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Gas Metal Arc Welding Process: Review of Historical and Recent Development

Swati

Junior Research Fellow Department of Mechanical Engineering Indian School of Mines Dhanbad Jharkhand, India
Email:swatibit26@yahoo.com

N K Singh

Associate Professor (Workshop) Department of Mechanical Engineering Indian School of Mines Dhanbad Jharkahnd, India
Email: nks_221@yahoo.co.in

Abstract
In this paper recent developments in Gas Metal Arc Welding (GMAW) process associated with the effect of chemical composition of electrode wire; input process parameters, arc characteristics, individual shielding gas and gas mixtures on quality of mechanical and metallurgical properties and bead geometry of welded plates have been discussed. The scope for future investigation has been highlighted.

Keywords: GMAW, Historical and Recent Developments, Electric Arc, Wire Electrode, Shielding Gas and Gas Mixtures, Metal Transfer Modes, Applications, Future Investigation.

Introduction

Gas metal arc welding (GMAW) or metal inert gas (MIG) or metal active gas (MAG) welding, is a welding process in which an electric arc is formed between consumable wire electrode and the work piece metal(s) which heats the work piece metal(s), causing them to melt and join. The wire electrode along with shielding gas is fed through welding gun which shields the process from pollution in the air. The process can be semi-automatic or automatic. The constant voltage and direct current power source is most commonly used with GMAW but constant current systems as well as alternating current can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray and pulsed-spray, each of which has distinct properties and corresponding advantages and disadvantages. MIG/MAG welding is inherently more productive than manual metal arc (MMA) welding, where productivity losses occur each time welder stops to replace consumed electrode. Material losses also result from manual metal arc welding when the stub of each electrode is thrown away. For every kilogram of coated stick electrode purchased about 65 per cent becomes part of the weld and the rest being discarded. The use of solid wire and flux cored wire has increased this efficiency to 80-95 per cent. MIG/MAG welding is a versatile process which can deposit weld metal at very high rate and in all positions. The process is widely used fabrication of materials of light to medium gauge steels and aluminum alloy structures particularly where high rate manual operator production is required. The introduction of flux cored wires is find in increased application in heavy steel structures.MIG welding process operates on D.C. (direct current) usually with the wire electrode positive. This is known as “reverse” polarity. ”Straight” polarity, is seldom used because of poor transfer of molten metal from the wire electrode to the work piece. Welding currents of 50 amperes up to more than 600 amperes are commonly used at welding voltages of 15V to 32V. A stable and self correcting arc is obtained by using constant potential (voltage) power system and constant wire feed speed. Continuing developments have made MIG process applicable to the welding of all commercially important metals such as steel, aluminum, stainless steel, copper and several others. Materials above 0.030 inch (0.76 mm) thick can be welded in all positions including flat, vertical and over head. It is simple to choose the equipment, wire electrode, shielding gas, and welding conditions capable of producing high-quality welds at a low cost. GMAW is the most common industrial welding process, preferred for its versatility, speed and relative ease of adapting the process to robotic automation. Unlike welding processes that do not employ shielding gas or gas mixtures, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility. GMAW is currently one of the most popular welding methods, especially in industrial environments. It is used extensively by the sheet metal industry and by extension, the automobile industry. It is also popular for automated welding in which robots handle work pieces and the welding gun to speed up the manufacturing process. Generally, it is unsuitable for welding outdoors because the movement of the surrounding air can dissipate the shielding gas and thus make welding more difficult, while also decreasing the quality of the weld. The problem can be reduced to some extent by increasing the shielding gas output, but this can be expensive and may also affect the quality of the weld. Furthermore, the use of a shielding gas causes GMAW to be unpopular for underwater welding. A schematic view of GMAW is shown in Figure1.

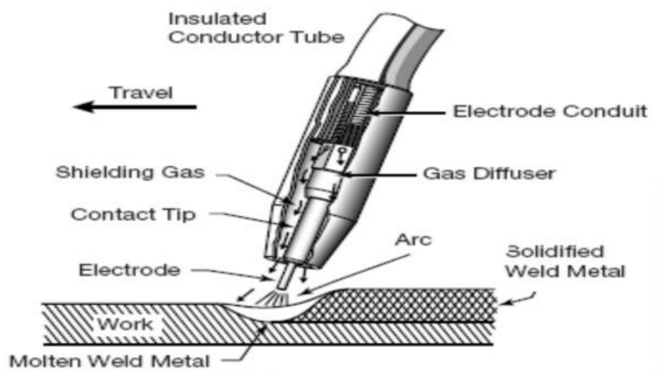

Fig.1. Schematic view of GMAW

History of GMAW Process 19thCentury

The history of MIG Welding started around the turn of the 19th century with Humphry Davy's discovery of the electric arc in 1800. At first carbon electrodes were used but by late 1800s, metal electrodes had been invented by N.G. Slavianoff and C. L. Coffin.

20thCentury

In 1920, an early predecessor of GMAW was invented by P. O. Nobel of M/s General Electric. It used bare electrode wire and direct current and used arc voltage to regulate the feed rate. It did not use shielding gas to protect the weld as developments in welding atmospheres did not take place until that decade. In 1926 another forerunner of GMAW was released but it was not suitable for practical use. Figure 2 shows picture of fine MIG welding

The beginning of MIG welding history is 1948. It was not until 1948 that GMAW was finally developed by the Batelle Memorial Institute. The work was sponsored by Air Reduction Company with the work conducted by Devers and Hobart. The features of this welding are mentioned below:

- It used smaller diameter electrode and constant voltage power source which had been developed by H. E. Kennedy.
- The process relied on an aluminum wire electrode fed continuously.
- Shielding was with argon gas.
- It offered high deposition rate but high cost of inert gases limited its use to non-ferrous materials.
- It used an axial spray transfer process. Spray transfer refers to process where tiny molten metal droplets are sprayed across the arc in the same way water is sprayed through a small hole in a garden hose nozzle. When the current is higher than the transition current, the electrode sprays onto the work in small droplets. These droplets detach and form at the rate of several hundred per second.

In 1953, the use of carbon dioxide as welding environment was developed and it quickly gained popularity in GMAW since it made welding steel more economical. It was

- based on work performed by Novoshilov and Lyubavshkii
- used large diameter steel electrode
- caused high spatter
- relied on higher heat generated by the arc, a part of the process that discouraged its use by welders
- In 1958 and 1959, short-arc variation of GMAW was released which increased welding versatility and made the welding of thin materials possible while relying on smaller electrode wires and more advanced power supplies. The features were:
- Small diameter electrodes were in 0.035"-0.062" (0.9-1.6 mm) range
- Enabled short-circuiting transfer where the electrode touches the work and short circuits. This causes the transfer of metal at the rate of 20x to 200x per second.
- Required lower levels of heat for welding thing sections of material
- Supports all-position welding.
- Excessive current results in excessive spatter.

During 1960s spray-arc transfer variation was developed, when experimenters added small amounts of oxygen to inert gases. Many developments in the 1960's were the result of improvements and research in power sources.

More recently, pulsed current has been applied, giving rise to new method called the pulsed spray-arc variation (GMAW-P). This process was based on research from the 1950's which used high-speed transition between high-energy peak current to low background current. The advantages were:

- Pulsed arc process uses axial spray transfer to reduce spatter and incomplete fusion defects
- Uses lower heat input
- Improved weld quality in comparison to short-circuit transfer

During 1970s additional developments in power source technology enabled improvements in GMAW-P and the GMAW processes which are mentioned below.

- Introduction of thyristor power sources. These devices can control a large amount of voltage and power with a small device (commonly used in light dimmers).
- Work completed by the Welding Institute of the United Kingdom determines the linear relationship between wire feed speed and pulsed frequency. Thos led to the development of synergic (one knob control) transistor controlled power sources which gave more control to the welder in the shop. The knob controls the wire feed speed and the amount of pulsed energy applied to the arc. The process improved the ease of use related to GMAW-P.

During 1990s major developments have been done by M/s Lincoln Electric including computerized controlled circuits and software to control the optimal arc welding. It introduces STT (Surface Tension Transfer) which uses a power source that reacts to the requirements of the arc. Power is generated by a waveform generator, technology that doesn't require constant current or a constant voltage power source. In the

Lincoln technology the power operates independently of the wire speed.

Today, GMAW is automated in many industries and uses robotics instead of its original manual application. It is highly utilized in the automotive industry, due to its versatility and speed. There are several other welding industries that have followed suit to save time and money during their welding applications. FANUC ArcMate, Motoman Expert Arc and KUKA Arc series are all well suited for this process. Each company has its own take on the process and provides the manufacturer with a robot that can quickly perform the welding process while producing superior quality weld.

Fig.2. MIG Welding (Source: M/s Lincoln Electric)

Literature Review

Kalpakjian and Schmid (2003) discussed briefly about metal transfer modes i.e. spray transfer, globular transfer and short circuit transfer and their applications in GMAW process. DeGarmo et al. (2005) discussed about GMAW, various gases, input parameters, various metal transfer modes, advanced gas metal arc welding (AGMAW), pulsed gas metal arc welding and their applications. Tani et al. (2007) studied and developed Hybrid Laser-GMAW welding technique. They investigated the influence of the shielding gas both on the stability of the process and on the dimensional characteristics of the weld bead. Two different parameters have been taken into consideration: the shielding gas composition and the shielding gas flow. The experiment, performed on AISI 304 stainless steel plates, has been carried out using Design of Experiment (DOE). The results have been analyzed statistically in order to determine the real influence of each parameter on the overall process. In order to obtain stable and effective process, the role of the shielding gas has been taken into consideration. Minimum helium content, equal to 30%, may be used to limit the plasma formation and consequently low laser power absorption. Gas mixture between 30% to 40% helium content allows default synergic curves in the GMAW and it results in good process suitability. Helium content above 40% yields to unstable arc conditions and does not lead to considerable increase of bead penetration depth. A shielding gas flow rate between 10 litres/min and 30 litres/min is enough to grant cheap welding condition.

Figure 3 shows bead penetration depths and widths as well as reinforcement height respectively. Figures 4 & 5 show mean bead penetration depth and mean bead widths as function of gas flow rate and their composition. The plotted lines show mean values between two repetitions for each helium percentage. These graphs show that bead penetration depth and bead width increase if helium percentage and gas flow increase. By comparing these graphs it is evident that at higher helium percentages of 60%, the dispersion of results becomes more important. This is, probably, due to the destabilizing effect of helium on the GMAW arc especially in pulsed mode. Iordachescu et al. (2006) describe the influence of the gases on the stability of the joining process and of metal transfer through the electric arc. The influence of the type of gas and welding speed, as well as other process parameters are addressed. The bead appearance and shape are analysed mainly underscoring the influence of gases on the convexity of the bead, colour, brightness, smoothness and porosity. They conclude that gases assuring very good stability are argon gas mixtures with H2 and He which also determine high values of heat input. Gases assuring lower heat input and lower zinc burn-off are Ar with O2 and Ar with N2 since these gases assure good stability and appearance of the bead. The only stable procedure assuring low heat input, for all the gas mixtures, is short circuit transfer mode.

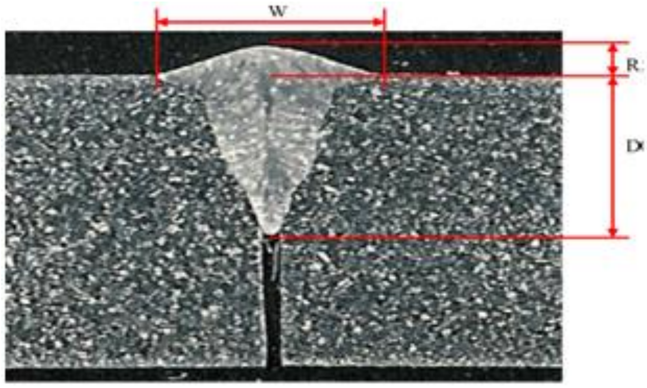

Fig. 3. Characteristic dimensions i.e. penetration depths (D), width (W) and reinforcement height (R) of weld bead obtained by using 40% He mixture and a 30 litres/min flow rate. {Source: Tani et al. (2007)}

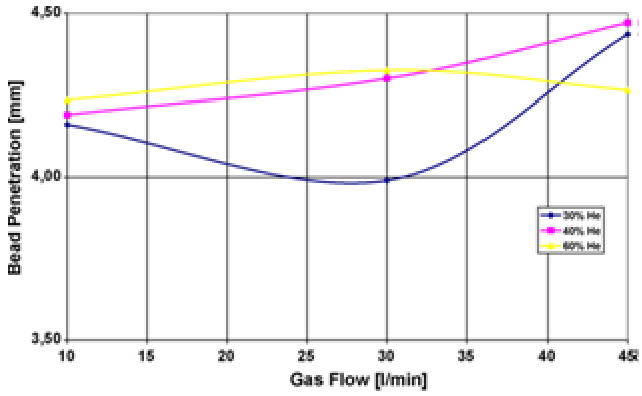

Fig.4. Comparison between penetration depths as function of gas flow rate and composition{Source: Tani et al. (2007)}

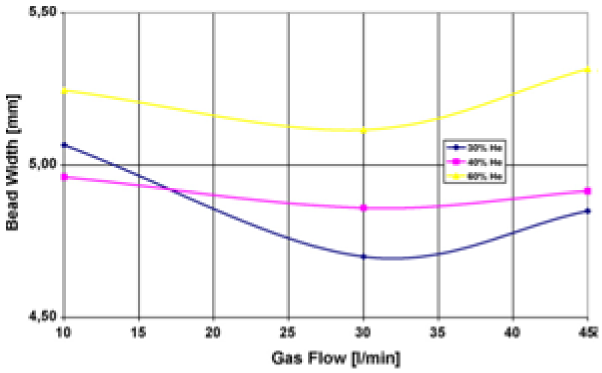

Fig. 5. Comparison between mean bead widths as function of gas flow rate and composition {Source: Tani et al. (2007)}

Conclusion

From the abovementioned discussion it is evident that historical developments have led to the improvements in quality of weldments on account of latest technological developments. Individual gas (inert and semi-inert) and gas mixtures; modes of their flow rates; GMAW combined gas welding methods; various modes of metal transfers apart from other input parameters influence various output parameters i.e. penetration depth, reinforcement height, bead width; strengths(tensile, compressive, bending, shear and combination thereof); Heat Affected Zone(HAZ) etc. Therefore, the control of input parameters can improve various properties of weldments for specific industrial applications as per specified design requirements.

Future Investigation

Authors propose to study the effect of input parameters i.e. welding speed, extension length, flow rate of CO2 gas, welding current, arc voltage, angle and direction of the torch etc. on output characteristics i.e. bead geometry, penetration depth, reinforcement height and bead width as well as strength, microstructure, temperature distribution and hardness of weldments of stainless steel plates of various grades e.g. AISI 202, AISI 304 etc. by MIG/MAG welding machine Model CVR-251 through using electrode wires of Grades e.g. AISI 308L, AISI 309 and measurement by Thermal Imaging Camera, Electron Probe Micro Analyser (EPMA) and Metallurgical Microscope apart from other measuring instruments. Various statistical and quantitative techniques may be applied for the optimization of output parameters of welded joints for the best performance in specific application.

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