SOME ASPECTS OF IMPROVING THE QUALITY OF WELDS IN MIG WELDING OF ALUMINIUM

K.L.Rohira, T.K.Mitra, A. Logithasan, A.Raja, R.S. Babu, Dr. V.Silvan ***
** Welding Research Institute, BHEL, Tiruchirapalli*
*** Professor, Regional Engineering, College, Tiruchirapalli*

INTRODUCTION

MIG Welding is widely used for welding of aluminium and its alloys. It is a fast, adaptable process and its ability to deposit large quantities of weld metal in any position in a comparatively short period of time makes it extremely attaractive. Also, it can be employed for wide range of thicknesses. However, for critical applications where high quality welds are required; MIG welding process is often overlooked since it is feared by many fabricators that it would not be possible to maintain the high quality requirements with this process. Though there are some typical problems associated with this process but they are not unsurmountable (1).

Porosity formation is considered as a major problem in MIG welding. Lack of penetration, lack of fusion and burn through in root pass welding are the other common defects encountered with conventional MIG welding of aluminium. Hence it is vitally important that adequate attention is paid to suitable welding conditions. The proper manipulation of weld pool, use of backing for root pass welding, proper interpass cleaning to remove the oxide layer, controlled agitation of weld pool can bring in a quantum leap in the quality of MIG welds of aluminium.

The introduction of synergic MIG process has revolutionised the welding of aluminium with its special characteristics, it provides controlled metal transfer and easier manipulation of the weld pool by providing spray transfer at very low average currents compared with those of conventional MIG welding. Thus, it has greatly extended the previously limited scope of the conventional MIG process. The developed countries were quick to adopt this process but the potential is yet to be exploited in our country.

Table 1 : CHEMICAL COMPOSITION OF BASE METAL AND FILLER WIRE

	Zn	Mg	Mn	Zr	Cr	Sii	Fe	Ti	Cu	Al
Base metal	3.8-4.8	1.8-2.2	0.25-0.45	0.1-0.25	0.05 max	0.2 max	0.3 max	0.05 max	0.1 max	Bal.
Filler wire 5556A BS2901 Part 4	0.2 max	5.0-5 5	0.6-1.0	-	0.05-0.2	-	-	0.05-0.2	0.1 max	Bal.

Table 2 : ARGON GAS SPECIFICATIONS

Impurities	PPM/Max.	Impurities	PPM/Max.
Oxygen	6.0	Nitrogen	50.0
Moisture	6.0	Hydrocarbons	2.5
Carbon dioxide	1 0	Super Compounds	Nil
Carbon monoxide	1.0	Mercury	Nil
Oxide of Nitrogen	1.0	Chlorine	Nil
Hydrogen	3.0		

These aspects to improve the quality of MIG welds in aluminium have been discussed in this paper.

The details are based on the experience gained over the years in MIG welding of aluminium and its alloys at WRI. Conventional transformer rectifier type of indigenous make MIG welding equipment and AWP M 450 PS synergic MIG Welding equipment were used entensively for these works. However, specific studies as reported in this paper were conducted with particular aluminium alloy, filler wire and shielding gas of which details are given in Table 1 and 2.

Conventional MIG Welding of Aluminium and Its Limitations

It is well known that the spray mode of metal transfer is most suitable for welding aluminium. To achieve spray mode in conventional MIG welding current and voltage settings must be kept high enough e.g. for 1.6 mm diameter wire which is commonly used (owing to wire feeding problems with smaller diameter wires) for semi automatic MIG welding; minimum reasonable current in the range of 180-200A and voltage in the range of 22-24V are required to achieve spray mode of metal transfer. To match these settings, wire feed rate has to be maintained accordingly which will be in the range of 5.8 -6 m/min and if high currents of 300-350 A are used, the wire feed rate would be 8 - 9 m/min. The MIG welding carried out with above parameters cause certain difficulties as enumerated below.

Control of Root Penetration

Welding in spray mode with wire feed rate in the range of 6 - 9 m/min will produce large weld pool at lower welding speeds (< 400 m/min) leading to weld pool flooding or weld metal running ahead of arc which can cause lack of penetration defects in the root run. Hence, arc travel speed shall be kept sufficiently high to avoid these problems. However, at higher speeds, the probability of lack of fusion and lack of penetration increases particularly in thick welds. Conversely, if arc is pushed at little lower speeds it would cause excess penetration and burn through defects. The problem can be very serious with thin sheet welding since occurrence of these defects will be quite high e.g. for root welding of 6 mm thick joints of single vee having root gap of 2 mm and with spray transfer using 1.6 mm dia wire arc travel speed shall be kept more than 700 mm/min to achieve good weld irrespective of welding position. It can be easily understood that how difficult it will be for the welder to control the weld pool in this situation. If the joint gap is reduced or IIP thickness is increased and welding speed is manipulated, it may either cause lack of penetration or excess penetration and burn through defects. Further, if intentional or unintentional chnages in arc length and wire extension are caused to control the depth of penetration and manipulate the weld pool to achieve controlled penetration it may lead to lack of fusion or surface porosity. Thus to achieve joints with controlled penetration in unbacked joints is practically impossible with conventional MIG welding.

Lack of Fusion and other defects in Multilayer Butt and Fillet Welds.

In welding of thick plate multilayer joints the problems as discussed under Para 21 can lead to lack of side wall fusion, interlayer lack of fusion defects if proper care is not observed in manipulation of weld pool to avoid weld pool flooding irrespective of welding position. It can also lead to poor shape, undercut and porosity defects.

Use of Backing

Use of backing bars and strips (temporary or permanent) certainly helps in achieving good root welds with conventional MIG welding. Wherever possible it is better to use temporary backing bars with suitable groove to achieve smooth beads. For curved and non-linear joint suitable backings from copper or austenitic stainless steel strips can be developed to suit the particular configuration. However even when backing bars or strips are used the weld pool flooding as welding progresses can cause lack of fusion, lack of penetration and uneven root beads with suck back at root. Hence, enough care is required to provide good fit-up of joints with sufficient root gap.

Positional Welding of Butt and Fillet Joints

In case of steel, short circulting mode of metal transfer is used with conventional MAG/CO_2 welding process for out of position welding. However, short circuiting mode is not considered suitable for aluminium welding since weld pool gets cold quite fast. The use of spray transfer is found ideal for positioned welding. Stringer bead techniques are generally employed for welding aluminium with careful manipulation to avoid large weld pools leading to defects such as cold lap, lack of fusion and oxide indusion. Thus, special attention is needed to a higher degree compared to welding in flat position.

Welding of Thin Sheets

It is difficult to achieve good quality in thin sheet welds of thickness below 3 mm even with 1.2 mm diameter wire and below 5 mm with 1.6 diameter wire since current and voltage settings are too high with spray trasfer of mode causing burn through defects even through high welding speeds (< 600 mm/min) are employed (2).

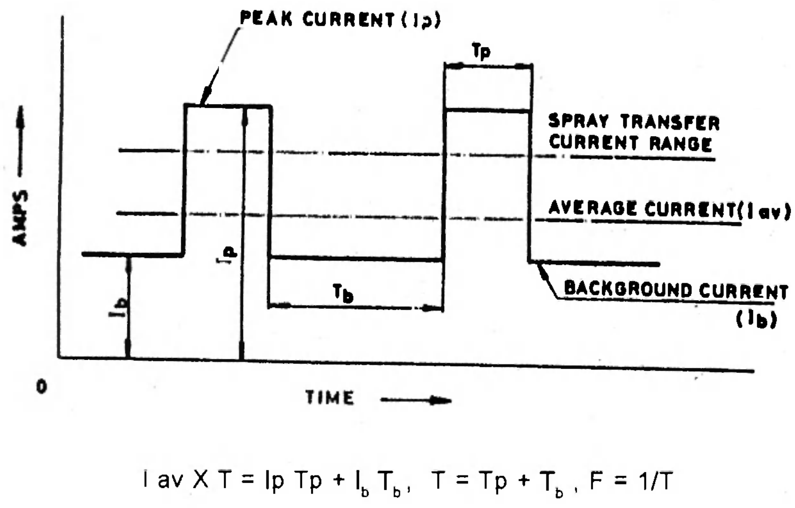
Welding technique and skill of welder

It is widely accepted practice in MIG welding of aluminium that weld deposit is made by traversing the gun in the forehand direction with the gun inclined at 10-15° from the vertical irrespective of the joint position. A slight rotary motion of the gun is necessary to ensure that the arc is actually rotated to agitate the weld pool. This helps in proper fusion between weld toes and base plate, Improves the bead shape, slows the cooling rate and reduces the porosity level. Wide weaves should be avoided as the weld deposit may become oxidised due to insufficient argon coverage. Normally welding gun is held by both hands to manipulate the weld pool, in practice arc length of 4.0-6.5 mm is considered satisfactory. However for root pass welding in butt and fillet welds arc length of 3 mm can be used for better fusion.

With manual welding, it is difficult to control the gun angle, nozzle to work distance and travel speed to the same degree as in the case of mechanised welding. Over and above greater attention is always required to avoid weld pool flooding leading to serious weld defects. The defects are controlled to certain extent by manipulative skill of the welder but slight lack of concentration particularly when long joints, abrupt changes in direction and positional welding is performed it may lead to poor quality of welds (3).

Synergic MIG Welding and its inherent advantages for Aluminium welding

Synergic MIG welding is a transistorised controlled pulsed MIG welding process wherein controlled metal transfer is achieved in such a way that for each pulse one drop is detached



$$I_{av} \times T = I_p T_p + I_b T_b, \quad T = T_p + T_b, \quad F = 1/T$$

Fig 1 : Output wave form of current in synergic MIG welding

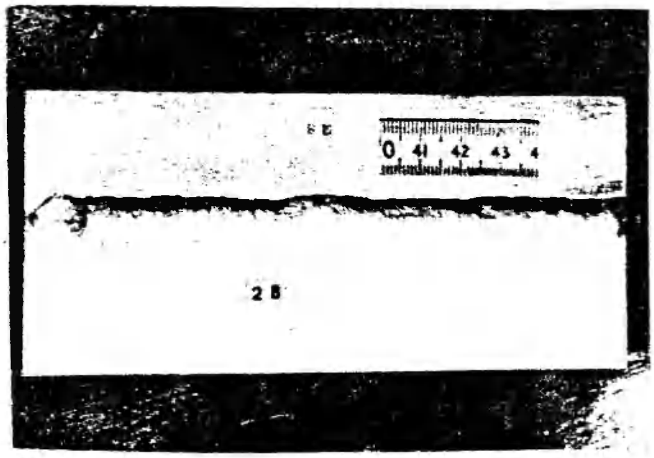


Fig.2. Bead on Plate : Synergic MIG.

Ip - 350 A	I_b - 50 A	Tp - 4 ms	T_b - 10 ms
Ave.I - 136 A	WS- 350mm/min	WF - 4.3m/min	T - 6 mm

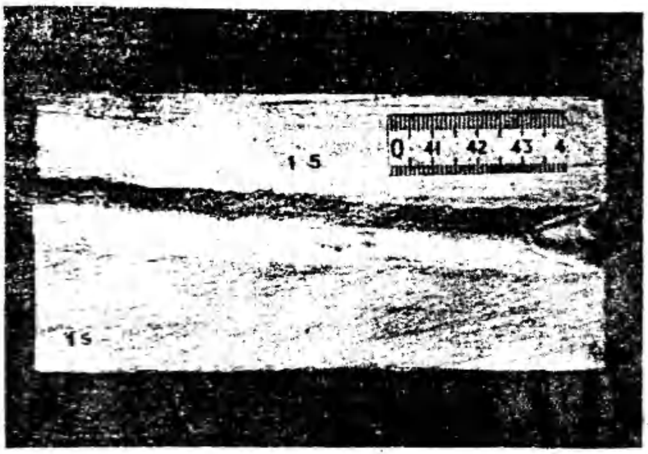


Fig.3. Bead on plate : Conventional MIG

I-220 A	V- 27 V	WS -500mm/min	WF - 6.7m/min	T - 6mm

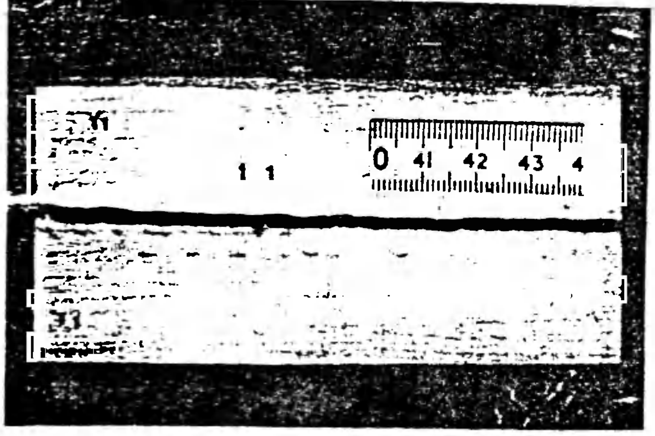


Fig.4. Root Bead Formation without backing : Synergic MIG

Ip - 300 A	I_b - 50 A	Tp - 3 ms	T_b - 10 ms
Ave.I - 112 A	WS- 300mm/min	WF - 3.3m/min	T - 6 mm

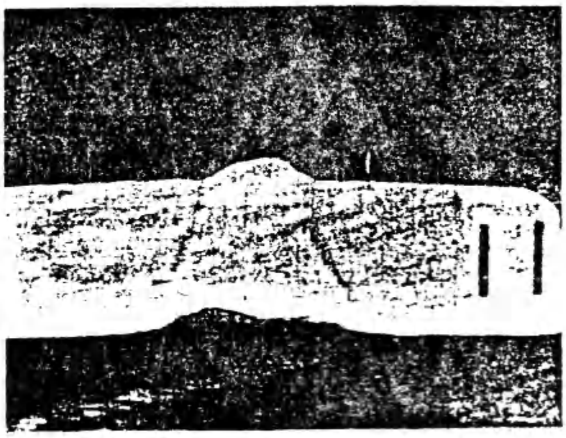


Fig.5. Macrosection of root bead without backing : Synergic MIG

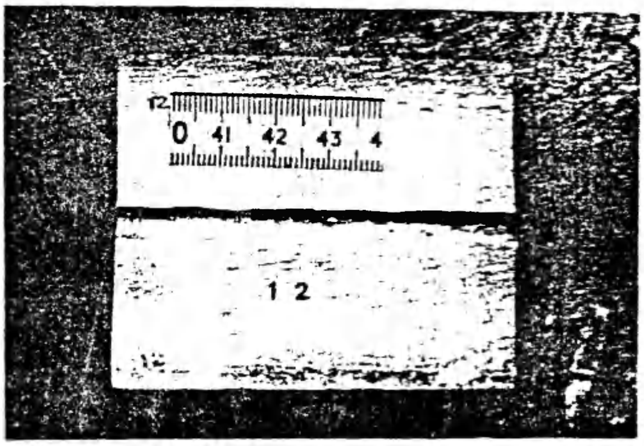


Fig.6. Root bead formation with backing : Synergic MIG

Ip - 350 A	I_b - 50 A	Tp - 4 ms	T_b - 10 ms
Ave.I - 136.5 A	WS- 320mm/min	WF - 4.4m/min	T - 6 mm

Fig.7. Macrosection of root bead with backing : Synergic MIG.

having a diameter more or less equal to wire diameter. Current is pulsed between low level (back ground current) and high level (peak current) for suitable duration so that average current is kept in the short circuiting range but metal transfer is achieved in spray mode. The high peak current pulse is kept well above the transition zone where only spray transfer is achieved. The low level background current is maintained which is sufficient to maintain the arc but it is below the transition current (Figure 1). Thus at very low average current spray transfer mode can be operated which is impossible to achieve in conventional MIG welding e.g. for 1.6 mm diameter wire, spray mode of metal transfer can be achieved at an average current of 90 A, (Ip = 260A, Tp = 3ms, Ib = 50A and Tb = 15 ms), with a wire feed rate just 2.3 m/min, It is possible to achieve spray mode even at an average current of 60A.

It can be easily understood that weld pool flooding and associated problems as observed in conventional MIG welding can be overcome to a great extent by using this process. Figure 2 and 3 shows the bead on plate trials on 6 mm plate with conventional and synergic MIG. Synergic can produce beads with less ripples simillar to TIG welding. Thin material can be welded with relatively large diameter electrodes and but welds can be welded without backing bars with controlled penetration with less skill requirements and with low heat input (Figure 4 and 5). Root run welding with backing can be performed with much ease compared with conventional MIG welding (Figure 6 and 7). Moreover, positional welding can be performed with relative ease with desirable penetration, bead shape and with negligible spatter at much slower welding speeds.

The direction of travel, gun angle and manipulative technique are basically the same as with conventional MIG welding. However, welder using pulsed MIG will be able to appreciate the distinct changes in operating characteristics which will occur with weld pool area compared to conventional MIG welding. Good fitup is essential and by providing suitable welding condition and travel speeds high integrity welds can be provided. Further, it allows the use of large diameter electrodes for wide range of thicknesses with combined advantage of improved quality and freedom from wire feeding problem often experienced with small diameter wires. Furthermore the risk of porosity is also significantly reduced since it provides stirring action in the weld pool (4,5).

Figure 8 and 9 show the bead shape, macrosections of various butt and fillet joints welded with conventional and synergic MIG in horizontal/vertical position. The details of welding conditions are given thereof. It was found that synergic MIG produces welds having much better and uniform bead shape with sufficient penetration at lower average current and slower welding speed providing easy manipulation of the arc and thus reducing the strain on the part of welder to produce better quality welds. However, with suitable welding conditions and greater attention conventional MIG welding in spray mode can produce better quality welds within its limitations.

Methods to control porosity formation and other common effects

Aluminium alloys are far more susceptible to porosity formation than all other structural metals. Hydrogen is the dominant cause of porosity in aluminium welds because the solubility of hydrogen in superheated liquid aluminium is 19 times greater than the solubility in liquid of solidification temperature. Thus small concentration of hydrogen contamination in aluminium welds can cause severe porosity. The sources of hydrogen most commonly encountered in commercial welding practice are hydrocarbons (grease, oil etc.) hydrogen and moisture contaminants on surfaces of the filler metal, plate and shielding gas. Both primary porosity (forming from the liquid) and secondary porosity (precipitating from solid) may occur in welds. The size, shape distribution and amount of the hydrogen pores generated in the weld are dependent upon the solidification mode, cooling rate, degree of convective fluid flow, welding parameters, bead shape, shielding gas mixture and external pressure (6).

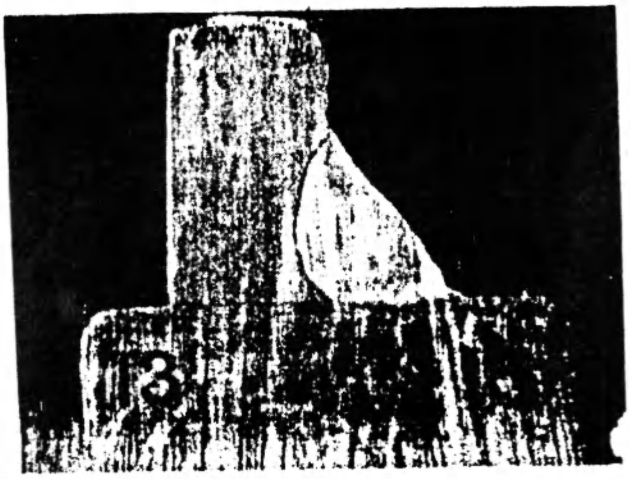


Fig.8. Macrosection of fillet weld : Conventional MIG

I-220 A	V- 26 V	WS -450mm/min	WF - 6.6m/min	T - 9mm
Welding position - Horizontal / Vertical (2F)				

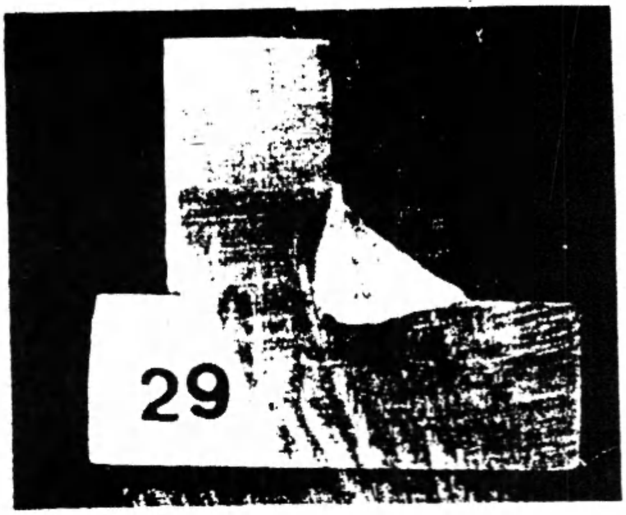


Fig.9 Macrosection of fillet weld: Synergic MIG.

Ip - 400 A	I_b - 60 A	Tp - 3 ms	T_b - 6 ms
Avs.I - 173 A	WS- 340mm/min	WF - 5.6m/min	T - 9 mm
Welding position - Horizontal / Vertical (2F)			

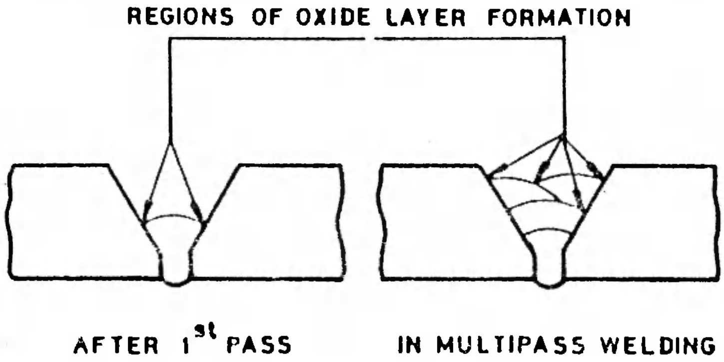


FIG: 10 - REGIONS OF OXIDE LAYER AND POROSITY FORMATION IN MULTIPASS WELDING.

Fig.11. X-Ray Photograph : Linear porosity formation in multipass welding; 14mm thick butt joint.

Fig.12 X-Ray Photograph : 14mm thick butt weld with proper interpass cleaning (Conventional MIG).

In comparing the GTAW : GMAW welds are more susceptible to porosity for two primary reasons. First, the large surface area associated with small diameter wires requires for GMAW provide ample opportunity for surface contamination and virtually all the moisture, grease and other hydrocarbon contaminants on the wire surface are immediately vaporised in the arc and converted into atomic hydrogen which is then available for absorption into the molten weld pool. Second, the higher droplet temperature in GMAW increases the amount of hydrogen absorption during metal transfer across the arc. Hydrogen bearing oxide films and inclusions on the plate and wire also contribute to porosity formation in MIG welding. Hence, storage and cleaning of joint edges before welding are very important considerations. Lack of fusion lack of penetration and oxide inclusions are the other common defects. Few methods have been already discussed to control these defects including the use of synergic MIG welding. Apart from the basic considerations, techniques and precautions generally observed for aluminium welding; the following factors are to be given to control the porosity formation and to achieve superior quality welds.

Removal of oxide layer and interpass cleaning.

An oxide layer is always present on aluminium and its alloys. Aluminium oxidises most readily in molten state in air i.e. above 600°C. The proper gas flow rate and coverage of weld pool is very important to avoid formation of oxide layer. The aluminium oxide has very high melting temperature (2060°C approx) and therefore interferes in welding causing improper wetting and lack of fusion defects. Hence, removal of this thick or thin oxide layer is very essential for successful welding. This oxide layer has to be removed by mechanical means like brushing, scrapping and filling. The lighter weight grinding machines with metallic end curtters and having tips of different shapes can be effectively used for removal of this oxide layer in multilayer welds in butt and fillet joints.

With MIG welding of aluminium, positive polarity is used for the electrode and this is very beneficial in breaking of oxide layer. The cleaning action takes place at the root of arc. However some thin layer of oxide is always formed at the adjacent regions which has to be removed essentially before depositing further passes. In our experience, the regions (as shown in Figure 10) are prone to oxide layer formation in multilayer welds. This shall be throughly removed by mechanical means as cleaning with wire brushing alone may not be enough. Also, the uneven beads forming cavities, large ripples and ridges shall be ground smooth before depositing next pass. Even though it consumes some time and effort but the trouble is worth to achieve superior quality welds. Further, these regions containing oxide layer if not cleaned properly not only interfaces with welding but also give rise to formation of secondary porosity of linear type near the edge or fusion boundary and porosity in the weld as applicable depending upon the number of passes in each layer (Figure 11). It has been already reported that oxide and other inclusions act as nuclei during solidification leading to greater porosity (6). In welding of Al-Zn-Mg alloys the degree of oxide, blackspot layer and spatter formation was found considerably higher compared to aluminium silicon alloys. These deposits have to be removed everytime before laying the next pass to avoid porosity and interlayer and side wall lack of fusion defects in multilayer welds, Figure 12 shows the X-ray photograph of 14 mm thick butt weld made with proper Interpass cleaning.

Controlled Agitation of Weld Pool

Turbulent convective fluid flow during solidification has been shown to produce a substantial reduction in porosity and grain size in aluminium welds deposited by the Gas Tungsten Arc Welding process. It is well known that dynamic simulation that induces extraordinary levels of turbulent convection in the melt will tend to transport heat pulses via fluid flow in the cellular dendritic interstacles causin secondary arms to melt off providing a means of grain multiplication, It has been found that electromagnetic strring produced substantial reductions in the porosity in aluminium welds. Convection appears to be vital in accelerating the nulceation growth and ultimate escape of bubbles from the molten pool (6).

This phenomenon was confirmed as welds produced by synergic MIG welding showed much less porosity compared to welds made by conventional MIG welding since pulsation between low and high level of current produces convective fluid flow and strring action provided by stiff arc of pulsed MIG welding which reduces formation of both primary and secondary porosity.

It was found that in conventional MIG welding, pronounced rotary motion to agitate the weld pool by the manipulation of gun greatly reduced the formation of porosity. This was found one of the most effective methods of controlling the porosity and technique has to be adopted to liberate the gas before the surface of the pool freezes (3). With manual welding technique, this is achieved readily by maintaining a large but controllable weld pool and agitating it sufficiently to eliminate the gas bubbles by use of slightly higher currents and gas flow rate. This technique combined with synergic MIG welding further enhanced its capability and produced welds of much superior quality since weld pool could be controlled in much better way compared to conventional MIG welding owing to weld pool flooding problems associated with this process as already discussed.

Bead shape and welding position

It was observed that welds having convex bead shape were found containing more porosity compared to welds with concave or flat bead shape. Consequently in multilayer welds convex beads have to be ground smooth to achieve superior quality welds. Good quality welds could be achieved with suitable welding conditions; however, particularly the welds made in vertical position were found having very shiny beads, much less black spot layer formation and porosity compared to welds made in other positions.

Preheating

The thermal conductivity of aluminium is three to four times higher than steel, although its melting point is relatively low (660°C). It is difficult especially with thick workpieces of aluminium to achieve a sufficiently intensive heat build-up with welding so that the weld pool remains sufficiently warm enough and in fact until degassing is complete. This applies in particular to the weld start. A good way of inhibiting heat dissipation is to preheat the workpieces (7).

The preheat temperature of 100-150°C is considered enough to achieve good results. This certainly helps in reduction of porosity and also to achieve smooth and better bead shape. The preheating of backing bar helps in reduction of porosity in root run welding.

Use of Gas Mixtures

Argon gas is widely used for aluminium MIG welding. Though for thick welds it is better to use Argon and Hellium gas mixture in different ratios varying from 75:25, 50:50 and 25:75. The shielding gas mixture of Argon and Helium is found better with regard to freedom of welding from porosity. Helium provides more heat in the arc and thus increases the depth of penetration. The hotter molten pool leads to slow cooling and less porosity formation.

CONCLUSION

Conventional MIG welding of aluminium can be performed advantageously to produce high quality welds joints having thickness above 5 mm (with 1.6 mm diameter wire) in butt and fillet welds in all positions using spray mode of metal transfer with proper attention and suitable welding conditions. Synergic MIG welding can overcome the limitations of conventional MIG welding to perform root pass welding, welding in spray transfer mode at lower average currents for better manipulation of weld pool, easy positional welding and thin sheet welding. With adequate attention paid to certain aspects in providing suitable welding conditions like proper manipulation of gun, controlled agitation of weld pool, use of backings, interpass cleaning to remove oxide layer, defects like porosity formation, lack of penetration, lack of fusion can be effectively controlled or eliminated to produce welds of high integrity.

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