**Title:** After Effects of Welding Armor Steels

**Author:** Matt Rogers

**Performing Organization:**
US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA

**Abstract:**
The original document contains color images.

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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18
Presenters:

Matt Rogers
Welding Engineer

- Dec 2009 Welding Engineer @ TARDEC
- Welding Engineer, 6 years Application Engineering experience
- Bachelors of Science in Welding Engineering Technology from Ferris State University
- Associates Degree in Welding Technology
- 14 years Welding Experience
Overview

• Materials and Types for Cracking
  – Hot Cracking
  – Cold Cracking
• Types of cracks
• Causes
  – Hydrogen
  – Electrode Selection
  – Electrode Storage
• Inspection Methods
  – PT, UT, RT, MT
• Preventions
• Conclusion
• MIL-DTL-46100, MIL-DTL-12560J, & MIL-DTL-32332

• Hot Cracking
  – Definition: Cracks in the weld, which results from stress in the material during solidification of the pool

• Cold Cracking
  – Definition: Cracks in the weld, which occur after the weld has solidified and cooled to ambient temperatures.
LEGEND:

1. CRATER CRACK
2. FACE CRACK
3. HEAT-AFFECTED-ZONE CRACK
4. LAMELLAR TEAR
5. LONGITUDINAL CRACK
6. ROOT CRACK
7. ROOT SURFACE CRACK
8. THROAT CRACK
9. TOE CRACK
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Causes

- Hydrogen cracking has been one of the biggest problems when welding of armor steels
- Cracks are delayed since hydrogen does not become entrapped above 200°C (392°F)
- Depending on the rate of hydrogen diffusion, the delay of the cracks can change
- Diffusion rates depend on the steel’s microstructure and temperature, lower temperatures mean slower diffusion
Hydrogen Cracking

- Is the process by which various metals, including high-strength armor steels, become brittle and fracture following exposure to hydrogen
- Begins during the welding procedure where there are elevated temperatures
- Usually happens 24-48 hours after the weldments are at ambient temperatures
Causes:

Conditions of Hydrogen Embrittlement

Three Conditions of Hydrogen Cracking

- **The presence of hydrogen**
  - Delivered by gases released from the electrode coating or flux, and some from the atmosphere

- **A susceptible microstructure**
  - Determined by the chemistry of the electrode and base metal and the welding parameters
  - Martensitic microstructures are above $\approx 35$ HRC are susceptible
    - All current armor steels are martensitic

- **Tensile stress**
  - Caused by thermal expansion and contraction of the weld as it is deposited, aligning the base materials, and handling
  - Martensitic structures have inherent residual stresses due to the 4% Volume expansion.
- Shielding gas also contains hydrogen from organic elements in the coating and moisture
- Different electrodes cause different hydrogen content in the weld metal
- SMAW electrodes produce the widest range of hydrogen content
- GMAW electrodes produce the smallest range of hydrogen content
- Electrodes must be stored and handled properly
<table>
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<th>Hydrogen Designation</th>
<th>Maximum Average Content, mL(H₂)/100g</th>
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<tr>
<td>High</td>
<td>&gt;15</td>
<td>Cellulosic electrodes, flux cored electrodes</td>
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<tr>
<td>Medium</td>
<td>10</td>
<td>Basic electrodes, flux cored electrodes, solid wire electrodes</td>
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<tr>
<td>Low</td>
<td>5</td>
<td>Basic electrodes, flux cored electrodes, solid wire electrodes</td>
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<tr>
<td>Very Low</td>
<td>3 to 5</td>
<td>Baked basic electrodes, solid wire electrodes</td>
</tr>
<tr>
<td>Ultra Low</td>
<td>≤3</td>
<td>Baked basic electrodes, solid wire electrodes</td>
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Basic vs. Low Hydrogen Electrodes

• Basic Electrodes
  - Most common type of electrode
  - Typical levels of hydrogen found in welds created using this type of electrode is 5ml/100g

• Low Hydrogen Content Electrodes
  - Typical levels of hydrogen found in welds created using this type of electrode is 3ml/100g
  - Electrodes are packed in hermetically sealed containers. This keeps moisture out for extended periods of time
Ceramic Weld Backings

- Used to reduce costly gouging and grinding
- Ceramics are absorbent to liquids and other materials
- Improper handling may result in moist ceramic backings releasing hydrogen into the weldments
• 48 hour holds
  - AWS D1.1 : ASTM 514, ASTM517
  - Ground Combat Vehicle Weld Code (GCVWC) : ASTM 514, ASTM517
  - MIL-DTL-46100, MIL-DTL-12560J, & MIL-DTL-32332

• Inspection Methods
  - Visual
  - PT
  - MT
  - UT
  - RT

• No cracks are allowed on Armor!!!
Prevention

- Reduce Source of $H_2$

- Low Hydrogen Processes
  - SMAW
  - FCAW

- Electrode Selection
  - Solid Core Wires or Metal Core
  - Non-Low Hydrogen Rods

- Electrode Storage
  - Rod ovens
  - Room temperatures/dew point control
  - Time spent in atmosphere

- Minimize causes of residual stresses
  - Fixture Gaps
  - Control Heat Input
Conclusion

• Materials and Types for Cracking
  – Hot Cracking
  – Cold Cracking

• Types of cracks

• Causes
  – Hydrogen
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  – Electrode Storage

• Inspection Methods
  – PT, UT, RT, MT

• Preventions
  – Hydrogen
  – Electrode Selection
  – Electrode Storage
Any Question???

TARDEC - RDTA-EN / Materials, Environmental and Corrosion Team

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