Gas Shielding of the Welding Arc —Some aspects

Keith Hartley Memorial Lecture—1982

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I consider it a great honour for me to be singled out this year for giving this Memorial lecture on this important occasion and to so distinguished a gathering of welding technologists of this country. The honour is doubly great because this lecture is instituted in memory of Keith Hartley with whom I was privileged to be associated for many years in the course of my working life and also in the course of work we were doing for this Institute.

Mr Hartley was one of those Englishmen who came to this country and were conquered by it. After his first stint in India during the war years, when he served in the Indian Army, he chose to come back to this country to work with industry here. This was in the period when India had just gained independence and had gone through the trauma of partition. Economically we were one of the poorest nations in the world and industrially also backward. The doubts of many persons in our ability to govern ourselves had not yet been dispelled. It was, therefore the deep faith Mr Hartley had in this country's future and his respect for and understanding of the people of India and their aspirations that made him adopt this country as his second home. It must have been a matter of satisfaction for him that in the last 25 years of his life he spent here, he was able to see this country well on the road to economic recovery without any sacrifice of the democratic traditions with which we started.

Our Institute was also very fortunate to have his services in the formative years. In his unostentatious way, as a member of the Council and later as the President of the Institute for two terms, he gave much of his valuable time to the affairs of this Institute and helped to set this organisation on the right path to make it the broad-based organisation that it is today, of professionals in welding technology.

Introduction

For my talk today, I have chosen as the theme, "Gas Shielding of the Welding Arc".

The first patent on shielding the arc was taken out by Kjellberg in 1907 and today, all arc welding being done is shielded by one means or another. I propose to limit my talk, only to certain aspects of shielding the arc by an externally introduced supply of suitable gas or gas mixture. Shielding by means of gases produced by decomposition of flux constituents of coated electrodes during welding is outside the scope of this paper, though many of the experiences of researchers in gas shielding of the arc are of relevance in predicting the behaviour of coating materials which evolve gases at welding temperatures.

As you know, Tig and Mig welding processes have been finding increasing use in India in recent years. In certain industries and for certain types of applications, these are used to the exclusion of all other processes. However, due to various reasons, almost all Tig and Mig welding here is being done with argon shielding only, the notable exception being Mig welding of carbon steel where CO_2 is used exclusively. The realisation that intelligent choice of the shielding gas and attention to equipment design for shielding can give very considerable practical benefits for many applications has come rather late even in many advanced countries. However, there have been considerable developments abroad in this regard in the 70s and we, in India, are in the fortunate position of being able to take advantage of work done elsewhere, thereby shortening the time required to catch up with the state of technology in advanced countries.

Gases for Shielding

As the initial use of gas shields was for the limited purpose of blanketing the arc and weld pool to exclude contamination by atmospheric air, an inert gas like argon or helium was the obvious choice and these have served very well indeed. However, it was soon realised that for many materials, a purely inert shield was not necessarily the best ; furthermore, the cost of these comparatively scarce gases precluded the use of the process for many applications. Research with reactive gases and additions of such gases to the inert gas shield have given such encouraging results that the very concept of shielding has changed now to that of providing a controlled and desired environment in which arc welding can take place. This has opened up

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vistas which were not imagined earlier. The use of CO_2, nitrogen, hydrogen, oxygen and freon type of gases, in some cases singly, or more commonly, as mixtures with other gases, reactive or inert, is a commercial proposition now.

Before going into the question of which shielding gas is appropriate for a given situation and how best to apply it, it will be necessary to understand better how the properties of gases and other factors in the arc environment can influence the ultimate weld.

Ionisation Potential

In Table 1 are given ionisation potentials for some of the gases used for arc shielding.

TABLE 1

Ionisation Potential of Gases

Gas			*E.V.*
Argon	..	..	15.68 (11.55)*
Hydrogen	..	..	15.6
Helium	..	..	24.46 (19.77)*
Nitrogen	..	..	15.51
Oxygen	..	..	12.5
Carbon Dioxide	..	..	14.4

*Excitation potentials.

Ease of arc initiation and stability depend very much on ionisation potential of the gas in the arc. For instance, in an argon shield, arc striking and smoothness of the arc is much superior when compared to the helium shield because of the lower ionisation potential of argon.

In general, the higher the ionisation potential, the hotter the arc. This is due to the ionised particles returning to ground state at work surface and liberating the higher energy of ionisation. On this count, helium produces the hottest arc.

Atomicity

In the case of diatomic gases, such as nitrogen, oxygen, etc., at arc temperatures, there is dissociation of the molecules, a process which absorbs heat energy, followed by re-combination at the surface releasing latent heat. (In argon and helium, both monatomic gases, this phenomenon does not occur). In addition to this, ionisation also occurs.

Figure 1, in which enthalpy is plotted against gas temperatures in the arc plasma, illustrates clearly the difference in behaviour between these two types of gases. While, for instance, either argon or nitrogen could be an effective plasma gas, they have somewhat different heating mechanisms.[1]

It may be noted here that for the same total heat content, the monatomic gases have a much higher arc plasma temperature, an important factor in heat transfer efficiency. Helium has the highest arc temperature among these.

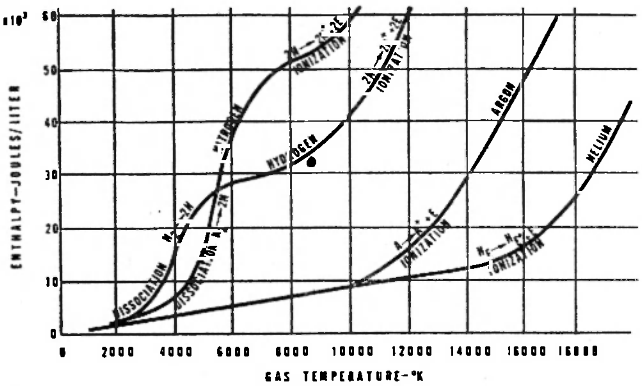

Fig. 1. Plasma temperature as a function of gas energy content at atmospheric pressure.

Energy Distribution in the Arc

As shown in Figure 2, only part of the total arc energy available is transferred to the weld metal. Furthermore, only part of the energy which enters the weldment is used to melt the weld bead; the remaining, heats up the base metal and forms the heat affected zone.

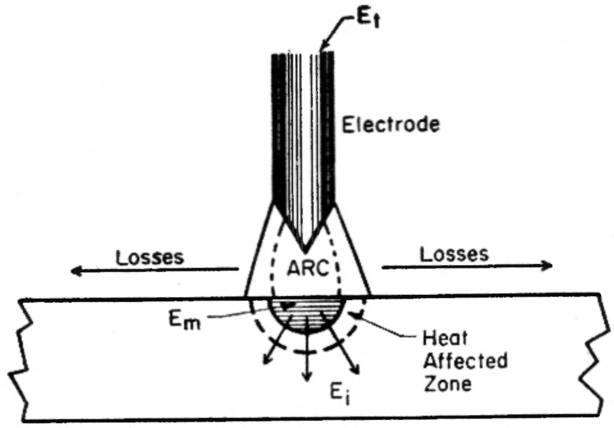

Fig. 2. Energy distribution at the welding arc. E_t=Total Energy input/unit length ; E_i=Total Energy entering plate ; E_m=Energy to melt Weld Bead ; $E_t=E_i$+losses.

In general, two thermal efficiencies are used to describe the energy distribution in the welding arc. These are referred to as Process Efficiency (Z_i) and Melting Efficiency (Z_m). Process efficiency is defined as ratio of total energy which enters plate to the total energy input of the arc. This is expressed by the relationship $Z_i = \frac{E_i \times 100}{E_t}$ where

Z_i = Process Efficiency (%)

E_i = Energy per Unit Distance Entering the Work

E_t = Total Arc Energy Available per Unit Length.

Melting Efficiency can be defined as the ratio of energy required to melt the weld bead to the total energy input. The relationship can be expressed as $Z_m = \frac{E_m \times 100}{E_t}$ where

Z_m = Melting Efficiency (%)

E_m = Energy per Unit Length required to melt weld bead

E_t = Total Arc Energy available per unit length.

Oviously, the highest process efficiency is desirable in any application. The highest melting efficiency is also aimed at in most applications, but it is of very great importance in materials where there is a need to control closely the heat input into the weldment due to metallurgical considerations.

Power density in the arc is a major factor influencing this efficiency. In a stable arc column, there exists a balance between the power input and radial heat losses. The use of a higher heat transfer efficiency gas (e.g., helium instead of argon) has the effect of reducing the surface area of the column in order to balance heat losses with energy input. The arc column contracts and this, in turn, has the effect of increasing the current density of the arc. If, as in the case of helium, the voltage gradient is also higher, the high power density and hence high arc temperature is concentrated on a smaller surface area.[2] The end result is that a greater percentage of heat is used for melting. (Fig. 3).

Specific Gravity of Shielding Gas

The flow rates required to give effective shielding are influenced a great deal by the specific gravity of shielding gas. The less dense a shielding gas is, the larger is the flow rate required to give a shield of comparative effectiveness. Reference to Table 2, will show that compared to argon (SG 1,380, c.f. air 1.00),

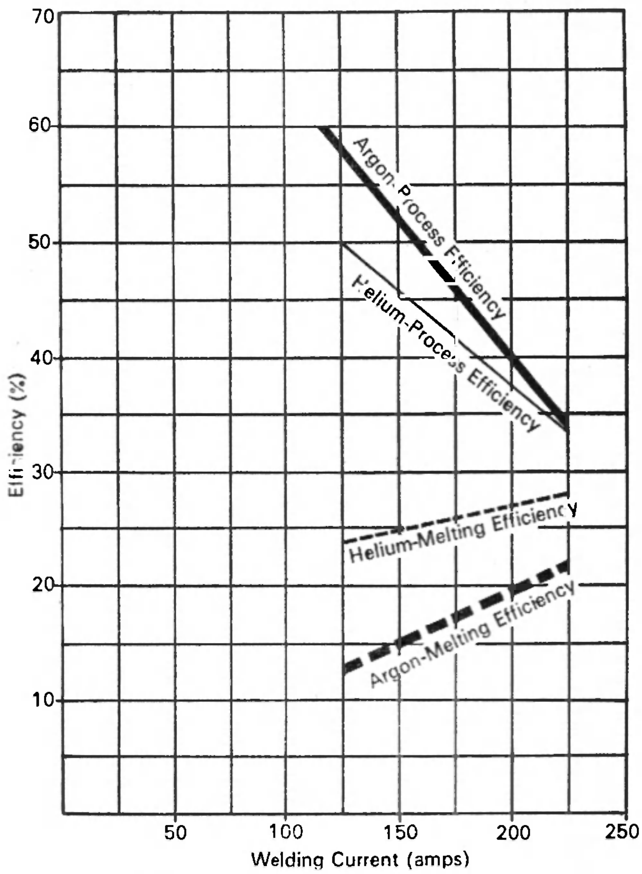

Fig. 3. Process efficiency and melting efficiency-vs-Welding current for GTA surface welds made on Hy-80 plate at 10 i.p.m.

helium (SG 0.1378) and hydrogen (SG 0.0695), flows must be considerably increased to be able to shield effectively.

Solubility in Molten Metals

Molten metals have a capacity to dissolve gases from the environment and these are given out during solidification. In the process, there is scope for formation of porosity type defects in weldments. One reason why argon and helium generally give relatively porosity-free welds is their comparative insolubility in the metals being welded.

TABLE 2

Specific Gravity of Shielding Gases

Gas		*SG* (Air=1 ; 70°F, 1 atm)
Argon	..	1.380
Hydrogen	..	0.0695
Helium	..	0.1378
Nitrogen	..	0.967
Carbon Dioxide	..	1.529

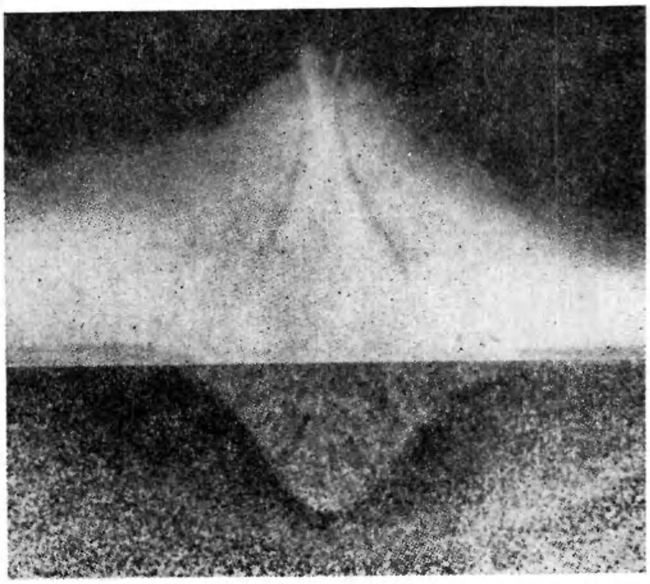

Fig. 4. Streaming transfer arc.

Metal Transfer Mode

In GMA welding (gas shielded metal arc welding) metal transfer in free flight happens in two modes, viz, "Droplet" and "Streaming" (the latter is also referred to as "Spray" Transfer).

In droplet transfer, the wire end becomes rounded and spherical droplets approximately of the same size as the wire detach at moderate velocity and a rate dependent on the wire feed speed. The detachment forces are principally electro-magnetic in origin.

At still higher currents, there is a transition to streaming transfer. This is associated with a self-induced magnetic field which exerts a strong radial constrictive force. The molten tip of the wire is constricted into a taper from which small droplets transfer at high speeds and frequency across the arc. (fig. 4)

In the streaming type transfer, the arc becomes stiff and the metal transfer is directional. Metal transfer rates and efficiencies improve sharply and spatter loss is minimised. Positional welding, especially in aluminium, at high currents is made possible. However, streaming transfer has a tendency to narrow "Finger" type penetration (Figure 5a). Under certain conditions of restraint and in materials like carbon and stainless steels, this type of penetration profile can give rise to porosity at the base of penetration and/or weld metal centre line cracking[3]. In such situations, therefore, it is necessary to choose parameters which would reduce this tendency.

The current level at which transition takes place from droplet to streaming transfer is influenced greatly by the shielding gas. The lowest practicable transition level current is obtained in an argon or argon-rich gas shield. Streaming transfer current levels are much higher for other gases. In general, they have less proneness to produce finger type penetration (Fig. 5b) and metal transfer is in droplets.

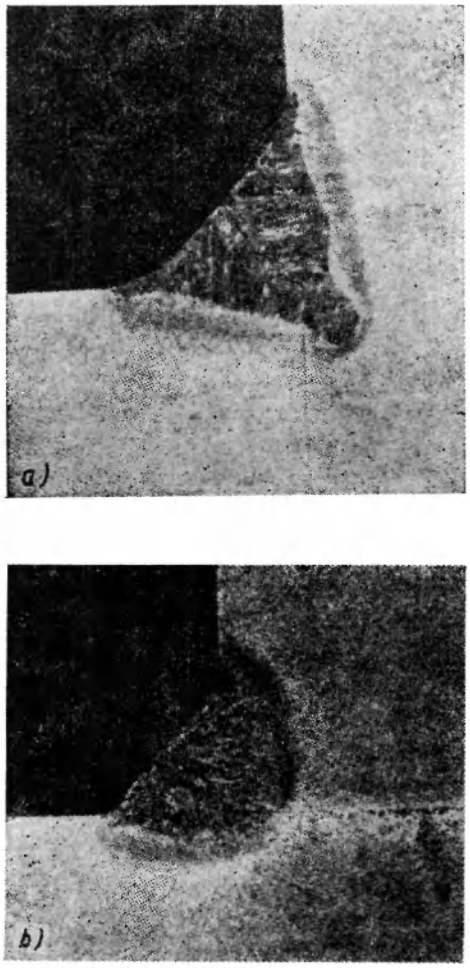

Fig. 5. a—Typical "Finger" type penetration of a fillet weld made with argon-rich shielding gas.

b—Bowl shape penetration profile made with CO_2 shielding.

Reactiveness

Argon and helium are completely inert chemically and this is why for GTA welding where the tungsten electrode needs to be protected from any contamination, these are the only gases used.

At arc temperatures, all the other shielding gases discussed so far react with the electrodes and weld metal. Depending on the proportion of the environment they

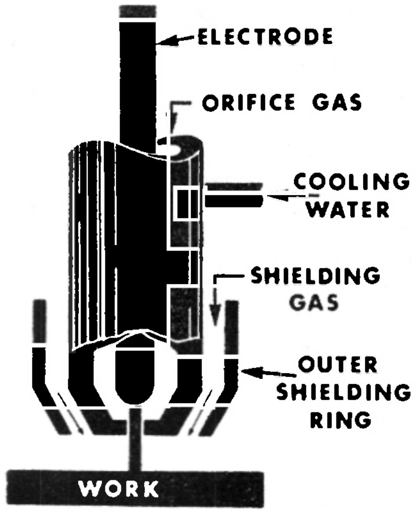

Fig. 6. Plasma arc welding—arrangement of nozzle.

constitute, the effects can be detrimental or, in some cases, beneficial. Oxygen added to argon in small quantities helps in GMA welding by reducing surface tension effects and giving good wetting characteristics. CO_2, another oxidising gas, has a likewise effect. Nitrogen is reactive with most metals and is not acceptable for any of them except copper for which it is virtually inert.

Addition of less than 1% of chlorine to argon has been found by researchers[4] to have given much better arc stability in GMA welding of aluminium with electrode negative polarity. The indications are that this can be due to improvement of electron emission capabilities of the cathode following reaction with the chlorine.

Freon type gases which are easier to handle than chlorine, have been found, in small additions to argon, to improve depth-to-width ratios in materials such as Inconel and Zircalloy[5].

Nozzle Design

In the early days of gas shielded welding, nozzle design was not given enough importance and it was only after quite some years that attempts at improvement were taken up.

In order to function properly, the gas nozzle must produce a shielded area where the gas is not contaminated with air. Ooviously, this is possible only for some distance from the nozzle after which the ingress of air gradually increases. A laminar flow of shielding gas gives protection for a longer length than a non-laminar flow where the turbulence accelerates mixing with surrounding air. The laminar flow has to be established within the nozzle itself. "Gas Distributors" and "Gas Lenses" in nozzles are the results of developments in this respect.

The development of plasma arc is an important milestone in arc welding technology. As you know, this was achieved mainly by constricting the gas shielded tungsten arc by the use of a specially designed nozzle configuration (Fig. 6). In plasma arc welding, the gas immediately surrounding the electrode known as orifice gas, serves the purpose of protecting the tungsten from contamination and also helps in forming the characteristic narrow and long plasma arc column. A shielding gas through an outer annulus blankets the whole arc and weld pool. The use of the dual shield brings in much greater flexibility by permitting the use of different combinations of gases or mixtures, chosen to suit applications. It also allows the use of reactive gases which may not be acceptable in single gas shields because of the risk of tungsten contamination[5].

The concept of dual shielding has been applied to GMA welding also. Wheatley describes experiments in which GMA welding of carbon steel was carried out with argon in the inner shield and CO_2 in the outer shield[6]. It was possible to retain the advantages of the streaming transfer, viz, process stability and low spatter, which are characteristics of argon shielding and, at the same time, reduce the finger type penetration to an acceptable level.

Choice of Shielding Gases

Table 3 gives an idea of the variety of gases and

TABLE 3

Material	*Shielding Gas*	*Comments*
Aluminium and Alloys	Argon	Most commonly used for both GTA and GMA. Gives smooth spray arc condition in GMA and efficient cleaning action.
	Argon+Helium	Helium addition usually upto 10% to increase heat input on thicker sections.

Copper and Copper Alloys	Argon	Good spray arc condition in GMA. Requirement for preheat on thicker sections, viz, over 6 mm in GTA. Suitable for both orifice and shielding for plasma arc welding.
	Argon+Helium	50/50 or 30/70 Ar/He an attractive mixture for reducing level of preheat. Can be used on thickness over 3 mm for GTA.
	Nitrogen	For GTA and GMA good heat input characteristics. Problem of spatter and fumes. Rough finish.
	Argon+N_2	For GMA 80/20 Ar/N_2. Heating superior to argon but problem of spatter.
Titanium, Zirconium and Alloys	Argon	For GTA and GMA, Suitable for spray transfer in GMA in flat position welding. In plasma arc welding for orifice and shielding gas.
	Argon+Helium	Ar+25% He improves heat input. Suitable for spray arc in flat position, pulsed and short circuiting arc in all positions.
Stainless Steels	Argon	Commonly used for GTA and plasma arc welding.
	Argon+O_2	Upto 2% addition normally employed for. GMA. Good spray or pulsed arc condition.
	Argon+O_2+CO_2	2%O_2+5%CO_2 addition improves short circuit and pulsed arc welding. For critical applications, possible carbon pickup to be considered.
	Argon+H_2	For GTA welding, H_2 addition gives increased speed and/or penetration. 5% H_2 optimum but upto 10% sometimes used. Can also be used for GMA. Upto 7.5% H_2 used for plasma arc, orifice and shielding.
Mild and Low Alloy Steels	Argon	For GTA welding.
	Argon+O_2	1—5% O_2 addition for GMA. Good spray arc, where weld composition is critical.
	Carbon Dioxide	Suitable for short circuit, droplet and spray type arcs. Limited on alloy steels where weld composition is important.
	Argon+0_2+CO_2	2% 0_2 +5% CO_2 for spray and pulsed GMA welding. 2%0_2+20%CO_2 for smooth spray and short circuit arc welding of thin sheets.
Nickel based Alloys	Argon	For GTA and GMA. For all modes of metal transfer.
	Argon+H_2	Increased speed and penetration.
	Argon+Helium	Upto 15—20% helium addition improves heat input and fusion characteristics.

gas mixtures currently used for shielding in GTA, plasma arc and GMA welding of various materials.

The Table given above is for guidance and does not limit the choice available to the knowledgeable practitioner or researcher in welding.

One other important feature of the shielding gas, that has to be considered when choosing the right gas or mixture is the ability of the gas to extend the workable boundaries of the process[7]. This is best illustrated using the tolerance box (Figure 7). The extremes of current and voltage at which satisfactory welds may be made are plotted against one another to show the maximum working boundary of the gas. In the experiments reported by Hilton, pure argon, helium and six other pre-mixed gases were evaluated by producing bead—on—plate Mig welds in aluminium. From the diagrams it may be seen that pure argon has a relatively small working area compared with high helium mixtures. The tolerance boxes show that additions of helium both increase the current carrying range of the gas and as the percentage of helium is increased, widens the voltage tolerance.

One factor which does play an important part in choosing the gas is, of course, the cost. Both argon and helium are comparatively expensive. There is a sharp difference between the two, volume for volume, as all supplies of helium have to be imported into this country. Decisions should not be based on the cost of gas only, but on careful consideration of overall economics. It is necessary to find out if the process advantages, such as higher welding speeds, lesser heat affected zone, the need for pre-heat being eliminated or minimised in case of highly conductive metals like copper and saving in edge preparation expenses may, in specific jobs, more than offset the cost of helium.

As regards purity, it is necessary to keep moisture in the gas as low as possible. IS 5760 for argon specifies that water vapour should not exceed 0.0056 mg per litre, which is equivalent to a dew point of - 40°C at 21.1 kgf/cm^2. Other impurities are critical depending on metals being welded. National specifications of most countries cover gases for welding. IS Specifications that would be relevant are :—

Argon	.. IS 5760.
Carbon Dioxide	.. IS 307, Grade 1.
Nitrogen	.. IS 1747 (Pure Nitrogen).
Hydrogen	.. IS 1090, Grade 1.

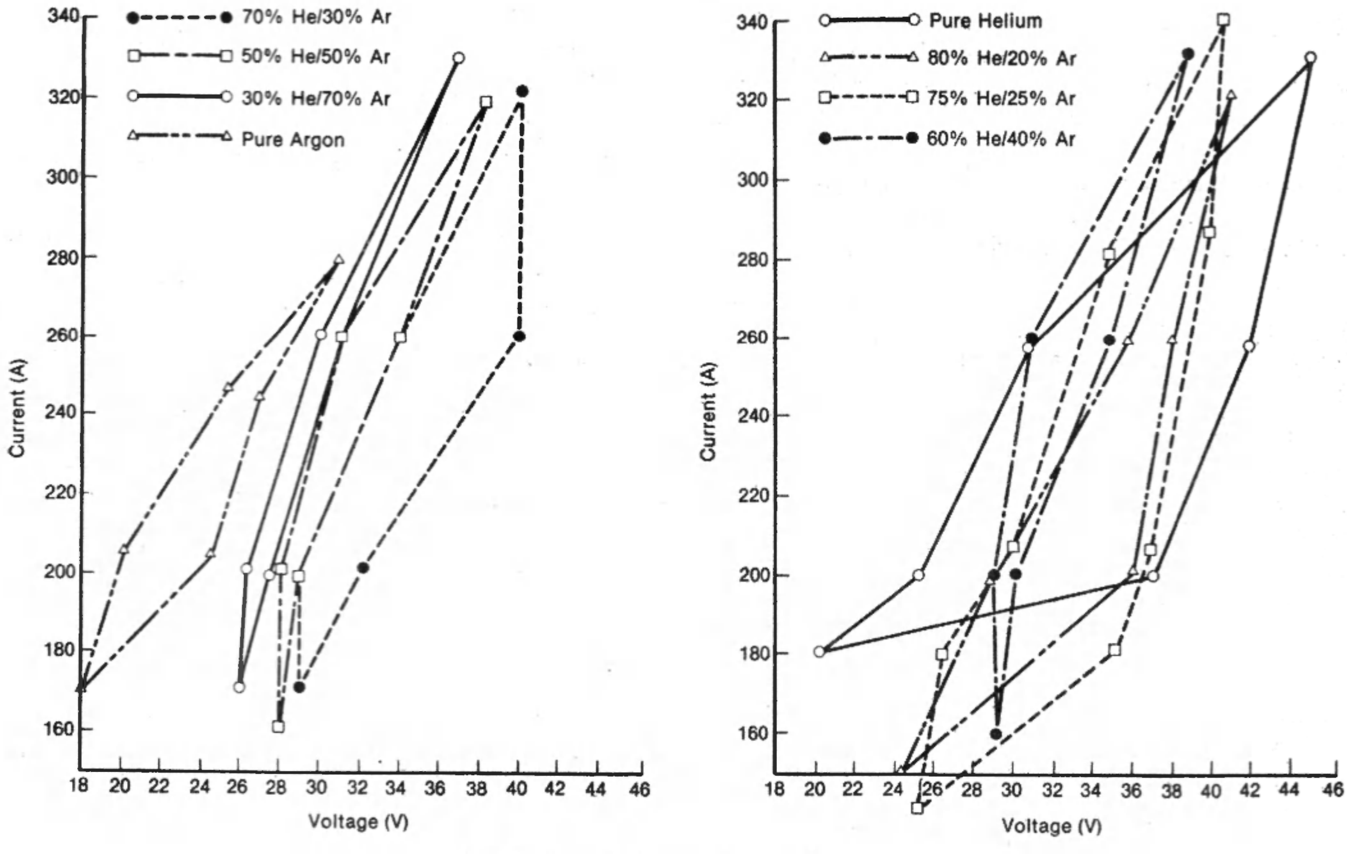

Fig. 7 Argon/helium tolerance boxes.

For critical work and materials sensitive to impurities, it may be necessary to specify purities higher than these.

It is worth mentioning here that gas delivery system to the torch should also be in excellent condition as any ingress of air at any stage would defeat the purpose of having a high purity gas for welding.

Case Study

At this stage, I would like to cite an interesting example to emphasise the point I have made earlier that there is always scope for improvisation to tackle specific problems.

Shackleton and Lucas have reported a case where heavy fabrication welding in Quenched and Tempered steels of the HY 100 and HY 130 varieties was involved.[8] Economic considerations dictated the use of high deposition mechanised welding process. Requirements in regard to bead shape, incidence of defects and mechanical properties, especially fracture toughness, were critical. Shielded metal arc and submerged arc processes could not give weld metal of the required minimum toughness. Mechanised GMA welding with argon-2% oxygen mixture shielding was then identified as most satisfactory on all-round performance. Laboratory tests showed that fracture toughness requirements and defect incidence level for both the alloys were achievable with this mixture. However, in actual field working, in this case under shipyard conditions, incidence of defects increased. This was traced to the arc shielding gas being blown away and also to the deep finger penetration typical of argon in such materials. Porosity and lack of side wall and inter-run fusion was noticed.

While, to some extent, with more careful attention to good site welding practice, these could be kept under control, it was decided it was necessary to build into the procedure more tolerance to adverse conditions.

Since the finger penetration phenomenon is associated with streaming mode of transfer, one way of solving the problem was to operate the process in the droplet transfer mode. However, with the same gas shielding mixture, transition to droplet transfer was at such currents that deposition rates obtained were too low for the process to be economic for production.

Shielding mixtures were investigated to give droplet transfer at a current level about the same as previously used with argon—2% oxygen for streaming transfer. A number of combinations were tried and it was found that a mixture of 75% helium and 25% of argon-CO_2 (95-5) mixture gave the required mode of metal transfer and smooth arc characteristies. In additon, it improved the process stability especially the tolerance to arc length variations, which was a somewhat critical factor with argon-2% oxygen mixtures used earlier. Mechanical properties were as good as those with argon-2% oxygen shielding and were acceptable.

Conclusion

While considerable progress has been made in recent years in understanding welding arc phenomena, there are still many which are not fully understood. Better understanding of the potential of gas environments of welding arcs can help a great deal all those engaged in application, procedure and process development and research. To researchers especially, the gas shielded arcs with their controllable conditions and fewer complicating factors can be a useful tool. There could perhaps be greater scope for the use of combined flux and gas shielded welding systems than are in use at present.

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