Effects of Shielding Gas on Gas Metal Arc Welding Aluminum

Contrary to the conclusion of previous investigators, argon may be the optimum shielding gas for the gas metal arc welding of aluminum

BY W. R. REICHELT, J. W. EVANCHO AND M. G. HOY

ABSTRACT. Argon, helium, and mixtures of these gases are used for shielding in gas metal-arc welding of aluminum. Considerable work has been done previously by other investigators to define the effects of these gases on penetration, arc stability and porosity. Most of this work, however, was performed by maintaining an “optimum” arc gap. Consequently, for various compositions and flow rates studies, weld parameters were also varied.

To further understand the effects of shielding gas on gas metal-arc welding aluminum, a study was conducted whereby all weld settings were preset at constant values and effects of shielding gas composition and flow rate on arc gap, voltage, and current, in addition to penetration, arc stability, and porosity were evaluated. Shielding gas composition and flow rate both affected depth of penetration. Maximum penetration was obtained with pure argon at 150 cfh, whereas minimum depth of penetration was associated with a 25% argon/75% helium mixture at 200 cfh.

Effects of shielding gas on depth of penetration correlated directly with effects of shielding gas on wattage. Gas compositions high in argon also produced best arc stability, and the minimum amount of micro-porosity. Results of this work suggest that, contrary to the conclusions of previous investigators, argon may be the optimum shielding gas for gas metal-arc welding of aluminum.

Table 1—Properties of Shielding Gas

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<thead>
<tr>
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<th>Argon</th>
<th>Helium</th>
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<tbody>
<tr>
<td>Ionization potential</td>
<td>15.8 eV</td>
<td>24.6 eV</td>
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<tr>
<td>Arc initiation</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Arc stability</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>0.406 x 10^-4</td>
<td>3.32 x 10^-4</td>
</tr>
<tr>
<td>Density (relative to air)</td>
<td>1.38</td>
<td>0.137</td>
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<tr>
<td>Cleaning action</td>
<td>Good</td>
<td>Poor</td>
</tr>
</tbody>
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Table 2—Advantages/Disadvantages of Helium and Argon

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Helium</td>
<td>• Higher arc voltage and assumed</td>
<td>• Poor cleaning</td>
</tr>
<tr>
<td></td>
<td>greater heat input (deep penetration and high</td>
<td>• Poor arc initiation and stability</td>
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<tr>
<td></td>
<td>welding speeds)</td>
<td>• Cost</td>
</tr>
<tr>
<td></td>
<td>• Broad weld root width</td>
<td>• Requires greater flow rates</td>
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<tr>
<td></td>
<td>• Good arc initiation and stability</td>
<td>• Narrow weld root width</td>
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<td></td>
<td>• More effective shielding</td>
<td></td>
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<td></td>
<td>• Low cost</td>
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action. Helium on the other hand provides no cleaning.

Because of the differences in physical properties and characteristics of helium and argon, each shielding gas has its advantages and disadvantages—Table 2. A higher arc voltage associated with helium results in a greater heat input and supposedly a deeper penetration. This greater heat input also permits welding at higher speeds. The main advantage associated with the high heat input, however, is the broad weld root width obtained when welding with helium.

Although the greater heat input is a major advantage for helium, this gas also has several disadvantages. Helium does not assist in cleaning the oxide from aluminum plate, and its high ionization potential results in difficult arc initiation and poor arc stability. A greater flow rate is also required with helium because of its lower density. Probably the greatest disadvantage of this shielding gas is related to its cost. Helium continues to be more costly than argon.

Argon has many advantages over helium. Because of its low ionization potential, it demonstrates good arc initiation characteristics and excellent arc stability. Argon is also effective in assisting cleaning of the oxide from aluminum plate, and its high ionization potential provides a more effective shield from the environment at lower flow rates than are required for helium; also, most importantly, argon is cheaper than helium. The main disadvantage attributed to argon is the narrow weld root width that results when using this shielding gas.

Many of these statements about argon and helium as shielding gases have resulted from qualitative evaluations over several years. However, only limited quantitative data on the effects of shielding gas composition or flow rate are available in the literature. As a result, several "rules of thumb" have evolved as to the benefits of the various shielding gases or the mode of using the various shielding gases without substantial theoretical verification. In this regard, most references on arc welding indicate that shielding gas flow rate should be selected by reducing flow rate until an unstable arc is observed. Then increasing the flow rate slightly for a safety margin. Another statement is that helium provides greater penetration.

Previous in-house process development work has suggested that shielding gas flow rates may be just as significant as shielding gas composition in affecting weld penetration and weld cross-section geometry. To quantify the effects of shielding gas composition and flow rate, a program investigating both argon and helium was conducted.

### Procedure

Effects of shielding gas composition and flow rate on weld penetration and weld cross-section geometry were determined by automatic GMA welding in the flat position. Shielding gas compositions ranging from pure argon to pure helium, including various mixtures, were evaluated at flow rates ranging from 50 cfh (23.5 liters/min) to 300 cfh (141 liters/min). The program was conducted in two phases as described below.

#### Phase I—No Arc Gap Control

Initial weld parameters were determined using a shielding gas composed of 50 cfh (23.5 liters/min) helium and 50 cfh (23.5 liters/min) argon. Wire filler metal feed speed, current and travel speed were adjusted to produce a smooth welding arc and a sound weld. The weld settings determined by an experienced welder's observations follow: voltage—35 V; current—404 A; travel speed—12 ipm (5 mm/s).

These parameters resulted in an arc length of 0.148 in. (4 mm). Subsequent welds were made maintaining these machine settings as shielding gas composition and flow rate were varied. Initially, three welded samples were made for each condition of shielding gas composition and flow rate. However, uniform results permitted the number of samples to be reduced to one per shielding gas variable.

#### Phase II—Arc Gap Control

The procedure for Phase II was similar to that of Phase I. In this phase, however, a constant arc gap of 0.150 in. (4 mm) was maintained first by adjusting current. The procedure was then repeated and arc gap was adjusted by voltage (filler metal feed).

Accurate shielding gas flow rates were maintained through the use of thermal mass meters. Voltage and current were recorded using a Brush recorder, and arc gap was observed by means of an arc viewer mounted on the travel carriage.

All welds were made on a grooved 5083-0 plate, 1 x 9 x 12 in. (25.4 x 228 x 305 mm), using 3/32 in. (2.4 mm) diameter 5183 electrode. The groove was 1/4 in. (6.3 mm) deep and 1/2 in. (12.7 mm) wide—Fig. 1. Shielding gas was commercial welding grade argon and helium.

All welds were cross-sectioned at the midpoint perpendicular to the weld. The cross-section was polished and etched; and weld penetration, width at varying depths,* and crown height were measured. In Phase II, welders' comments concerning arc characteristics were also documented.

*Weld width measured approximately 1/4 in. (6.4 mm) from bottom of weld

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Fig. 1—Grooved 5083 plate. Groove dimensions: 1/4 in. (6.3 mm) deep and 1/2 in. (12.7 mm) wide

Fig. 2—Commercially available equipment utilized during weld evaluation. Shown are the welding torch, arc viewer, track wire filler metal feed controller
Equipment

Commercially available equipment was utilized for this investigation—Fig. 2. This equipment included a water-cooled welding torch with a 3/4 in. (19 mm) gas cup, a wire filler metal feed controller, a Gulco KAT track, and a drooping volt-ampere characteristics power supply.

Results

Phase I—No Arc Gap Control

When arc gap was allowed to vary, both shielding gas composition and flow rate significantly affected weld penetration—Fig. 3. For pure argon, maximum penetrations were associated with 150 cfh (70.5 liters/min) flow rates. Flow rates greater than or less than 150 cfh (70.5 liters/min) resulted in lesser penetrations. Minimum penetrations were associated with shielding gas compositions between 60 and 80% helium at approximately 150 cfh (70.5 liters/min) to 200 cfh (94 liters/min) flow rates. Increasing or decreasing the flow rate or increasing or decreasing the percentage of helium in the shielding gas resulted in increased penetration. In no case, however, was penetration as great as the level obtained with 150 cfh (70.5 liters/min) pure argon.

Shielding gas flow rate had little effect on weld root width. However, shielding gas composition significantly affected weld root width. Root widths less than 0.250 in. (6.3 mm) were produced with pure argon and increased to 0.4 in. (10 mm) with compositions containing 70% helium—Fig. 4.

Effects of shielding gas on weld cross-sectional area were complex and are shown in Fig. 5. For shielding gas compositions rich in argon, flow rate had a significant effect on cross-sectional area. Maximum cross-sectional areas of 1 square inch (645 mm²) was obtained at flow rates between 100 cfh (47 liters/min) and 150 cfh (70.5 liters/min) for compositions containing 50% or more argon. As the compositions became richer in helium, flow rate had less effect; however, variations in composition between 70 and 90% helium did affect cross-sectional area.

These results are further illustrated in Fig. 6, which shows weld cross-section profiles as affected by shielding gas composition and flow rate. Of particular interest is the effect of flow
rate on increasing the weld root width when pure argon is used. Weld root profile for 150 cfm (70.5 liters/min) argon is similar to profiles using an argon-helium gas mixture. A flow rate of 150 cfm (70.5 liters/min) pure argon provides adequate weld width and deep penetration and is a significant improvement over the narrow weld spike typically associated with pure argon. Wide weld widths generally associated with pure helium or compositions high in helium are most evident at the top of the weld. However, this wide weld bead provides no significant benefit.

Phase II—Arc Gap Control
Arc Gap Controlled by Current. When arc gap was adjusted by current to 0.150 in. (4 mm), penetration was primarily affected by shielding gas flow rate; shielding gas composition had essentially no effect—Fig. 7.
Increasing the gas flow rate beyond 100 cfh (47 liters/min) decreased weld penetration.

Both shielding gas flow rate and composition affected weld root width—Fig. 8. Minimum weld root widths were associated with pure argon shielding at 50 cfh (23.5 liters/min). Maximum weld root widths were associated with pure helium at flow rates exceeding 100 cfh (47 liters/min).

Flow rate had a significant effect on weld cross-sectional area for shielding gas compositions rich in argon—Fig. 9. Increasing flow rate decreased weld cross-sectional area. On the other hand, shielding gas compositions rich in helium were not affected by flow rate, although changes in helium concentration did affect the weld cross-sectional area. Maximum cross-sectional areas of 1 square inch (645 mm²) were obtained with pure helium.

The results are further illustrated in Fig. 10. The spike typically associated with welds made using pure argon shielding gas are evident in this figure. It is also obvious that the larger cross-sectional area associated with welds made using pure helium shielding gas results primarily from a broadening of the top of the weld (weld surface bead). Contrary to what would be expected, the weld root width is not significantly affected either by shielding gas composition or flow rate.

Effects of shielding gas composition and flow rate on arc characteristics are summarized in Fig. 11. A smooth welding arc was obtained with a wide range of shielding gas compositions at flow rates between 100 cfh (47 liters/min) and 125 cfh (58 liters/min). Increasing
flow rates beyond 125 cfm (58 liters/min) resulted in a rough, undulating arc. Violent arc characteristics were associated when pure helium was employed.

Arc Gap Adjusted by Wire Feed. Contrary to the results obtained when arc gap was adjusted by current, when arc gap was adjusted by wire feed, shielding gas flow rate did not affect weld penetration significantly. Penetration, however, was significantly affected by shielding gas composition—Fig. 12. Maximum penetrations were obtained for pure argon and decreased as percentage of helium was increased.

Weld root width was affected primarily by shielding gas composition. However, shielding gas flow rate slightly affected root width, especially at flow rates exceeding 150 cfm (70.5 liters/min). Minimum weld root widths were associated with pure argon, and maximum weld root widths were associated with pure helium, as shown in Fig. 13.

Both shielding gas flow rate and composition affected weld cross-sectional area slightly. Maximum cross-sectional areas are associated with pure argon at flow rates less than 100 cfm (47 liters/min)—Fig. 14. These results are dramatically illustrated in Fig. 15. The tremendous benefit of pure argon on weld penetration is obvious from Fig. 15. Of particular interest is the tendency towards a wider weld root width for pure argon at 100 cfm (47 liters/min) than is normally associated with pure argon shielding. Weld root width increased considerably when pure helium was employed; however, penetration decreased significantly. Benefits of ad-
Fig. 17—Effect of welding current on weld penetration

Discussion

It is evident from this investigation that both shielding gas composition and flow rate significantly affect weld cross-section geometry. These effects,
however, are not consistent with those previously reported in the literature. Depending on how arc gap was adjusted, much deeper penetration could be obtained when pure argon was employed. More important, however, is the effect of flow rate. Flow rate not only affects weld penetration but weld root width and, by employing proper controls, a desirable weld cross-section geometry can be obtained when using pure argon.

Reasons for the effects of shielding gas composition and flow rate on weld cross-section geometry are not obvious. Contrary to what had been reported previously, greater penetration did not result from a higher arc voltage associated with pure helium shielding. Penetration, however, was affected by the welding parameters, particularly current (Fig. 17), regardless of voltage (wire feed speed) employed. The differences in weld cross-section geometry then are attributed to the effects of changing shielding gas composition and flow rate on welding current. This is further illustrated in Figs. 18, 19 and 20.

The effect of heat input on weld cross-sectional area is indicated in Fig. 18. Regardless of shielding gas composition and method of arc gap adjustment, weld cross-sectional area increased as expected with increasing heat input. The method of arc gap adjustment did, however, affect the weld cross-section geometry. As indicated in Fig. 19, increasing heat input increased weld penetration when adjustment in arc gap was made by wire feed adjustments. Current adjustments, however, resulted in a constant weld penetration even though total heat input was affected substantially. The opposite effect is noted for weld root width—Fig. 20. Increasing heat input by wire filler metal feed adjustment decreased weld root width as heat input increased. Conversely, increasing heat input increased weld root width when arc gap was maintained by current adjustment.

True improvements in weld bead geometry are associated with increasing weld root width while maintaining a constant penetration or increasing penetration. Such improvement has normally been attributed to the use of helium mixtures in shielding gas. Figure 21 shows the ratio of weld penetration to weld root width as a function of shielding gas composition. Greater weld root widths for a given penetration were obtained when pure helium was employed; however, greater depths of penetration were obtainable with pure argon. Most interesting, however, is that additions of helium to shielding gas up to a level of 75% helium did not significantly affect ratio of weld penetration to weld root width.
Conclusion

Results of this work indicate that selection of shielding gas in gas metal-arc welding is an important criteria which affects not only the arc characteristics but the weld geometry. Although much concern has previously been expressed regarding the narrow weld root widths resulting from argon shielding, proper selection of shielding gas flow rate and method of arc adjustment can optimize weld root width when pure argon shielding is employed and produce satisfactory weld geometries. Consequently, the following conclusions are warranted:

1. Shielding gas composition and flow rate can affect weld penetration and cross-sectional area.

2. The manner by which shielding gas composition and flow rate affected weld penetration and cross-sectional area is dependent on method of arc gap adjustment.

3. Maximum penetrations are produced with pure argon or argon-rich shielding gas.

4. Desirable weld cross-sectional geometry can be obtained with pure argon shielding provided flow rate is optimized.