Quantifying Hydrogen Induced Cracking (HIC) Susceptibility of Welding Filler Wires Used in the Welding of Armor Steel

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Product Life Cycle Engineering – Application & Integration
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TARDEC View of Joining

Joining

Welding

Mechanical Fastening

Adhesive Bonding

Homogeneous (same materials)

Heterogeneous (multi-material)

Hybrid Joining

A combination of any two of the three joining processes.
• Objective
  – Understand the joint quality and welding process efficiency of welded armor steels (MIL-DTL-12560 RHA, MIL-DTL-46100 HH, ASTM A514)
  – Establish weld wire selection criteria for the new MIL-Standard on the welding of armored steel
  – Provide practitioners a point of comparison between current joining practices and future welding practices.
  – Create validation data for ballistic and blast models of welded armor plates

Tasks

Phase 1
- Robotic Welding
- Material Characterization
- Fatigue Testing
- Evaluation

Phase 2
- Robotic Welding
- Radiography
- High Strain Rate Test
- Evaluation

Phase 3
- Robotic Welding
- Ballistic Testing
- Evaluation

Phase 4
- Robotic Welding
- Fatigue Testing
- Evaluate/Transfer
## Base Materials and Consumables

<table>
<thead>
<tr>
<th>Brand</th>
<th>AWS Classification</th>
<th>Size</th>
<th>Type</th>
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<tr>
<td>Lincoln Electric; SuperArc</td>
<td>LA-100 (ER100S-6)</td>
<td>.045&quot;</td>
<td>Solid</td>
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<tr>
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<td>Lincoln Electric; Blue Max</td>
<td>MIG 308LSi</td>
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<td>LMN 347 Si</td>
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<td>Lincoln Electric; Metalshield</td>
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<td>Cored Wire</td>
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<td>ESAB; SPOOLARC</td>
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<td>ESAB; SPOOLARC</td>
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### Steel Composition

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<tr>
<th>Steel</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Si</th>
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<tbody>
<tr>
<td>MIL-DTL-12560</td>
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<td>1.2</td>
<td>0.005</td>
<td>0.002</td>
<td>0.17</td>
<td>0.12</td>
<td>0.12</td>
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<td>MIL-DTL-46100</td>
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<td>0.95</td>
<td>0.006</td>
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<td>0.17</td>
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<td>0.5</td>
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<td>ASTM A514</td>
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<td>0</td>
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### Additional Elements

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<th>Ti</th>
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<th>Co</th>
<th>B</th>
<th>N</th>
<th>Mo</th>
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<td>MIL-DTL-12560</td>
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<td>0.025</td>
<td>0.025</td>
<td>0.001</td>
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<tr>
<td>MIL-DTL-46100</td>
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<td>0.025</td>
<td>0.04</td>
<td>0.001</td>
<td>0.0003</td>
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<td>ASTM A514</td>
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<td>0.00275</td>
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Phase 1 - Mechanical Test

- Robotically welding
  - MIL-DTL-12560 class 1
  - MIL-DTL-46100 class 1
  - ASTM A514 Grade A

- 14” x 21” x 1/2” single V-groove sample

- 15 different weld fillers
  - Solid
  - Stainless
  - Metal Core
  - 70ksi-140Ksi in tensile strength.

- Mechanical Testing
  - Hardness
  - Tensile
  - Charpy Impact
  - Bend Testing
Phase 2- Ballistic Shock Evaluation

- Robotic welding
  - 3’x 3’ x 1/2” H-plate configuration.
  - Single V-Groove configuration

- Radiographically tested

- SABL lab for Ballistic Shock testing

- ARL helping with Digital Imaging Correlation (DIC) evaluation
  - Deformation Response vs. Crack Length
# Projectiles

<table>
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<th>Caliber</th>
<th>Nomenclature</th>
<th>Weight</th>
<th>Target Thickness [in]</th>
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<tbody>
<tr>
<td>20mm</td>
<td>M1005</td>
<td>0.31 lbs</td>
<td>0.25</td>
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<tr>
<td>37mm</td>
<td>M1000</td>
<td>1.85 lbs</td>
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<tr>
<td>57mm</td>
<td>M1001</td>
<td></td>
<td>1</td>
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<tr>
<td></td>
<td>M1001A</td>
<td>2.18 lbs</td>
<td>0.50</td>
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<tr>
<td>75mm</td>
<td>M1002</td>
<td>~15 lbs</td>
<td>1.25 to 1.50</td>
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<td></td>
<td>M1002A</td>
<td>5.17 lbs</td>
<td>0.75 to 2.00</td>
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MIL-DTL-12235A (MR) – Projectile, Plate-Proofing (For Impact or Shock Testing)
Phase 3 - Penetration Test

• Robotically welding
  – 4’ x 1’ x 1/2”
  – Single V-groove plates.

• Penetration testing
  – Determine the joint efficiency as defined by the magnitude vulnerability
  – Filler material performance

• Transfer results to MIL-STD
Phase 4- Fatigue

- Will use the same Phase 1 welding procedures and welding techniques.

- Two Plates per filler and base
  - Plate 1: Cut with water jet into 5” x 14” strips (4 strips per plate) discarding the end ½” of each side.
  - Plate 2: Cut into ½” strip discarding the end 1” per side.
    - machined to final round bar fatigue sample dimensions.

- Fatigue testing @ TARDEC
- Data transfer to Analytics
H2 Testing @ Oakridge National Lab (ORNL)

- Tekken Test (Y Groove)
- 15 fillers
- Same Base Material from Weld Wire Characterization
- Preheat 0°C 50°C 100°C

- Small Scale cold cracking test
- Simulate Hydrogen Embrittlement
- Developed by Japan

"Quantifying HIC Susceptibility of Welding Filler Wires Used in the Welding of Armor Steel", Matthew Rogers, Martin McDonnell: US-ARMY TARDEC
Zhili Feng, Xinghua Yu: Oak Ridge National Laboratory, Oct 13, 2016
Example Cross Section

- An example of HIC using ER100 filler metal with MIL-DTL-12560 base plate (a) appearance of the crack on weld surface (b) macroscopic graph of cross-section (c) crack surface showing intergranular fracture mode

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Zhili Feng, Xinghua Yu: Oak Ridge National Laboratory, Oct 13, 2016
Surface Cracking @ Different Preheat Temp’s

- Appearance of the crack on weld surfaces at difference preheat temperatures

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Zhili Feng, Xinghua Yu: Oak Ridge National Laboratory, Oct 13, 2016
Macrographs

• **Macrographs Of Weld Cross Sections @ Different Preheat Temp**

![75°C Preheat](image1)

![100°C Preheat](image2)

![125°C Preheat](image3)

![150°C Preheat](image4)

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Remaining Technical Barriers

- The relationships between filler and base materials and their associated mechanical and high strain rate properties are unknown.

- Lack of validated models and methods to accurately predict joint response to blast (high strain rate) and ballistic events

- Weld characterization data of new parent materials, such as advanced high strength steels, as a function of various available weld wires does not exist.

- Dynamic and static deformation response data to ballistic shock events does not exist.

- Arc Blow due to Magnetization
Transition

• This data will transition and be used by both TARDEC engineers and vehicle manufacturers to further optimize vehicle designs.

• This data will transition to Industry, PM’s, Depot’s, and Arsenals through the new welding mil standard, by creating filler metal selection charts.

• The data from this project will also be easily transitioned to help industry, such as the automotive and heavy equipment companies, in the selection of weld filler materials for their types of AHSS due to the similarities in properties.

• The data obtained in this study will also be used to refine material models for modeling and simulation.
Conclusion

• Preheats during welding process recommend for armor grade steel welding

• Generated Selection Table Preheat for MIL-STD-3040

• SS Less Susceptible to Hydrogen Embrittlement

• MetalCore filler materials are the most susceptible to hydrogen embrittlement for armor steels
Questions

Questions and Comments

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