Helium additions to MIG shielding gas – an economic option?

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Abstract

An investigation has been carried out to establish the technical and economic benefits of adding two levels of helium to a normal shielding gas. Technically no adverse issues were established using the two levels of helium, and the most significant positive one was the highly beneficial effects on travel speed increase and heat input decrease,

Although helium gas carries a significant cost premium the economic evaluation showed that overall this was a beneficial approach as the man-hour reduction associated with the welding process dominated the process cost effects.

Introduction

There is an ongoing requirement to reduce rework related to heat induced distortion on thin plate structures. The most evident area for this is currently in the shipbuilding industry where there is a drive to reduce weight by using higher strength steels. This has resulted in the extensive use of 4 and 5mm thick plate, especially in naval vessels, particularly Lloyds DH36 grade steel. The top side of destroyers, Figure 1, has been the focus of this for some time and landing craft units (LCU) , Figure 2, are relatively light weight structures overall. In the case of the LCU much of the thin steel plate was Lloyds EH32 grade steel.

Whilst hybrid laser welding is seen as a possible option to control the distortion, there can be significant capital costs incurred depending on individual build yard configuration. In addition, many factors contribute to thin plate distortion but reducing heat input has a dramatic effect, hence the interest in hybrid laser welding. However, there is still scope within the accepted arc welding processes to reduce heat input. Increasing the welding speed has a significant effect, but can only if it can be achieved without compromising the weld quality in any way.

It has been recognised that helium additions to shielding gases can have beneficial effects, particularly by increasing the weld penetration. This is mainly related to the good thermal conductivity of the gas and its ability to improve the heat transfer from the arc to the component. Much of this was founded on TIG welding research carried out on steel some time ago (1,2) and also for welding aluminium (3)

There is also evidence (4) that helium additions to twin wire automated MIG systems appear to generate some benefits too. The outcome of that work could be transmitted to single wire MIG welding of carbon steel plate by aiming for the same penetration with the helium containing shielding gases, by increasing the welding speed.

On the basis of this a series of trials was set up to establish the technical and economic feasibility of using helium additions to a standard shielding gas.

Three shielding gases were used to produce 4mm thick butt welds in DH36 steel with a 1mm diameter metal cored wire at constant gas flow of 15l/min. The all weld metal composition of the cored wire is shown in Table 1. 4mm thick plate was selected as it would accentuate any distortion effects.

The base case gas was argon / 20% carbon dioxide, and the two helium-bearing gases were

- Argon / 10% helium / 14% carbon dioxide
- Argon / 20% helium / 14% carbon dioxide

Welding was carried out on a welding jig which held the plate rigid as it travelled beneath the fixed welding nozzle. This allowed the jig to be used to carry out distortion measurements before and after welding, with a laser scanner. It was important also to capture thermal data from the plates during and after welding, and this was achieved by having an array of thermocouples at right angles to the weld, 10, 20 and 30mm from the weld centreline. This was validated using thermal imaging equipment.

All welding was monitored using a PAMS unit, to be able to quantify parameters in the location of the thermocouples.

<u>Bead-on-plate welds</u>

The initial welds were bead-on-plate produced using 500x500x4mm pieces. This allowed basic parameters to be set for the butt welds, but also contributed useful data on weld and HAZ dimensions. In addition, travel speed optimisation was established in this part of the work.

The data shown in Table 2 summarises the findings. Basically the two gases containing helium showed benefits in terms of reducing HAZ width and increasing depth/width ratio. Every 1% increase in helium content produced a 0.2mm/sec increase in travel speed, on average. Each 10% addition of helium to the shielding gas created a 20% increase in welding speed, which was linked to about a 4% decrease in voltage, and 21% decrease in HAZ width. Therefore these data were viewed as being highly encouraging in terms of the subsequent butt welding.

It was also evident that as the helium content increased , the depth/width ratio of the weld also increased, which is in line with the findings of Mills (1) on TIG welds, although in that work the effects were more marked due to the much higher helium contents involved.

<u>Butt welds</u>

The butt welds were created from 500x250x4mm plates with 35^{O} weld preps and a 1mm face. As before thermocouples were attached to the plates, but only to one of the plates as it was considered that the heat flow would be symmetrical.

A ceramic backing tile was fitted to the root side of each weld prep. Apart from that, the same format was followed as for the bead on plate welds, with the exception that the weld was left to cool for 10 minutes, while thermocouple data were collected.

For each case the material distorted in the same manner i.e. with a saddle shape shown in Figure 3 , which was the base case (argon / 20% carbon dioxide).

The maximum distortion for each case was as follows

- Argon / 20% carbon dioxide -7.28mm
- Argon / 10% helium / 14% carbon dioxide -6.34mm
- Argon / 20% helium / 14% carbon dioxide -6.69mm

The increased helium content did not have a beneficial effect on distortion over the 10% helium-bearing shielding gas.

The welding parameters for each weld are shown in Table 3 and show a reduction in heat input (which is based on an arc efficiency of 0.8) with increase in the helium content. It should be noted that this is related to an increase in travel speed too. Thermal measurements showed there was little difference between the peak temperatures of the two helium-bearing gases (~ 360^{O}C at 10mm from weld centreline). This was confirmed from the thermal imaging measurements.

<u>Weld physical attributes</u>

The macrosections of each weld are shown in Figure 4(a-c) . The asymmetric roots in the helium bearing shielding gas welds were due to having to fit the ceramic backing bar in the vicinity of the thermocouples. The smallest weld metal volume was found in the 20% helium welds. In addition there is a need to refine the cross sectional root profile in areas such as undercut on the cap, and the root profile. This is particularly the case in the 2
`0% helium weld.

The weld width data is shown below

- Argon / 20% carbon dioxide 11.7 mm
- Argon / 10% helium / 14% carbon dioxide 9.5mm

- Argon / 20% helium / 14% carbon dioxide 7.2mm

The hardness data were expected to indicate that as the helium and travel speed increase the weld metal hardness should increase due to the higher cooling rate. Micro and macro hardness measurements (Vickers) were taken and found to be in broad agreement, with the micro data being slightly higher than the macro data. The maximum weld metal hardnesses are shown below

	Macro HV_{10}	Micro HV_{10}
• Argon / 20% carbon dioxide	202	215
• Argon / 10% helium / 14% carbon dioxide	216	235
• Argon / 20% helium / 14% carbon dioxide	208	231
• Parent plate	165	175

The differences in hardness from each shielding gas are not considered significant, although there is a slight rise with the helium enhanced gases. With this grade of steel and its weld metal there is a tentative relationship between hardness and toughness, i.e. as the hardness increases the toughness decreases. As a result it can be inferred from this data that there would not be a weld metal toughness problem

The porosity contained in each weld was assessed from a number of images of each weld and the average volumetric porosity is shown below

- Argon / 20% carbon dioxide 0.41%
- Argon / 10% helium / 14% carbon dioxide 0.09%
- Argon / 20% helium / 14% carbon dioxide 0.035%

It is not particularly evident why the helium addition should influence the porosity within the weld metal, but even at the worst level there is not a cause for concern, in typical circumstances

A further positive benefit has been identified from Miklos' work (4) where there is significantly less top leg undercut on fillet welds and a very smooth transition from weld to plate when helium is present in the shielding gas.

It was also evident that as the helium content increased, the depth/width ratio of the weld

The technical evaluation has implied that the shielding gas could be used with a 10 or 20% helium addition without adversely affecting the weld metal properties, and in most cases it has improved the overall weld and heat affected zone.

Economic evaluation

It is pointless to add a component to the process unless it is going to generate value to the process. For this reason an economic evaluation was carried out to supplement the technical evaluation. The cost has been based on figures available at a particular point in time for gas costs and labour costs. All the data has been tabulated in Table 4. Although the gas cost per metre rises with increase in helium content, it is not particularly significant in terms of differentials. The dominant cost factor / metre is the labour cost. As a result of the increase in speed developed from the use of the helium gas there is an overall increase in productivity which results in a reduction in the cost/metre of the welded length.

Indications from the practical situation means that leaks will probably be present in the supply system. Taking a scenario where the leak rate is the same as the gas usage rate/metre, the last row in Table 4 shows that this has an almost insignificant effect on the total cost per metre.

Some factors have been omitted from this evaluation

Power cost	will be lower with helium added gases due to increased welding speed
Consumable cost	will be lower due to increased welding speed at constant wire feed speed
Distortion rework	A reduction in the manhours associated with heat line straightening.

Overall there is at least a 27% and a 16% cost benefit in adding 20% and 10% helium respectively to the base case shielding gas. This could potentially create a very high level of saving in a high throughput shipyard.

Concluding comments

Despite the apparent increased cost of adding helium to shielding gases it has been shown to be technically and economically a sound proposal. The only outstanding piece of work is to where to introduce the helium into the shielding gas delivery system. The most significant benefits would be seen in automated welding systems as the manual process creates a number of variables.

The small reduction in the carbon dioxide content of the shielding gas will create a positive impact on the carbon foot print.

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% C	% Si	% Mn	% P	% S
0.06	0.5	1.5	<0.015	<0.015

Table 1 All weld metal chemical analysis of metal cored wire

Argon (%)	Carbon dioxide (%)	Helium (%)	Travel speed (mm/s)	Wire feed speed (mm/s)	Voltage (volts)	Heat input (kJ/mm)	Maximum temperature ^{O}C)
80	20	nil	10	7	27.5	9.53	480
76	14	10	12	7	26.5	7.52	360
66	14	20	14	7	26.5	5.89	365

Table 2 Welding parameters and related data for bead-on-plate welds

Argon (%)	carbon dioxide (%)	helium (%)	travel speed (mm/s)	Voltage (volts)	Current (amps)	Heat input (kJ/mm)
80	20	nil	10	26.5	258	0.54
76	14	10	12	25.1	285	0.47
66	14	20	14	25.3	272	0.395

Table 3 Welding parameters for butt welded plates

	Argon 20% CO_2		Argon 10% helium 14% CO_2		Argon 20% helium 14% CO_2
Travel speed	10 mm/sec		12mm/sec		14mm/sec
Weld time	50 secs		41.67 secs		35.714 secs
Gas volume used	$0.0125m^3$		$0.01042m^3$		$0.00893m^3$
Actual gas cost /500mm	£0.01566		£0.01930		£0.0235
Actual gas cost /metre	£0.03132		£0.0386		£0.0470
Actual labour cost/m	£1.25		£1.0417		£0.8929
Total cost/m	£1.281		£1.0803		£0.94
Gas cost as percentage of total cost	2.44%		3.56%		5.00%

Table 4 Financial assessment of helium additions to MIG shielding gases.

Figure 1 A Type 45 destroyer with a top side containing a significant proportion of 4 and 5mm thick plate

Figure 2 A Landing Craft Unit (LCU) which contains significant quantities of 4mm thick plate

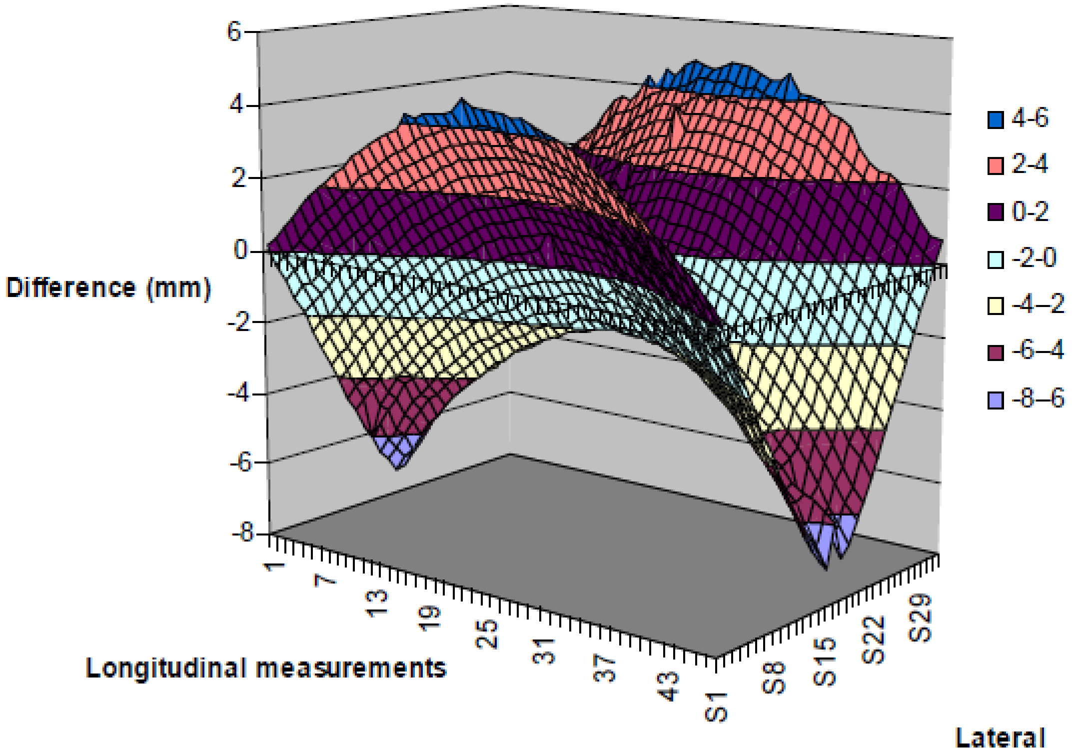
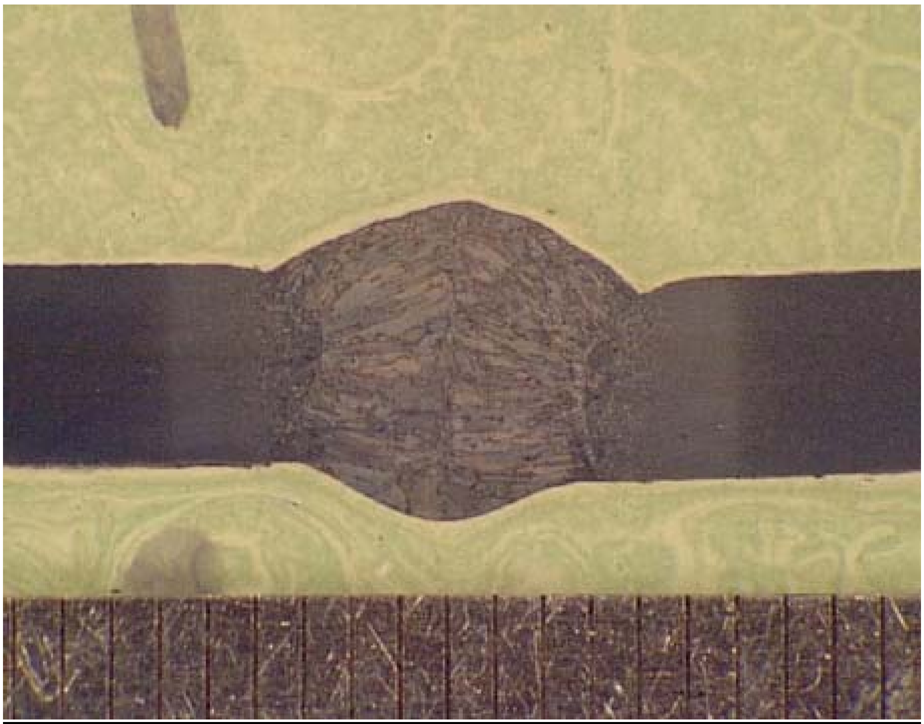
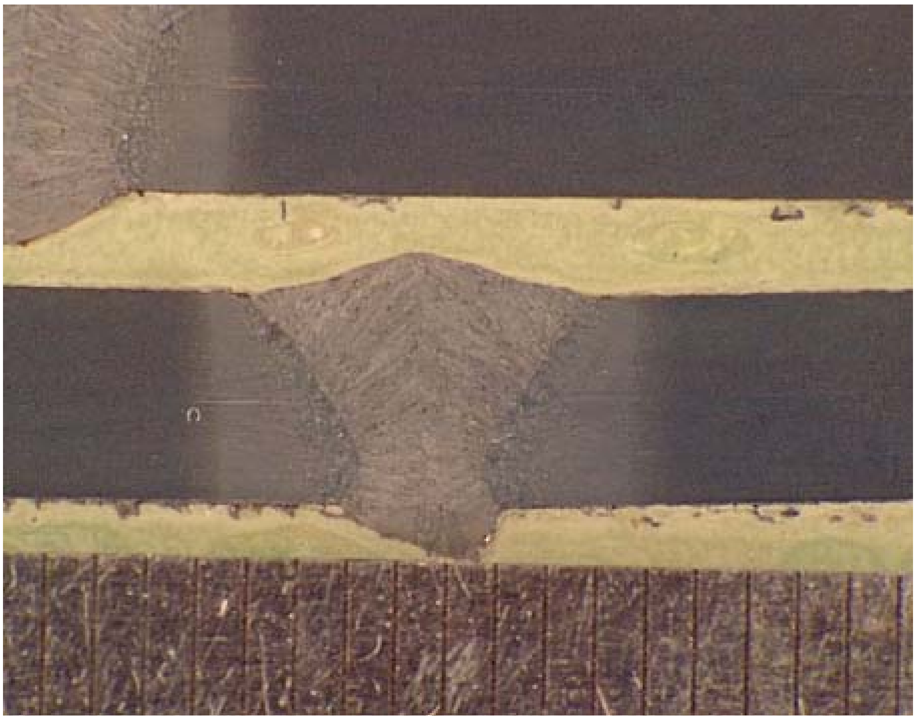


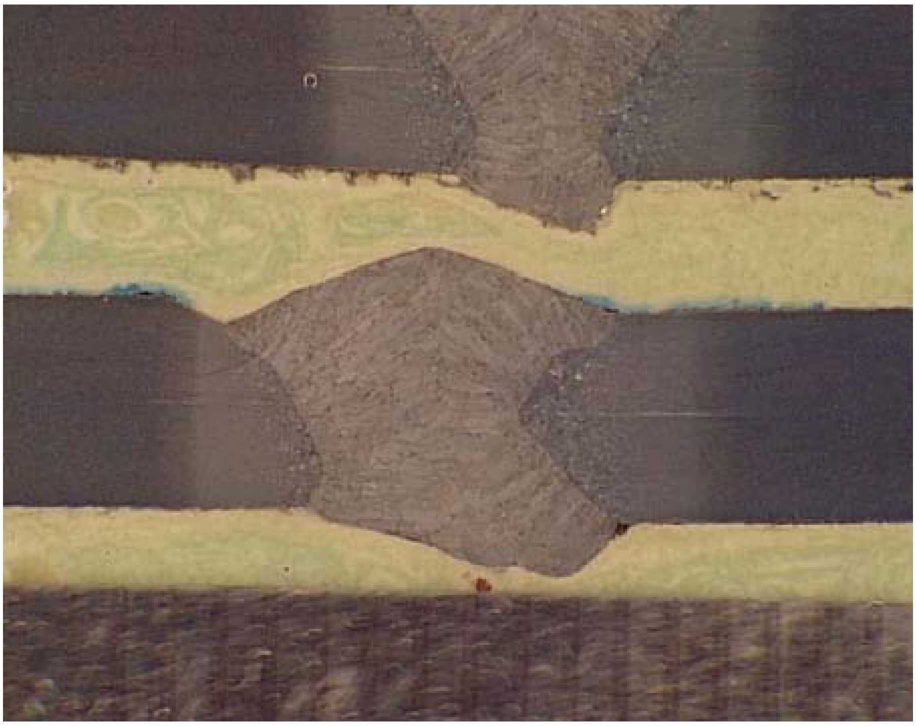
Figure 3 Distortion induced in 4mm thick plate when welding with argon / 20% carbon dioxide



(a)



(b)



(c)

Figure 4 Weld macro cross sections

(a) Argon / 20% carbon dioxide
(b) Argon / 14% carbon dioxide / 10% helium
(c) Argon / 14% carbon dioxide / 20% helium