"The Role Of Gases in Welding and Cutting Processes"

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Abstract

From the time that Edmond Fouche and Charles Picard developed the first oxy-acetylene torch, which gave a flame hot enough to melt steel in 1900, gases have played a very important role in the development of welding and cutting processes. In the early 1900s it was gas welding which laid the foundation for the commercial application of welding as a repair and joining process for steel and other metals, till the development of the coated electrode and shielded metal arc welding process by Oscar Kjellberg. Gas cutting, first introduced commercially in 1907, has however continued to be the backbone cutting process for the fabrication industry till today.

Arc welding in a shielding gas atmosphere was patented by C.L.Coffin in 1890. However it was only in the 1940s that commercial use of inert gases Argon and Helium for shielding of the arc in the Gas Tungsten Arc and Gas Metal Arc welding processes was developed. The use of carbon dioxide and later argon based gas mixtures further enhanced the productivity and performance of Gas Metal Arc welding so that it has become the dominant welding process today.

Gases and gas mixtures have also played a crucial role in the development of more advanced welding and cutting processes such as plasma and laser and today they play a very significant part in controlling the quality and cost effectiveness in any welded fabrication.

The paper attempts to review the history and role of gases in the development of the welding and cutting processes through the years till the modern times.

INTRODUCTION

I am extremely grateful to the Governing Council of the IIW for the honour done to me by inviting me to deliver the 'Sir L.P.Mishra Memorial Lecture ' at the 'IIW - International Conference 2005'. It is a happy coincidence that this honour has come in a year that the IIW is hosting the International Conference for the first time. It is indeed a proud privilege for me to be making this presentation before such an august gathering of eminent persons in the welding field from India and abroad. I express my heartfelt thanks to the President and council of IIW for the invitation.

It has been my good fortune to be associated with the welding industry for the last 38 years, working for BOC India Ltd. formerly Indian Oxygen Ltd, who were the pioneers in the welding industry in India and have just completed 70 years of operation in this country. The importance of the role of gases in welding and cutting is often not given due recognition. But when one considers that except for the SMAW, SAW and the resistance welding processes, every major welding and cutting process uses gases, one can appreciate our dependence on them. This has become more so after Gas Metal Arc Welding has become the dominant process world-wide. For every ton of MIG wire deposited you require on an average one and a half tons of shielding gas.

Working for a gas company has given some understanding of the application of gases in these various processes and it is only natural that I have selected the topic " The Role of Gases in Welding and Cutting Processes " for my talk this morning.

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GAS WELDING AND CUTTING

The use of an intensely hot gas flame for welding seems to date back to the mid 1800s when a torch was devised which could burn a mixture of oxygen and hydrogen. Apart from gold and silver this oxy – hydrogen flame could melt platinum and found good use in jewelry manufacture.

However the beginning of the practical application of fusion welding in industry can be said to have started with the oxy – acetylene flame which was the first heat source hot enough to melt steel. Although acetylene was discovered by Edmund Davy in 1836 it was not until the 1890s that a number of technological developments made gas welding using the oxy-acetylene flame possible. First was the discovery of a process for making calcium carbide economically by Morehead and Wilson in 1892 so that by 1895 commercial carbide plants were operating in England, France and the USA. Second was Le Chatelier discovering in 1895 that a flame having a 1:1 ratio of oxygen to acetylene, had a temperature of around 3200°C which was the hottest known. He also devised a safe method of storing acetylene, dissolved in acetone, contained in a cylinder with a porous mass inside. Next was the development of a suitable torch to control the flame by Edmond Fouche and Charles Picard around 1900 in France where gas welding was started.

Although gas cutting was demonstrated at the Seattle fair in 1902, it was not until 1907 that a commercially useful cutting torch was developed in the USA by Eugene Bournville. He demonstrated to the Navy that 14 inch portholes could be cut in 2-3 inch thick armour plate in 12 minutes. Before that it took 5 chippers 10 days to cut the holes. From 1912 – 1917 the oxy-acetylene processes really came into their own for the manufacture and repair of railroad cars and also for scrap cutting in the steel industry.

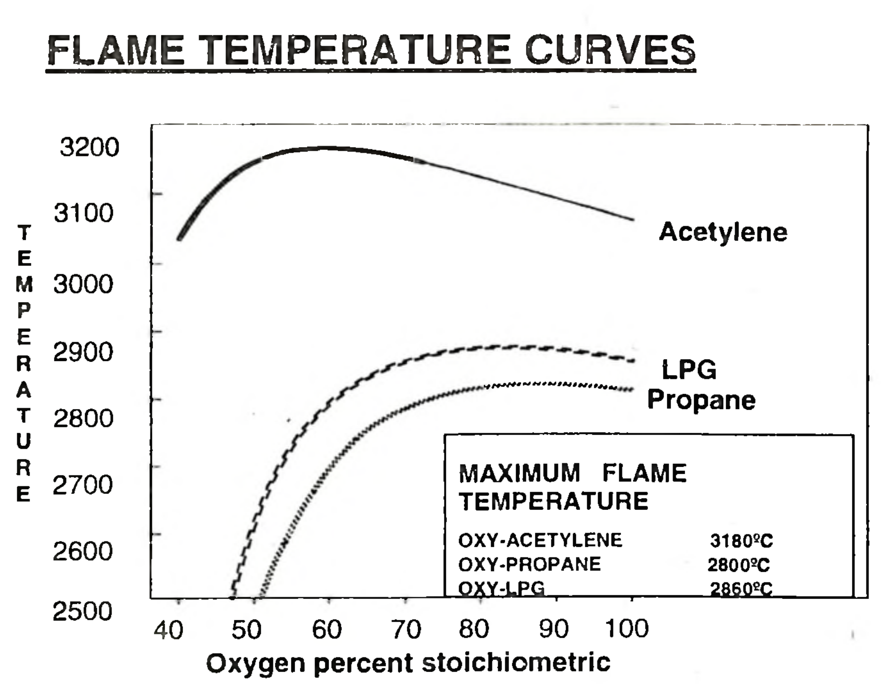


Figure 1

From the 1920s however, the rapid development of the electric welding processes, with their higher productivity and economy, has resulted in their taking over the production welding field and gas welding has had to take a "back seat" except for repair welding and brazing applications. But gas cutting has continued to expand and is still the dominant cutting process in the steel production and fabrication industry.

THE OXY – ACETYLENE FLAME

It is the triple bond structure of the acetylene molecule, which is responsible for the high temperature of the oxy-acetylene flame as compared to other hydrocarbon gases eg. methane, propane, butane etc although these may have higher calorific values. During combustion when the triple bond is broken it releases energy, whereas for other hydrocarbons breaking of the carbon bonds absorbs energy. This energy is released as heat in the inner cone of the oxy-acetylene flame and that is why the oxy-acetylene flame is hotter than any other hydrocarbon flame. To combust one molecule of acetylene stoichiometrically two and a half molecules of oxygen are required as per the formula

$$C_2H_2 + 2.5\ O_2 = 2CO_2 = H_2O$$

However as seen from the curve in fig.1 the maximum flame temperature of 3180°C is achieved at a 55% stoichiometry which corresponds to a acetylene : oxygen ratio of 1 : 1 . This is because the balance oxygen is taken from the

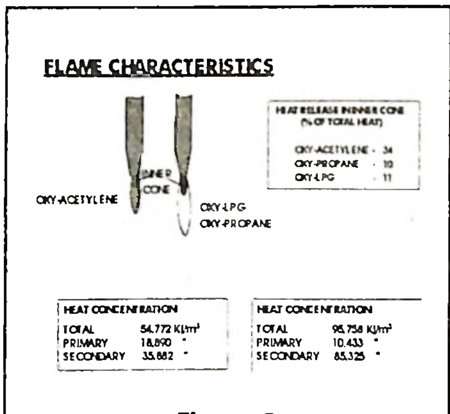


Figure 2

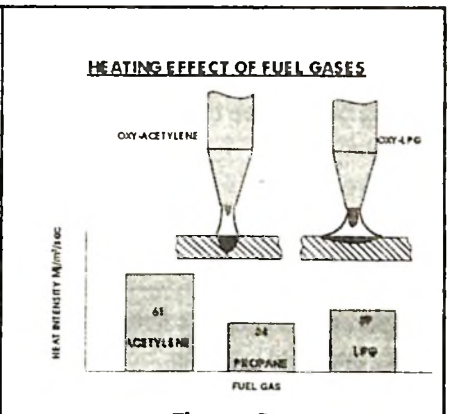


Figure 3

surrounding air and excess oxygen through the blowpipe would dilute the flame and lower its temperature. For propane and LPG the maximum flame temperatures of 2800 – 2850°C are reached at 80% stoichiometry.

The advantage of the higher flame temperature and greater heat release in the inner cone is that the heat intensity, which dictates the ability of the flame to transfer heat to the job, is higher by 50 – 80 % for oxy-acetylene as compared to oxy-LPG or oxy-propane flames. This is critical when trying to melt steel, as the rate of heat input has to be higher than the rate at which the heat flows away as shown in Figs 2 and 3. Thus oxy-acetylene is the only flame with which you can weld steel. Also because of the neutral nature of the flame gas welding using suitable fluxes can be used for welding and brazing of most metals including aluminium, stainless steel, copper, brass, nickel alloys etc.

THE GAS CUTTING PROCESS

In oxy-fuel gas cutting, the steel is first raised to a temperature of 850°C by a ring of preheat flames provided in the torch nozzle. At this temperature steel oxidises spontaneously in the presence of pure oxygen, which is provided by a separate orifice in the torch nozzle. This oxidation or combustion of steel is an exothermic process producing additional heat to sustain the cutting process as it proceeds downwards. Fortunately the iron oxide produced forms a low melting fluid slag which is swept downwards from the cut face by the cutting oxygen jet giving a clean cut surface for steel. Materials like aluminium and stainless steel cannot be cut by the oxy-fuel process as they produce high melting oxides which hinder the cutting process.

From the above description it will be understood that the faster the steel can be heated to the oxidation point the faster the cut can proceed. It is for this reason that, despite its higher cost as compared to LPG and propane, acetylene is still preferred in many cases due to its higher speed of cutting and cut quality giving improved productivity. LPG and propane also require much greater volumes of oxygen per meter cut, thus the overall cutting costs are very often lower with acetylene despite the higher cost of the fuel gas as seen from Fig 5.

The Cutting Process

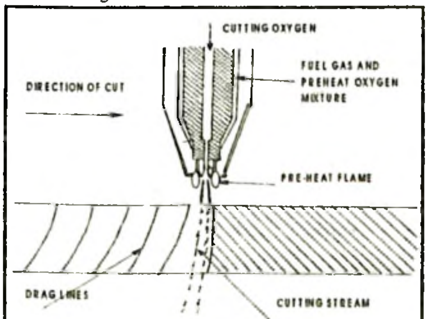


Figure 4

However for cutting of very thick sections eg. billets and blooms the longer flame length of oxy-propane and oxy-LPG is an advantage. Their lower cost is also an advantage where cut quality is not so important or for scrap cutting.

The purity of the cutting oxygen also plays an important role. Lower oxygen purity significantly reduces cutting speeds and increases oxygen consumption as seen from the graph in Fig 6. Lower purity also results in poor cut quality and gives a sticky slag with bits of un-oxidised iron. This is because the spontaneous oxidation process is retarded by any impurity gases eg. nitrogen or moisture.

Besides welding and cutting, oxy-fuel gas processes are used for a number of applications such as brazing and soldering, pre-heating, gouging and grooving, flame cleaning, metal spraying, carburising and heat treating etc. and one can well appreciate the important role oxygen along with acetylene and other fuel gases play in the fabrication industry.

THE GAS SHIELDED ARC PROCESSES

One of the major problems in fusion welding is to shield the weld pool from the harmful effects of oxygen, nitrogen and moisture in the atmosphere. These gases can cause

Material	Gas	Compatibility
Carbon & Low Alloy Steels	O_2 N_2 H_2 CO_2 Ar, He	Oxidizing but may be tolerated in moderate levels
Austenitic stainless Steels	O_2 N_2 H_2 CO_2 Ar, He	Gross porosity and embrittlement Porosity and Cold cracking Slight oxidation of alloying elements No reaction
Aluminium & Alloys	O_2 H_2 N_2 Ar, He	Oxidizing but may be tolerated upto 2-3% Stabilizes austenite upto 5% Reduces oxide at levels upto 10% Oxidizing but may be tolerated upto 8-10%. Carbon pick up above 3% No reaction
Copper	H_2 O_2, CO_2 Ar, He, N_2	Gross oxidation Gross porosity Embrittlement No reaction
Nickel	N_2 O_2, CO_2 Ar, He	Porosity May be tolerated upto low levels No reaction
Titanium	O_2, N_2, H_2 Ar, He	Embrittlement No reaction

Table : 1

porosity, embrittlement, cracking and oxidation of the weld.

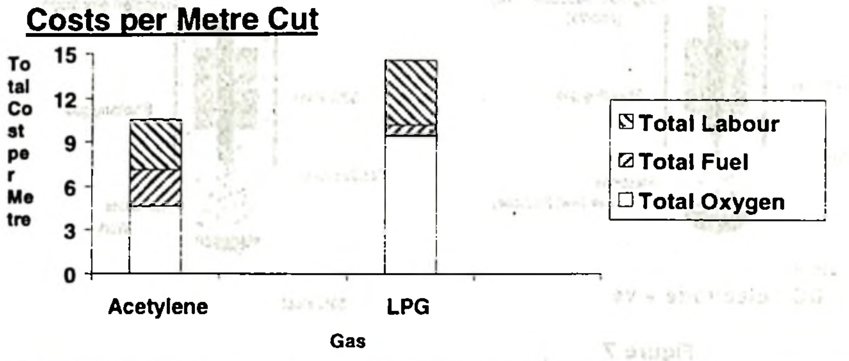
Table 1 gives a summary of the compatibility of various gases with commonly welded material groups. It will be noted that argon and helium being inert gases are the only ones which are compatible with all materials and thus were initially selected as shielding gases.

Arc welding, by using a shielding gas to protect the weld was patented by C.L.Coffin in 1890. Subsequently Alexander, Hobart, Devers, and a number of people did sustained work to develop the processes and equipment. However it was only in the 1940s that the Gas Tungsten Arc Welding (GTAW) process could be successfully commercialised for the welding of Magnesium by using the inert gases Argon and Helium for shielding of the arc. This process was soon extended to the welding of aluminium, titanium and stainless steel. Gas Metal Arc Welding (GMAW) was developed shortly afterwards, initially for aluminium using argon as the shielding gas, but was soon extended for welding steel and other materials. However it was only after the Russians Lyubavskii and Novoshilov developed the use of carbon dioxide as a low cost shielding gas for GMAW of mild steel in 1953, did the process really take off to become the dominant process it is today.

There is a common notion that the only function of a shielding gas is to protect the welding arc and the weld pool. But in reality it plays a number of critical roles, which influence the process parameters, metal transfer, penetration and weld-bead geometry, weld chemistry and weld properties and finally process economics.

INFLUENCE OF GASES ON PROCESS POLARITY

In the GTAW process when an arc is struck between the Tungsten electrode and work piece using argon as the shielding gas, the gas ionises to form a plasma consisting of high velocity - high energy, negatively charged electrons and heavier slow moving positively charged particles. As the electrons impinge on the positive pole (anode) 70% of the arc heat is generated here and 30% at the negative pole or cathode. By keeping the work piece as the anode, the higher heat is utilized to obtain better penetration of the weld while the lower heat at the tungsten cathode prevents it from overheating and erosion. This polarity can be used for steel, stainless steel, copper



	Acetylene	LPG
Total Oxygen cost	4.61	9.43
Total Fuel cost	2.50	0.73
Total Labour cost	3.40	4.31
Total Cost per Metre	10.52	14.48

Figure 5

and nickel alloys but not for aluminium or magnesium due to the tenacious, high melting oxide film on the surface. It was discovered that if the polarity is reversed the heavy positive ions help to break up this oxide film, a process known as cathodic cleaning. But the Tungsten electrode, which is now the anode, became overheated due to the high heat generated. The problem was solved using an AC current for aluminium which gives cathodic cleaning each half cycle and cools the electrode in the next half cycle.

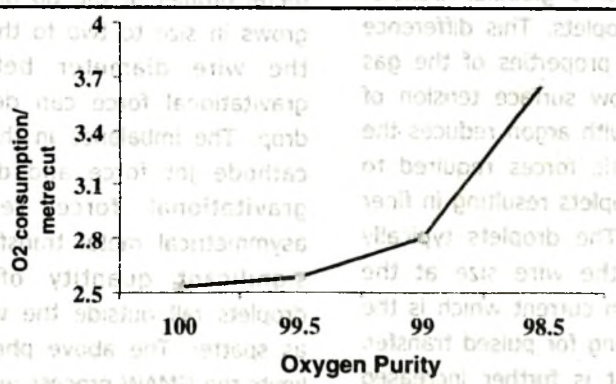
In the GMAW process due to the relatively higher currents used, penetration at the weld is not a problem and this is kept as the cathode. Here keeping the filler wire as the anode helps in faster melt down of the wire increasing deposition rates and productivityFor aluminium there is a double benefit as now, there is continuous cathodic cleaning of the weld.

Thus it will be seen that it is the properties of the gas plasma which dictate the process polarity to be used for both GTAW and GMAW.

INFLUENCE OF GASES ON THE ARC PLASMA AND PENETRATION PROFILE

The thermal conductivity of the shielding gas influences the size, shape and properties of the arc plasma. This determines the radial heat distribution pattern across the plasma from the core to the outer edge of the arc column. Argon, having a low thermal conductivity, generates a plasma with a narrow inner core of high temperature and a comparatively cooler outer zone as shown in fig 8. On the other hand helium which has very high thermal conductivity gives a wider inner core and less marked outer core. Helium, due to its higher ionization potential and increased voltage required also gives a hotter arc. A similar profile is obtained with the CO_2 arc plasma due to re-combination of the dissociated carbon mono-oxide and oxygen on top of the weld pool producing a wider hot zone.

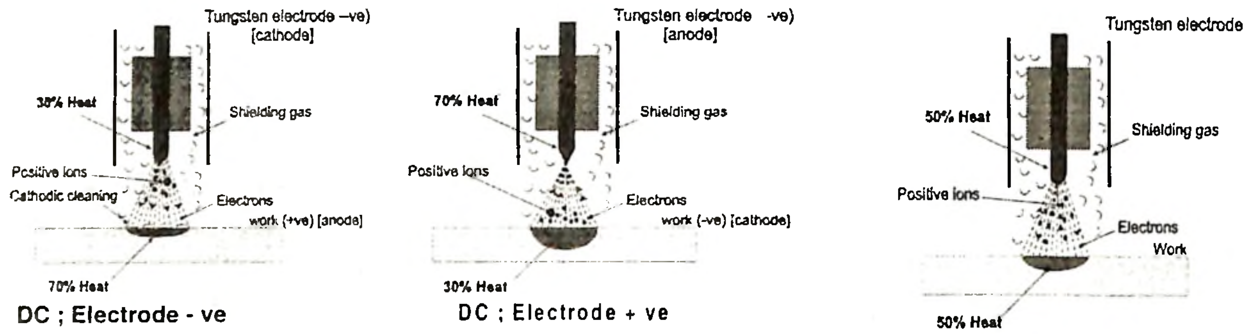
The arc plasma temperature and shape in turn affect the weld penetration characteristics, the argon plasma giving the typical wine glass shaped penetration profile (fig 8) while the helium and CO_2 plasmas give wider and deeper penetration profiles (fig 9). It is possible to change the shape of the penetration profile by mixing two or more gases, i.e., helium with argon or CO_2 with argon to obtain optimum penetration profiles.



Drop on O_2 purity from 99.5 % to 98.5 % for cutting 25 mm plate results in

- 20 % increase in oxygen flow requirement
- 15 % decrease in cutting speed
- 40 % increase in O_2 consumption per metre cut

Figure 6



DC ; Electrode - ve

DC ; Electrode + ve

Figure 7

INFLUENCE OF GASES ON THE MODE OF METAL TRANSFER

The shielding gas along with the welding parameters determines the mode of metal transfer and droplet size in the GMAW process. Both argon and CO_2 at lower currents and voltages give a dip mode of metal transfer, where the wire short circuits with the plate each time a droplet is detached. As the welding currents and voltages are increased an open arc is obtained and the transfer changes to a free flight mode. With argon or helium spray transfer with fine droplets is obtained, whereas with CO_2 there is globular transfer with larger droplets. This difference is due to the properties of the gas plasma, the low surface tension of molten steel with argon reduces the electro-magnetic forces required to detach the droplets resulting in finer droplet size. The droplets typically approximate the wire size at the spray transition current which is the situation existing for pulsed transfer. As the current is further increased the droplets become finer in size and a streaming spray transfer is obtained, which accelerates the drops across the arc column in a highly unidirectional manner.

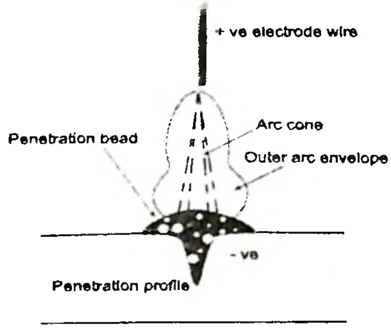


Figure 8

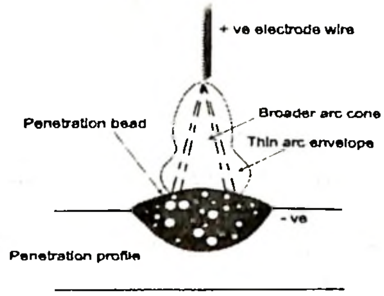


Figure 9

CO_2 dissociates in the welding arc, which results in certain upward directional cathode jet forces in the plasma arc column. Due to the high surface tension of CO_2, the molten metal droplet at the tip of the wire grows in size to two to three times the wire diameter before the gravitational force can detach the drop. The imbalance in the upward cathode jet force and downward gravitational force results in asymmetrical metal transfer and a significant quantity of molten droplets fall outside the weld zone as spatter. The above phenomenon limits the GMAW process with CO_2 to dip and globular transfer modes and true spray or pulse transfer cannot be achieved.

As the current and / or voltage are further increased with argon based gases one can have other types of transfer such as forced short arc or rotating spray arc which are used in high deposition rate variants of the GMAW process, e.g., Rapid Arc, Rapid Melt or T.I.M.E. These processes give deposition rates of 10-14 kg / hr compared to 2 – 6 kg / hr in the normal GMAW process.

INFLUENCE OF GASES ON WELD BEAD SHAPE AND WELDING SPEED

Here again, the surface tension of the gas with the molten weld pool dictates the convexity of the bead and CO_2 having a higher surface tension produces a more convex bead as compared to argon. Gases can also influence welding speed by lowering surface tension and viscosity of the weld pool, e.g., oxygen and helium.

Gas	First Ionization Potential (Electron volts)	Density (Kg/m³)
Argon	15.75	1.78
Helium	24.58	0.18
Hydrogen	13.59	0.08
Nitrogen	14.54	1.16
Oxygen	13.61	1.33
CO_2 (Dissociation Potential)	15.89	1.98

Table : 2

They also flatten the weld bead. This iis illustrated in the figure below:

INFLUENCE OF GASES ON WELD METAL COMPOSITION AND PROPERTIES

During transfer through the arc plasma, the metal droplets, along with any alloying elements they contain, are oxidized to varying degrees due to the high temperatures existing. The degree of oxidation is a function of the oxidation potential of the gas, the reactivity of the elements in the metal droplets and also the time of flight.The oxidation potential of any gas or gas mixture may be determined as per the IIW index = $\%O_2 + 0.5 \times \%CO_2$

However, even in the case of inert gases there is a loss due to volatilization of the metal vapours, due to the very high arc temperature, and oxidation as they leave the protective gas shroud. The amount of element loss and the ultimate composition of the weld metal will obviously influence the metal properties such as tensile strength and toughness. Apart from this, oxide inclusions can have a significant effect particularly on toughness. In the case of ferritic steels an optimum level of inclusions may improve toughness by promoting nucleation of acicular ferrite. However, too high an inclusion content will reduce toughness. The higher oxidation potential shielding gases eg. CO2 also produce larger amount of slag on the weld bead surface.

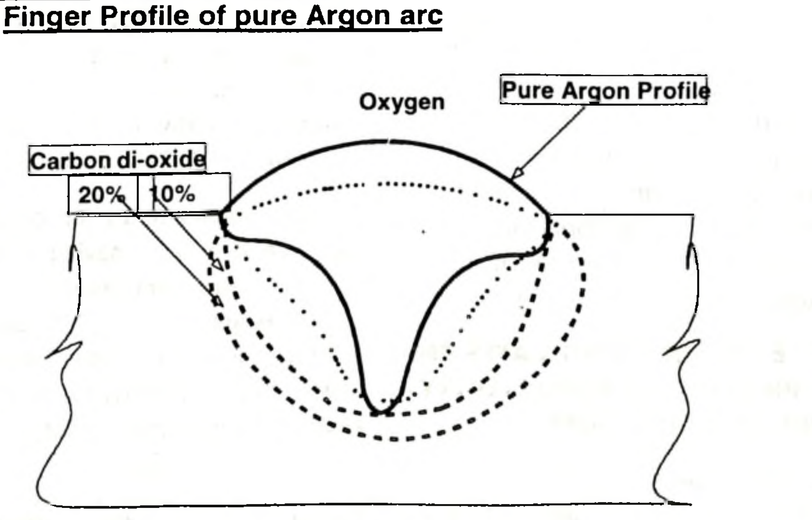


Figure 10

SELECTION OF GASES AND GAS MIXTURES

The principal factors influencing the selection of a gas for a particular material and welding process would be its technical suitability and the overall weld cost. Apart from the material compatibility factors given in table 1, two other important factors are its ionization potential which dictates its ease of establishing a stable arc and its density which is a measure of its shielding efficiency.

The welding process is also a factor since in GTAW, no oxidizing gas can be used, as it would burn out the tungsten electrode. This restricts the choice of gases to argon, helium and hydrogen. Thus initially Argon was the main gas used for GTAW as well as GMAW of all materials except carbon steels where CO_2 was extensively used because of its low cost and easy availability. Helium was used to an extent in USA where it is cheaply available but its cost inhibited wide spread use in other countries.

With the growth of the GMAW process people began to appreciate the iimportant role the shielding gases could play in improving the quality and productivity of the process. During the 1970s and 80s in the developed countries, considerable research was directed towards understanding the role of individual gases and how they influenced the welding process. It was found that often a mixture of gases gave improved welding performance and weld properties than the basic shielding gases argon, helium or CO_2 used individually.

One of the major developments has been the use of argon-based binary and ternary gas mixtures for welding of carbon steels in GMAW. The high spatter and fume levels along with convex bead and limitation in welding speed had long been problems with CO_2, particularly in open arc welding. Argon eliminated most of these problems but itself has a poor penetration profile as shown in the figures below. It was found that addition of CO_2 improved the penetration. The higher the CO_2 level, greater the penetration but there was a trade off in increasing spatter levels, thus CO_2 contents have to be limited to 25% max. It was further found that addition of a small amount of oxygen reduced surface tension and increased fluidity of the weld pool giving flatter beads and improved welding speeds. Oxygen also helped to stabilize the arc root by having a uniform degree of oxidation on the weld pool surface.

For welding of aluminium and non-ferrous materials where oxidizing additive gases cannot be tolerated, helium plays the same role of improving penetration, reducing convexity and increasing welding speed. For austenitic stainless steels

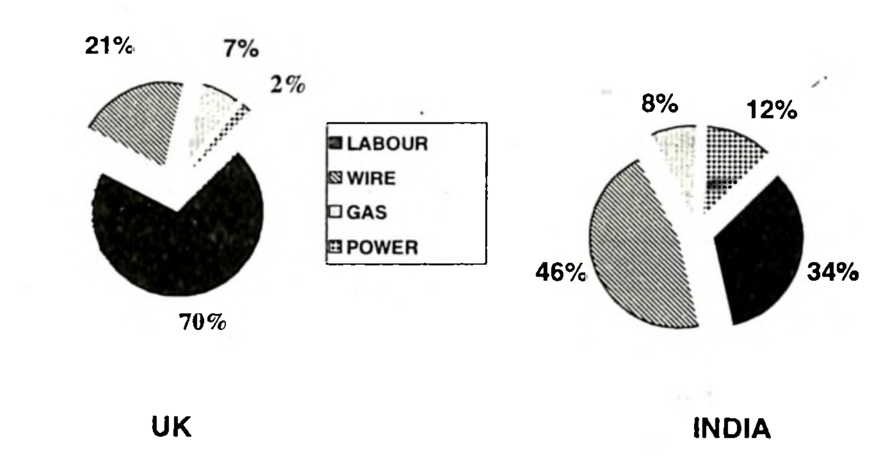


Figure 11

which can tolerate hydrogen, upto 10% of this gas is added to argon in the GTAW process to improve penetration and welding speed and also to give a cleaner bead.

Argon-helium-carbon dioxide-oxygen, 4 - component gas mixtures are used in the high deposition rate Rapid arc and T.I.M.E. processes where each component has a specific role in the process. Thus we find that over the years a large range of gas mixtures have been developed for different applications in GMAW and GTAW and these are covered by EN 439.

Research in shielding gases has also been directed to make the environment safer for the welder. Thus replacement of CO2 by argon mixtures has significantly reduced particulate fumes and carbon monoxide levels. Similarly addition of helium to argon mixtures help to reduce ozone levels in the fume.

ROLE OF SHIELDING GASES IN IMPROVING PRODUCTIVITY AND REDUCING COST

It would be apparent from the foregoing that the modern shielding gases, based on argon and argon-helium-based mixtures, are designed to produce more stable arcs, reduce spatter and weld bead convexity and increase welding speed apart from improvement in weld quality. These mixtures thus facilitate advanced processes like pulsed welding, mechanization, use of robots, etc., and also high productivity processes like T.I.M.E. and tandem MIG. They also facilitate the use of feedback controls and seam tracking devices. This has led to GMAW becoming the dominant welding process in most of the developed countries accounting for over 70% of weld metal deposited. Even in India, in some industry segments like two-wheelers and auto components it has become the dominant process and overall its share is rapidly growing and is reaching 18 -20%.

Reduced spatter and bead convexity can give filler wire saving upto 25 to 30% and increased welding speeds result in 15 to 20% savings in power and gas besides improving weld shop productivity. Reduced spatter also eliminates a lot of clean up time and labour.

Figure 11 shows the approximate expenditure on the direct welding cost inputs and it will be appreciated that any reduction in wire, labour and power cost can easily offset any increase in gas cost. Thus, the selection and use of an optimum shielding gas can significantly reduce overall weld cost although the gas itself may be slightly more expensive.

PLASMA AND LASER WELDING AND CUTTING PROCESSES

Gases also play a significant role in these two comparatively modern processes which are gaining increasing popularity for both welding and cutting. Plasma welding was developed by R M Gage in the US in 1953 and when it was introduced it proved to be a much more concentrated and hotter energy source making it possible to reduce the overall heat input at the same time increase welding and cutting speeds. A similar advantage applies to laser cutting and welding, developed by Peter Houldcroft and Martin Adams at the BWRA in the late sixties, which provides an even more intense heat source.

The difference between the GTAW and PLASMA process is that the arc plasma in the latter is constricted physically by a nozzle, which increases the plasma temperature and pressure. The arc may be struck between the electrode and this nozzle called the anode (non-transferred arc) or between the electrode and work piece (transferred arc). Apart from the plasma gas, which is generally argon or helium, there is an additional shielding gas required to prevent the weld from atmospheric contamination. These shielding gases may be mixtures of argon with low levels of active gases e.g., hydrogen. The intensity of the plasma arc allows very low currents of the order of 0.5 Ampere to be used which promotes its use for very thin sheet welding e.g., stainless steel bellows.

Plasma cutting uses high plasma gas flows and active gases both of which increase the arc voltage required. The electrode is tipped with tantalum or hafnium and may be water-cooled to prevent erosion. The cutting is done using a transferred arc although a non-transferred arc may be used as a pilot arc for starting. It is possible to use a "single plasma" gas torch design but a secondary gas flow improves torch cooling and cut quality. The gases used for the arc plasma may be argon-hydrogen mixtures, nitrogen, air and even pure oxygen. The secondary gas may be carbon dioxide, nitrogen or air. Alternatively, water may substitute the secondary gas or be injected into the plasma nozzles enabling the cutting process to be carried out under water.

LASERS

Gases are used in two types of lasers, CO_2 lasers and Excimer lasers using rare gases e.g., He. Ne, Kr, Xe etc. However, the main use of gases is in CO_2 lasers, where carbon-dioxide along with nitrogen and helium are used in the laser resonator or gun. Here it is the excitation of the CO2 molecules which generates the laser beam with the nitrogen and helium playing modifying roles. Further process gases like oxygen, nitrogen and argon are also used to assist in removing the molten metal from the cut and shielding it from the atmosphere.

Laser cutting is the largest industrial application of higher power lasers. It is used in industry in a range of applications from prototyping and smaller batch manufacturing up to continuous production line systems. The process lends itself to automation with offline CAD/CAM systems controlling either 3-axis flat bed systems or 6-axis robots for three dimensional laser cutting. In recent years the increase in laser cutting has been dramatic, replacing more conventional mechanical processes due to its increased flexibility. The improvements in accuracy, edge square-ness and heat input control means that other profile cutting techniques such as plasma cutting and oxy-fuel cutting are being replaced by laser cutting.

RECENT DEVELOPMENT – LASOX PROCESS

Patented by BOC sometime back, this process is now being developed for commercial application for cutting of carbon and low alloy steels. Here the laser is only used to pre-heat the steel to the oxidation temperature and a jet of oxygen is used for actual cutting similar to that for gas cutting. This process can cut much thicker steel sections at higher speeds than ordinary lasers.

CONCLUSION

From the foregoing it will be evident that gases have played an essential part in the development of fusion welding and cutting processes for the 20th century fabrication industry. Initially there role was to produce a concentrated heat source by using oxygen for combusting hydrogen and fuel gases. In fact the large requirements of oxygen projected for welding and cutting of steel was one of the incentives for development of the cryogenic process, for low cost bulk production of oxygen at the turn

Cutting characteristics	Benefits
♦ Cuts carbon manganese steels up to 20mm ♦ Cuts stainless steel up to 12mm ♦ Cuts aluminium up to 10mm ♦ Cuts brass and titanium ♦ Cuts thermoplastics, wood and many non-metals	♦ High quality cut - no finishing ♦ Ultra flexible - simple or complex parts ♦ Non contact - no surface blemishing ♦ Quick set up - small batches ♦ Low heat input - small HAZ, low distortion ♦ Lends itself to nearly all materials

of the 20th century. Subsequently in the development of various gas shielded arc welding and cutting processes they have played a crucial role in producing the arc plasma and shielding the weld. Here also the wide spread requirement for argon has been a motivation for developing argon purification processes to improve argon availability to the industry at reduced cost. Even in the latest laser processes, assist or process gases are essential whichever the type of laser used. Recognising the potential of gas mixtures for achieving further improvements in productivity and weld quality of the various processes, the gases industry has invested in developing and making available such mixtures to the fabrication industry, even with on-site installations for bulk requirements.

It is expected that whatever be the technological developments in the 21st century, gases will continue to play a very important and integral role in welding and cutting processes for the fabrication industry. ■