

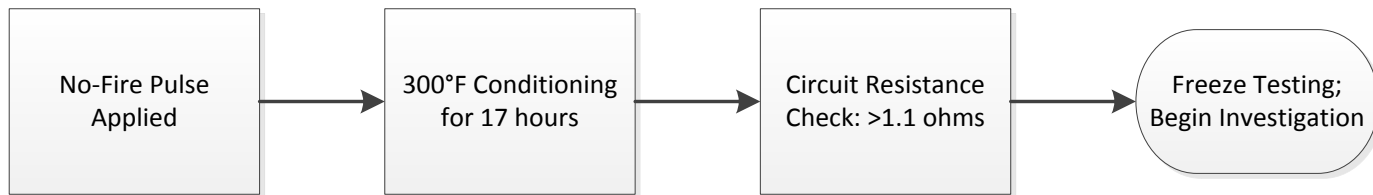


Stress Corrosion Cracking in Ordnance Devices

Nick Ferentheil | 5/24/2016

Background

- During Destructive Lot Acceptance Testing sequence, a unit from the sample had an elevated circuit resistance when measured just prior to All-Fire testing.
- The unit had been exposed to a No-Fire application of 1 amp DC supplying 1 watt for 5 minutes followed by temperature conditioning at 300°F for 17 hours in preparation for All-Fire testing.

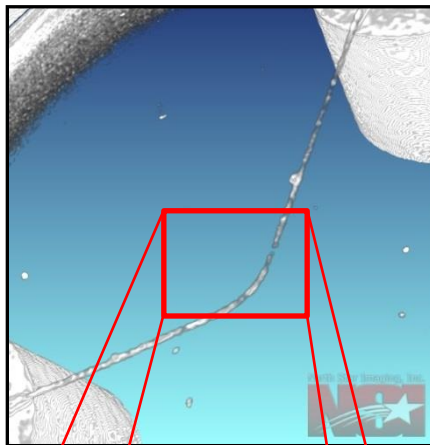


This condition was unexpected and non-typical as this product has been in production since circa 1978.

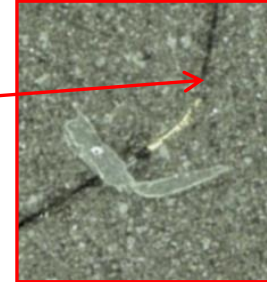
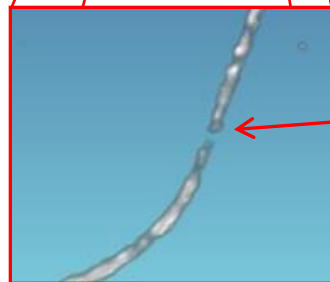
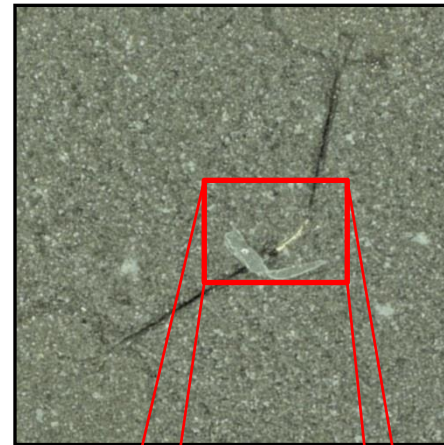
Forensics – Involved Unit

- The suspect unit underwent CT Scan to obtain a visual representation of the bridgewire and its condition prior to any potentially destructive disassembly.
- As shown in the photos below, the CT scan indicated a separation in the bridgewire that was verified by the fracture location seen during disassembly of the unit.

CT Scan Image

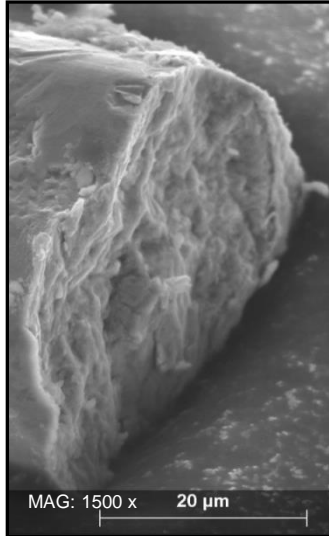


Disassembly Image

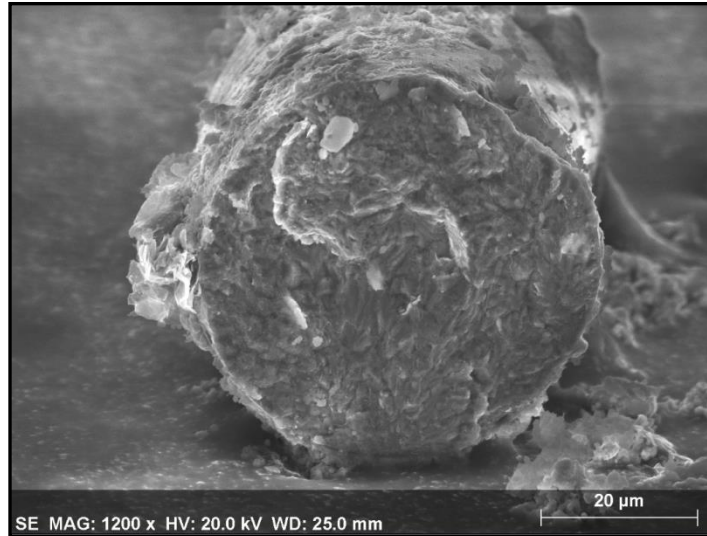


Forensics – Involved Unit

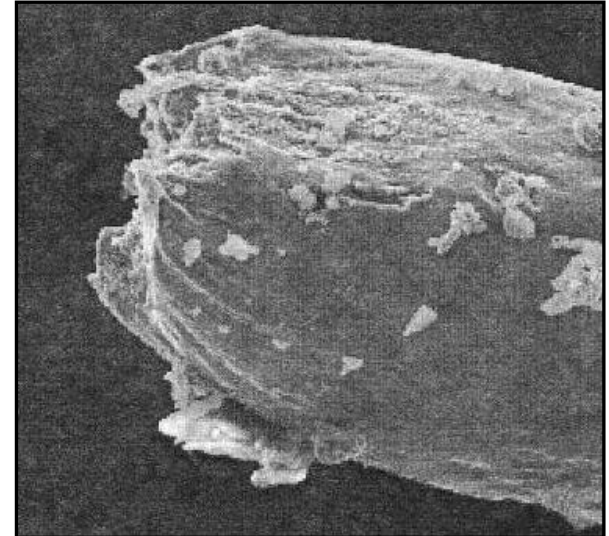
- SEM photographs of the fracture face indicates transgranular fracture with cleavage type fracture features. There is no evidence of melting or discoloration.



Fracture of subject unit
(side view)



Fracture of subject unit
(normal view)



Ductile break (for comparison only)

SEM analysis results indicates the bridgewire material separated in a brittle fashion as evidenced by the cleavage fracture features.

- The material of the bridge-wire is 304 austenitic stainless steel
 - 304 stainless steel will fracture in a ductile manner across a large temperature range, especially at the hot conditioning temperature the involved part was exposed to.
 - The analysis of the fracture face shows cleavage (brittle) fracture face features
 - There are no applied tensile forces on the bridge-wire that would induce an overload condition to cause a separation.

The overarching question is how does the 304 stainless material become brittle and become separated with no apparent applied tensile load?

Hypothesis

- How did the 304 material become embrittled and separate with no apparent applied tensile load? Two Hypothesis:
 1. Hydrogen Embrittlement
 - The process in which the ingress of hydrogen into a metal such as steel leads to a reduction of ductility and cause brittle fracturing.
 2. Stress Corrosion Cracking
 - The cracking induced from the combined influence of tensile stress and a corrosive environment. It can lead to unexpected sudden failure of normally ductile metals subjected to a tensile stress, especially at elevated temperature in the case of metals.

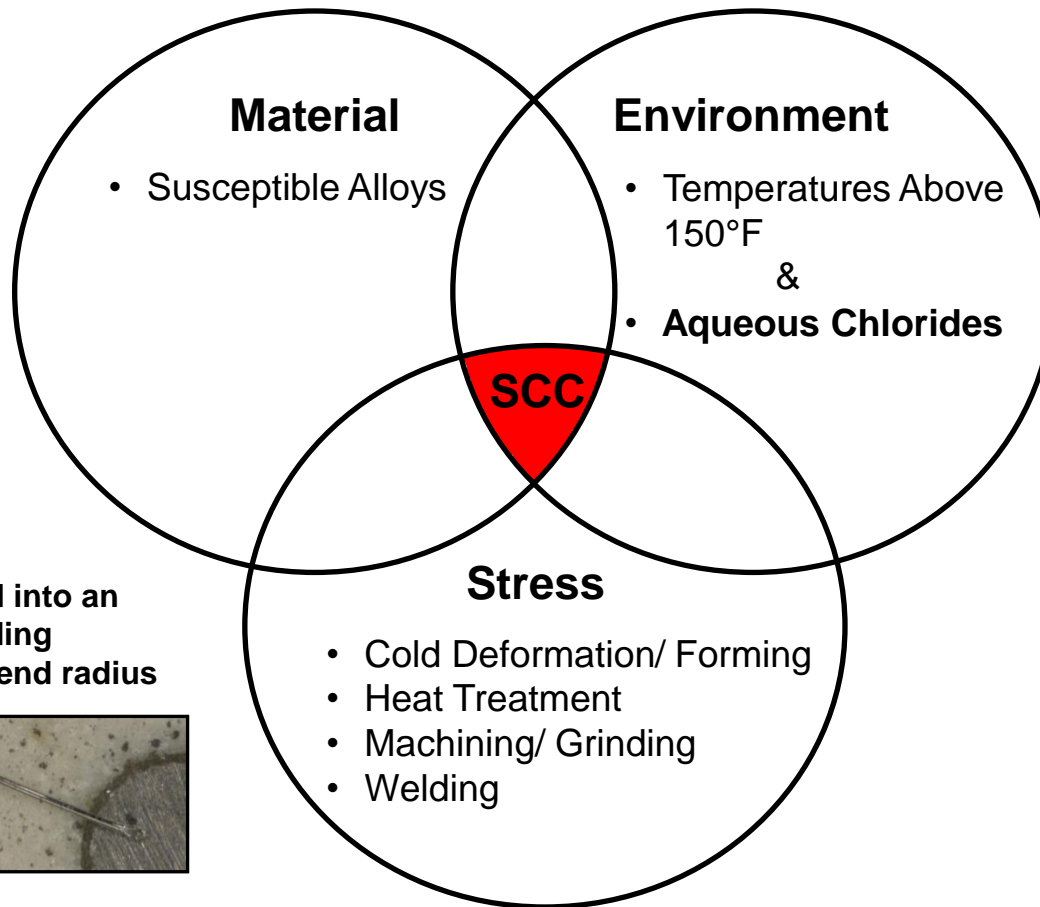
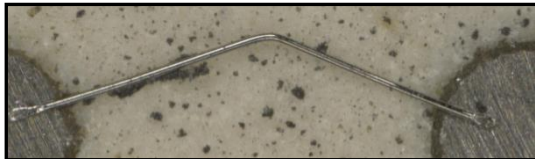
Our primary suspicion is Stress Corrosion Cracking

Stress Corrosion Cracking

- Three Factors Influence the Presence of Chloride Stress Corrosion Cracking:

✓ Bridgewire is comprised of 304 austenitic stainless steel, known to be highly susceptible to SCC.

✓ Bridgewire is formed into an apex during the welding process creating a bend radius

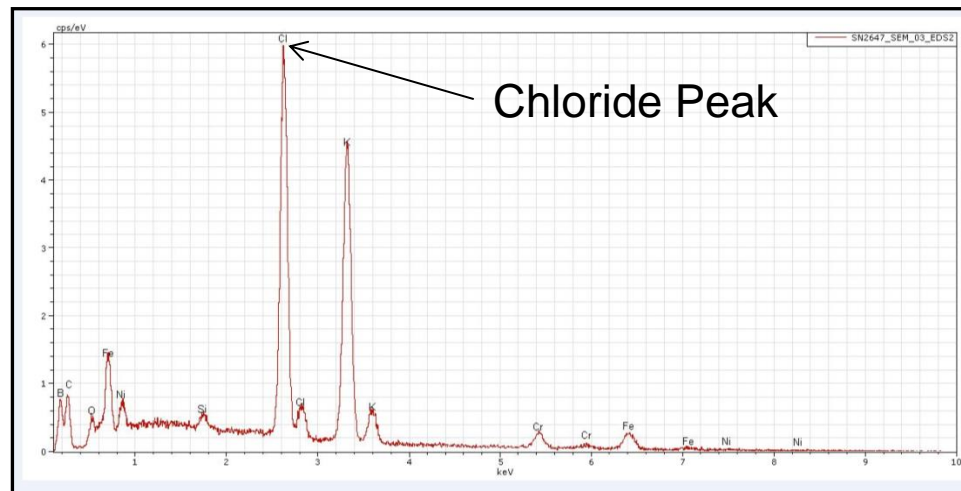


✓ High Temperature Exposure at 300°F between 4-24 Hours



Analysis

- Free Chlorides were detected in several units Energy Dispersive Spectroscopy (EDS) and X-Ray Diffraction (XRD):
- Detection of these free Chlorides reaffirmed the hypothesis that Chlorine induced stress corrosion cracking was the most likely mechanism for the observed cleavage fracture.



- The bridge-wire as assembled into the device:
 - The material is susceptible to S.C.C.
 - The bend in the bridge-wire induces a residual tensile stress
 - The environment posed questions to establish if S.C.C. is the mechanism for the separated bridge-wire condition:

**Where did the Chlorides originate from?
The ignition composition contains Chlorine**

**Can the Chlorine in the ignition composition decompose as aqueous
Chlorides?**

Addition testing/analysis will be necessary

- A series of experiments were conducted in an effort to examine potential causes that would result in producing the environment necessary to propagate S.C.C. (aqueous chlorides).
 - Intentional contamination with plausible substances used in manufacturing of the bridge-wire and the ordnance device it is assembled into.
 - Variations in the environmental exposure types and levels
 - Examination of bridgewire material properties/characteristics.
 - Energetic material lot variance

Analysis Conclusion

- The S.C.C. condition was able to be repeated only through the following means:
 - An “As-Designed” unit had to be exposed to both
 1. No-Fire of 1.0 amp DC supplying 1 watt for 5 minutes
Followed by
 2. Temperature Conditioning at 300°F for 8 or more hours

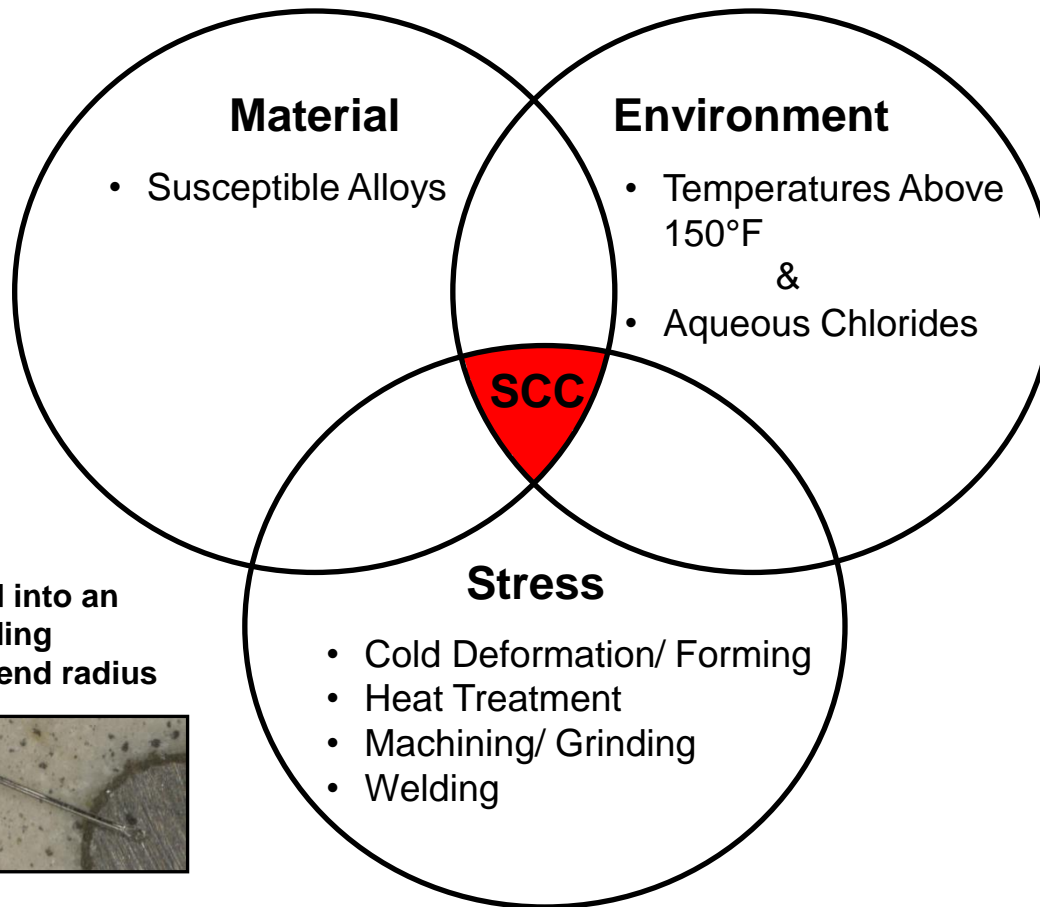
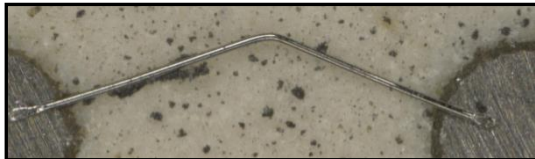
Testing indicated that ALL three conditions were available to promote SCC: Susceptible material (304) AND sufficient tensile stress (bend radius) AND environment (aqueous chlorides). Sufficient time at high temperature (8 hrs at 300°F) drove the SCC condition.

Stress Corrosion Cracking

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✓ High temperature generated by application of no-fire current pulse & high temperature conditioning

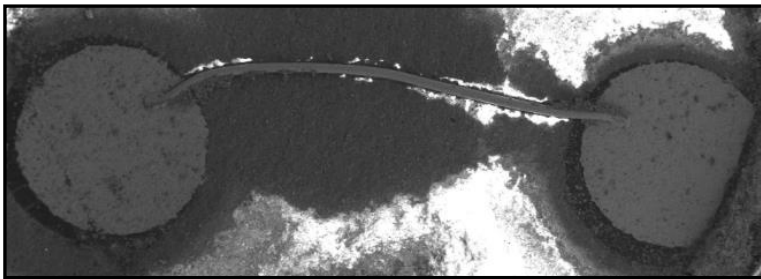
✓ Available chlorides from ignition charge
✓ Sufficient moisture within the ignition charge mixture

Question

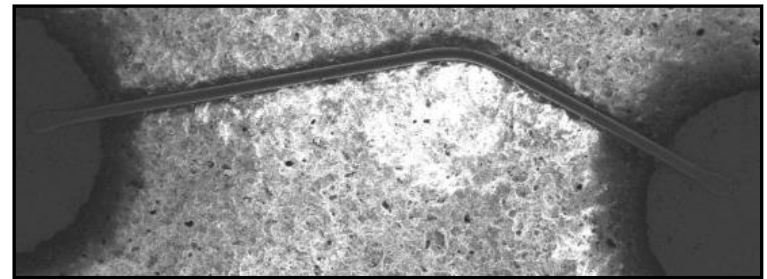
Why has S.C.C. not been prevalent in the past?

Process Shifts

- Units manufactured historically show a much less severe bend radius formation, if any at all. Whereas recently manufactured units show visually sharper bend radius.
- This indicates that the bridge-wire forming process may have changed over time and that bridgewires formed in recent lots resulted in a residual tensile stress sufficient to support S.C.C.



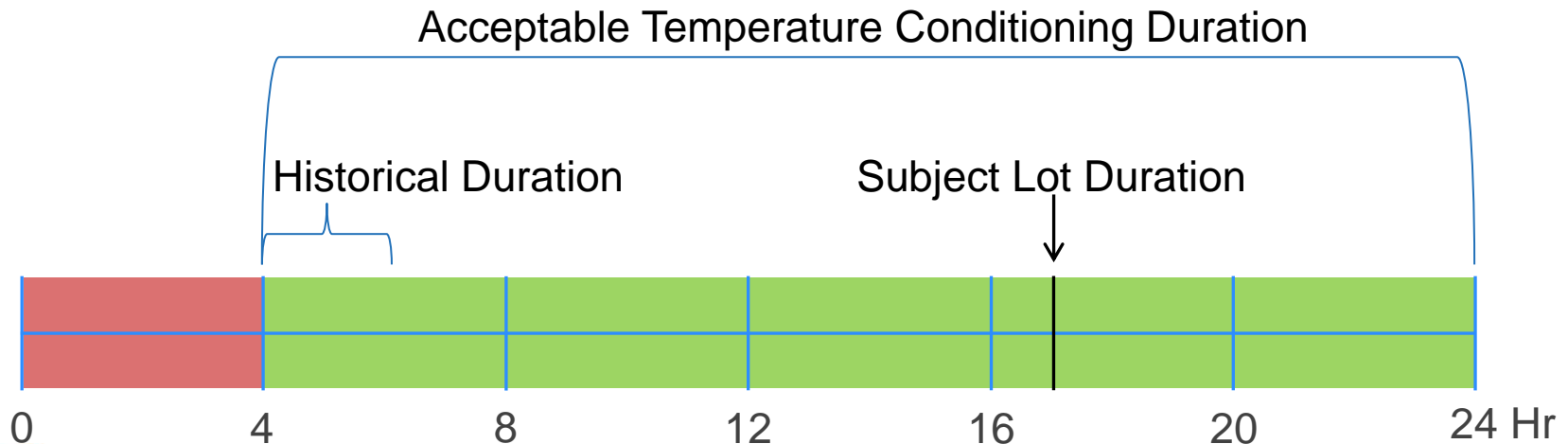
Historical



Current

Process Shifts (cont.)

- Moisture and volatile testing was omitted from the manufacturing process on this product in the past.
 - This hindered the control of the moisture level within the ignition mix, allowing latent moisture to draw out from the powder and condensate on the bridgewire.
- Per the specification, the DLAT sample is to be conditioned to a temperature of 300°F for a duration of 4 to 24 hours.
- Parts tested historically were conditioned for no longer than 6 hours.
- On the lot in question, parts were conditioned for 17 hours overnight.



Considerations for S.C.C

- Understand austenitic steel's susceptibility to S.C.C. should be considered in design/manufacturing processes.
 - Plan and complete appropriate testing/analysis to detect if S.C.C is prevalent in the application using a susceptible material.
 - Is there sufficient tensile stress in the material to promote S.C.C.?
 - Is there conditions available to produce the needed environment to promote S.C.C.?
- Determining the threshold levels for the three factors that influence S.C.C is essential to understand what appropriate countermeasures can be applied to mitigate the S.C.C in specific product applications and associated assembly conditions.
- Monitor manufacturing processes for changes/shifts and assess the impact they may have on material behavior and product performance.