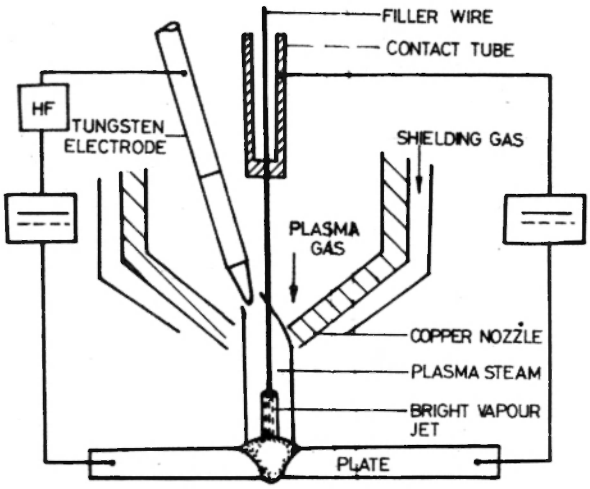

Fig.10 - Schematic Representation Of Plasma-MIG Welding

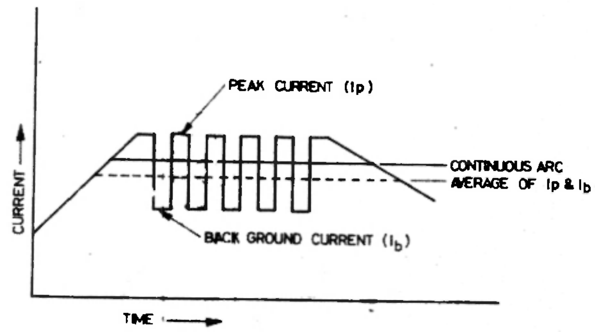

Fig.11 - Pulsed Mode Of Arc Current

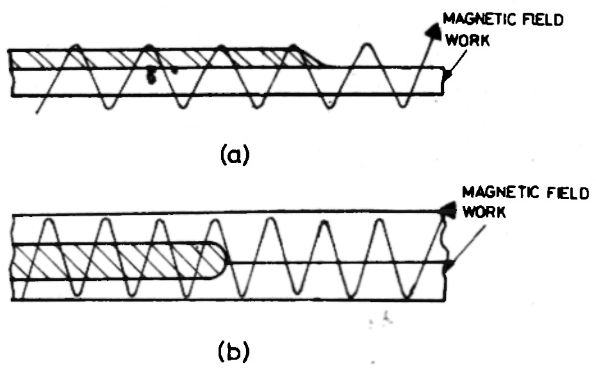

Fig.12 - Travelling Magnetic Field : (a) Normal To Weld Surface (b) Parallel To Weld Surface

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