Assessment of Conventional Gas Metal Arc Welding (GMAW) versus Cold Wire and Double Cold Wire Gas Metal Arc Joints

R. A. Ribeiro, P. D. C. Assunção, E.M. Braga, A. P. Gerlich
Summary

- Motivation for this work;
- Background
- Experimental set-up and welding parameters;
- Superficial aspect
- Welding oscillograms;
- Welding cyclogrammes;
- High speed videos;
- Macrographs;
- Hardness map;
- Tensile test with Digital Image Correlation (DIC);
- Economic analysis;
- Other ancillary benefits to DCW-GMAW process
- Conclusions;
- Future Processing Capability at CAMJ
- Acknowledgments
Motivation
Background

**Cold wire gas metal arc welding (CW-GMAW)**
- Originally developed to meet increasing demands of the ship-building industry for higher deposition;
- Low initial investment.

**Double cold wire gas metal arc welding (DCW-GMAW)**
- Further development of the CW-GMAW process. Aiming even higher deposition with lower investment.

**Multi-wire Arc Welding**
- Increases deposition rate by feeding cold wire into arc
- Product already commercialized (TRL9) eg: ESAB ‘ICE’

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**EFFECTS OF EXCESSIVE HEAT INPUT**
- Higher heat input leads to distortion and residual stresses;
- Overall the cost of re-work for distortions is around 30% of the total cost of the project;
- High residual stresses can lead to poor fatigue performance and toughness.
Experimental set-up and welding parameters

Preliminary study performed using bead on plates for different cold wire feeds, to determine stable range of parameters
Experimental set-up and welding parameters

ASTM A131 Gr. A (Steel)

<table>
<thead>
<tr>
<th>WFS (in/min) [m/min]</th>
<th>Voltage (V)</th>
<th>TS (in/min) [cm/min]</th>
<th>CTWD (mm)</th>
<th>Shielding gas</th>
<th>Power source/Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>394 [10]</td>
<td>34V</td>
<td>25 [63.5]</td>
<td>19</td>
<td>Ar-25%CO₂ at 40 cfh</td>
<td>Lincoln R500/Constant voltage</td>
</tr>
</tbody>
</table>
# Experimental set-up and welding parameters

<table>
<thead>
<tr>
<th>Material</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Cu</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM A131 Gr A</td>
<td>0.21</td>
<td>2.5*C</td>
<td>0.5</td>
<td>0.035</td>
<td>0.035</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>Bal.</td>
</tr>
<tr>
<td>ER 100S-G (NiMo)</td>
<td>0.08</td>
<td>1.7</td>
<td>0.6</td>
<td>-</td>
<td>-</td>
<td>1.5</td>
<td>0.2</td>
<td>0.5</td>
<td>-</td>
<td>Bal.</td>
</tr>
<tr>
<td>ER90S-D2 (LA90)</td>
<td>0.1</td>
<td>1.6</td>
<td>0.6</td>
<td>0.025</td>
<td>0.025</td>
<td>0.04</td>
<td>-</td>
<td>0.4</td>
<td>0.2</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process</th>
<th>Electrode wire diameter (in) [mm]</th>
<th>Cold wire diameter (in) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard GMAW</td>
<td>0.045 [1.2]</td>
<td>0.035 [0.9]</td>
</tr>
<tr>
<td>CW-GMAW</td>
<td>0.045 [1.2]</td>
<td>0.035 [0.9]</td>
</tr>
<tr>
<td>DCW-GMAW</td>
<td>0.045 [1.2]</td>
<td>0.035 [0.9]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process</th>
<th>Cold wire feed rate (%)</th>
<th>Equivalent in in/min [m/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard GMAW</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CW-GMAW</td>
<td>50%</td>
<td>498 [12.65]</td>
</tr>
<tr>
<td>DCW-GMAW</td>
<td>100% (50 % each feeder)</td>
<td>498 (in each feeder)</td>
</tr>
</tbody>
</table>
Bead Appearance

Standard GMAW

CW-GMAW

DCW-GMAW
Ultrasonic and Visual Inspection
Welding oscillograms – root pass

Standard GMAW

CW-GMAW

DCW-GMAW

These spikes indicate occasional short-circuits when the droplet touches the weld pool.
Welding oscillograms – fill pass

These oscillations indicate in DCW- GMAW indicate instability which may cause spatter.
Welding oscillograms – cap pass

These spikes indicate instability caused by surface roughness of the welds during the cap pass.
Welding cyclogrammes – root pass

These cyclogrammes indicate way to seeing all the arc phenomena over the welding time. A smaller area indicates lower variability, and better arc stability.

Standard GMAW

CW-GMAW

DCW-GMAW
Welding cyclogrammes – fill pass

The DCW-GMAW presents events of short-circuit during the fill pass which accounts for the instabilities observed.
Welding cyclogrammes – cap pass

The arc stability of DCW-GMAW is still comparable to that of standard GMAW, thus allowing it to provide similar bead surface quality.
High speed videos

The videos show the wettability of the weld pool over the walls of the groove. As well the metal transfer of droplets.
High speed videos – The cold wire effect

Shortest path for the electrical current can explain the arc climb phenomenon.
Macrographs

Standard GMAW

CW-GMAW

DCW-GMAW

The purple squares show where the hardness map was performed.
Hardness maps

Standard GMAW  CW-GMAW  DCW-GMAW

Vickers Hardness (HV)

Load: 500 gf. Dwell time: 10s.

Hardness map are used to assess the strength of the joint and the matching strength design criteria.
Tensile test of the weld joints with DIC

Overall fracture strength is highest for DCW-GMAW, with most capacity for work hardening (which is correlated well to toughness)
Tensile test of the welded joints with DIC

Yielding Stress (YS):
- GMAW
- CW-GMAW
- DCW-GMAW

Ultimate Tensile Stress (UTS):
- GMAW
- CW-GMAW
- DCW-GMAW
Tensile test of the welded joints with DIC

The DIC shows the iso-strain lines on the tensile sample. The maximum strain is always experienced in the base metal.
Tensile test of the welded joints with DIC

The videos show the evolution of the engineering strain in time until failure.
The strain accumulation of DCW-GMAW in the HAZ is more uniform than standard GMAW and CW-GMAW.
Microstructures

Different microstructures found in the cap pass (centre), they suggest different thermal signatures for the three processes.
Economic analysis

\[
\text{Wire total cost} \left( \frac{\$}{ft} \right) = \frac{\text{Wire cost} \ (\$/lb) \times \text{Lbs of weld metal deposited to fill the groove} \ (lb/ft)}{\text{Deposition efficiency}}
\]

<table>
<thead>
<tr>
<th>Process</th>
<th>Deposited weld metal (lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMAW</td>
<td>1.36</td>
</tr>
<tr>
<td>CW-GMAW</td>
<td>1.34</td>
</tr>
<tr>
<td>DCW-GMAW</td>
<td>1.29</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wire cost ($/lb)</th>
<th>Deposition Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Deposition efficiency = \( \frac{\text{Deposited weld metal (lb)}}{\text{Filler metal consumed (lb)}} \)

Decrease of 5%
Economic analysis

\[
\text{Labor total cost} \left( \frac{\$}{ft} \right) = \frac{\text{Labor rate} (\$/h)}{\frac{\text{Welding speed (in/min)} \times \text{Duty cycle}}{12 \text{ (in/ft)}} \times 60 \text{ (min/h)}}
\]

<table>
<thead>
<tr>
<th>Operation</th>
<th>Duty cycle (%)</th>
</tr>
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<tbody>
<tr>
<td>Manual</td>
<td>5-30</td>
</tr>
<tr>
<td>Semi-automatic</td>
<td>10-60</td>
</tr>
<tr>
<td>Automatic</td>
<td>50-100</td>
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<table>
<thead>
<tr>
<th>Process</th>
<th>Open arc time (h)</th>
<th># of passes</th>
<th>Total time (h)</th>
<th>Total labor cost ($/ft weld)</th>
</tr>
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<tr>
<td>GMAW</td>
<td>0.003937015</td>
<td>11</td>
<td>0.043</td>
<td>1.51</td>
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<tr>
<td>CW-GMAW</td>
<td>0.003937015</td>
<td>8</td>
<td>0.031</td>
<td>1.10</td>
</tr>
<tr>
<td>DCW-GMAW</td>
<td>0.003937015</td>
<td>6</td>
<td>0.023</td>
<td>0.82</td>
</tr>
</tbody>
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45% decrease
### Economic analysis

**Shielding gas total cost** ($/ft) = \( \frac{\text{Shielding gas cost ($/ft}^3) \times \text{Gas flow rate (ft}^3/\text{h})}{\text{Welding speed (in/min)} \times \frac{60(\text{min/h})}{12(\text{in/ft})}} \)

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<tr>
<td>Manual</td>
<td>5-30</td>
<td>0.025 (Ar-CO}^2)</td>
<td>25</td>
<td>40</td>
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<td></td>
<td></td>
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<tr>
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<td>6</td>
<td>0.023</td>
<td>0.007</td>
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45% decrease
Other ancillary benefits to DCW-GMAW process

1. Reduced thermal distortion, costs to straighten panels in ship making can be more than 20% of labor costs
2. Minor increase in equipment costs, since wire feeder is only about 10% of typical welder equipment
3. Most increased cost related to using CW-GMAW is due to repeating qualifying, and certification since new welding procedure specifications are required
4. Current standards for naval weld joint design in Canada are lagging behind rest of world, most other countries no longer limit weld designs to 55 degree V-groove.

Collaboration between industry, university, and standards committees needed to advance use of technology

US Naval shipyards adopted new process called Tip-TIG because the benefits outweigh the new costs.
Conclusions

1. Groove welds were successfully manufactured using GMAW, CW-GMAW, and DCW-GMAW process;

2. The DCW-GMAW provided enhanced stability during the welds;

3. The productivity was compared, where DCW-GMAW enabling a 45% improvement in productivity, filling the grooves with 6 passes (versus 11);

4. The thermal signature of CW-GMAW and DCW-GMAW differs from standard GMAW, likely due to decreased heat diffusion;

5. The CW-GMAW and DCW-GMAW can offer superior mechanical performance over the GMAW joint for the same welding parameters.
**Future Work** (New hybrid system being commissioned)

Custom system being designed by Lincoln Electric/Wayne Trail & IPG

1. **Fibre Laser, 8kW + Wobble Head**
2. **GMAW Torch**
3. **Hot-wire**

Hybrid Laser Arc Welding (eg: thick sections, high strength steels, naval applications, aerospace alloys)
Future Work (New hybrid system being commissioned)

Hybrid Laser System Layout

- Laser dynamic depth sensor
- 8kW Fiber Welding head
- Laser + GMAW hybrid head
- 2 Auxiliary cold wire feeders (add on to any head)
- Shielding gasses
- Cutting head
- Wobble laser head
- Laser + Hot wire hybrid head
- Welding table

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