DYWIDAG-SYSTEMS INTERNATIONAL

Environmentally Induced Degradation in Post-Tensioning Steels

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Stressing the Stronger Concrete Solution™

Environmental Degradation

What is environmental degradation?

Synergy between tensile stress and a corrosive environment

Can result in brittle, unexpected failure

Environmentally Induced Cracking (EIC)

An issue occurs where we previously predicted:

Low corrosion rate, safe loading, ductility

Types of Environmental Degradation

Corrosion Fatigue (Cracking)

Stress Corrosion (Cracking)

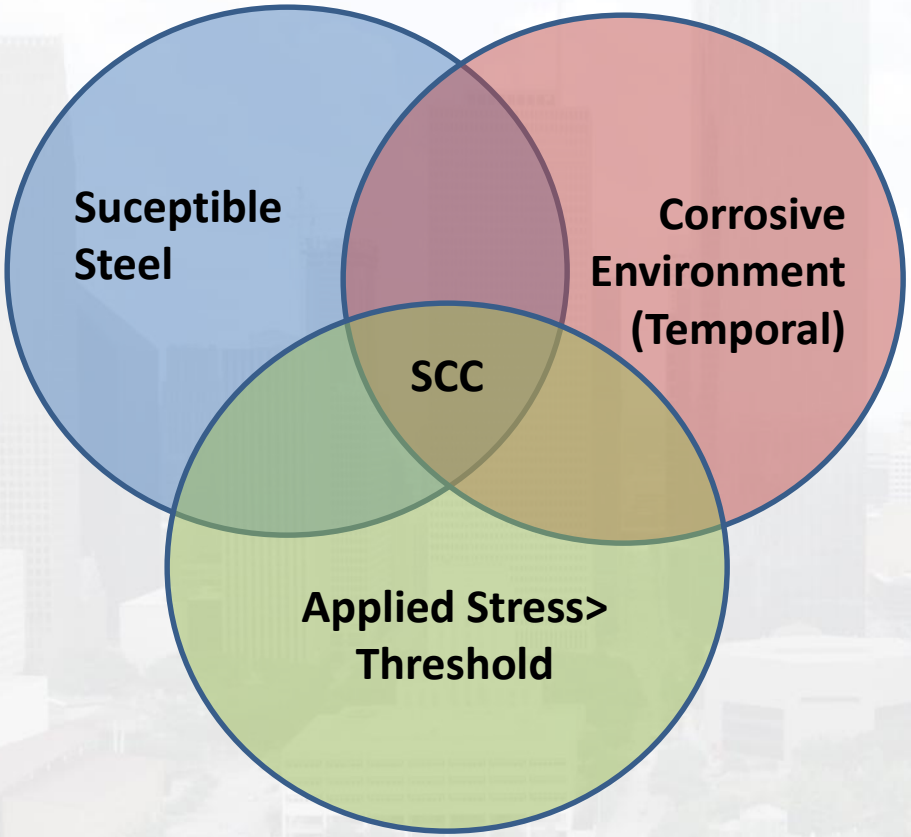
Hydrogen Damage

Hydrogen Induced(Cracking)

Hydrogen Embrittlement

Stress Corrosion Cracking

Hardness/
Tensile Strength
-and-
Structure



At the Mill
During Heat Treat
During Construction
Final Service

Something greater than 50% of UTS (?)

How does stress-corrosion cracking work?

Hardness

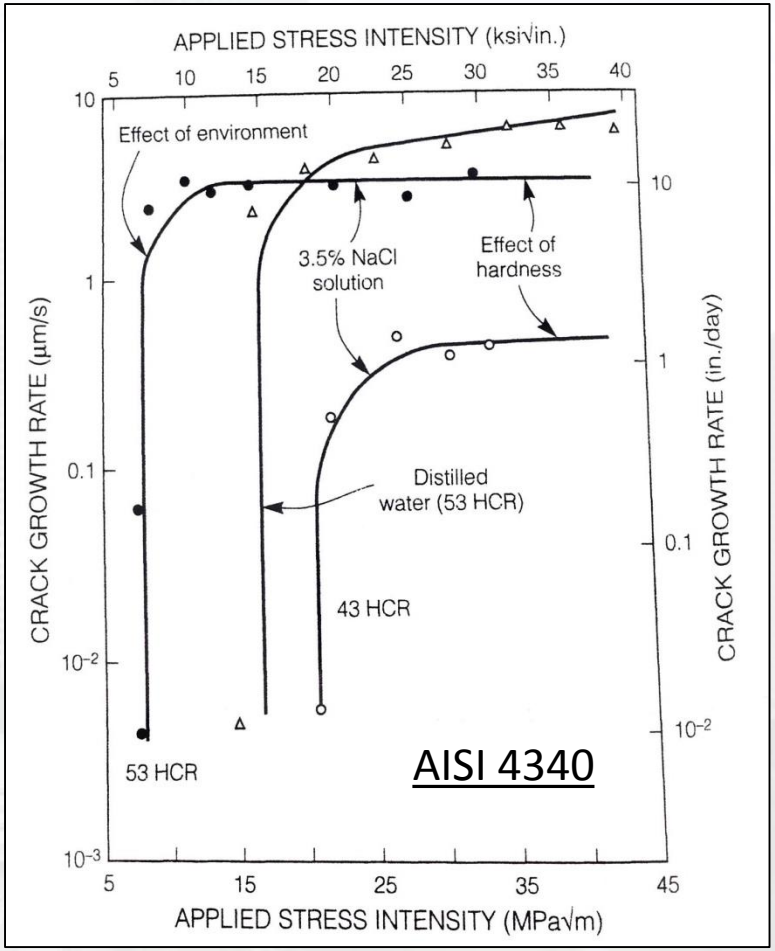
Raises crack growth rate=

Crack grows longer/faster than softer steel

Environment

Lower stress intensity=

Lower stress needed to grow a crack



L. Raymond, Metals Handbook, Corrosion, Vol. 13, 9th ed., ASM, Metals Park, OH. P 286. 1987.

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Is Stress Corrosion a suspect?

Suceptible Steel: Prestressing?

Reinforcing steel has little to no alloy, low hardness, is generally not considered suceptible to SCC. Prestressing steel has high hardness and moderate alloy.

Applied Stress> Threshold
Is load >50% ultimate?

Generally accepted threshold is > 50% of ultimate. Passive applications would not be suspect unless environment is highly corrosive. Be wary of bending, which applies large surface tensile stress.

Fracture Appearance: Does the fracture appear abnormally brittle?

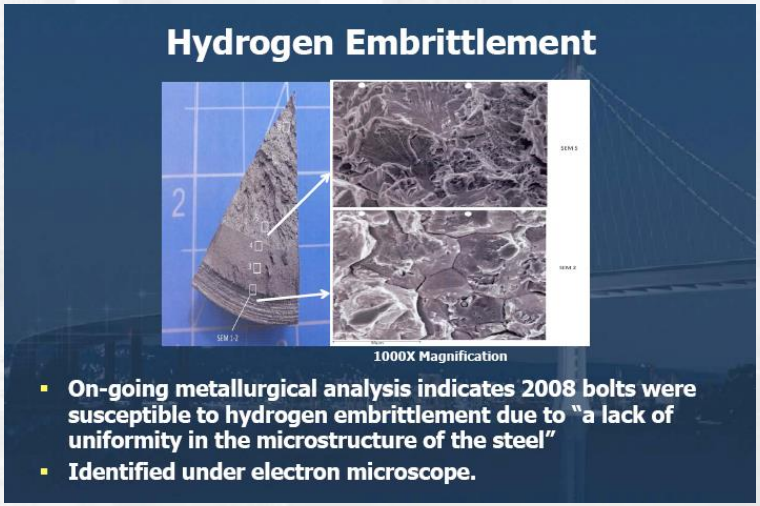
Prestressing steel by it's nature is moderately brittle- it's important to compare failed pieces to "normal"

What's the corrodant in the environment?

The hardest part is to figure out what the corrodant is, or how much, particularly because of the temporal nature- corrodant may have fled the scene

Hydrogen

- Hydrogen embrittlement is a sub-set of SCC (hydrogen being the corrodant or environment)
- Hydrogen's effect on high-strength steels has taken front stage due to high profile failures
- Hydrogen's effect on steel was first known in 1940's
- Much is still not known about the mechanism
  - Hydrogen flees the scene!
  - Difficult to measure



Source: http://www.practicalmachinist.com/vb/attachments/f23/75604d1367206172-seismic-safety-bolts-sb3.jpg
http://ww2.kqed.org/news/2013/04/24/bay-bridge-bolts/embrittlement

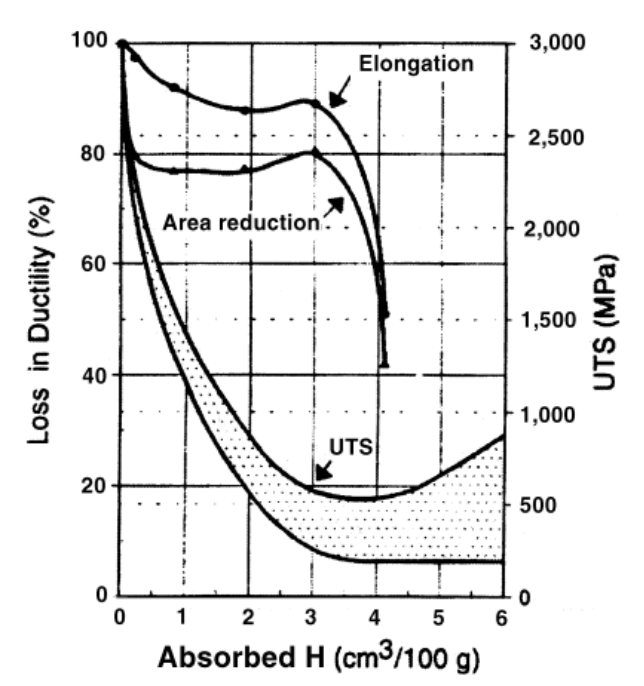
Hydrogen Damage

- Hydrogen Induced Cracking (HIC) and Hydrogen Embrittlement (HE) are typically used interchangeably, but are not the same
  - HIC is typically associated with aggressive hydrogen absorption IN-SERVICE
  - HE is used to describe lower levels of hydrogen from processing PRE-SERVICE
- Atomic Hydrogen (corrodant) enters the steel structure and fundamentally changes the way cracks propagate
- Takes time! Fracture can be delayed hours, days, weeks for hydrogen to migrate to crack interface

Where does the atomic Hydrogen come from?

Numerous opportunities..

1. Molten steel
2. Heat treatment- rolling, Q&T
3. Welding
4. Aggressive descaling/pickling
5. Grout reactions
6. End use application



Klodt, D. T., 1969, "Studies of Electrochemical Corrosion and Brittle Fracture Susceptibility of Prestressing Steel in Relation to Prestressed Concrete Bridges," Proceedings of 25th Conference of National Association of Corrosion Engineers, Mar. 10-14, Houston, Tex., pp. 78-87.

Responsibility of Prestressing Steel Suppliers & Users

- Understand your steel
  - Is it susceptible to Hydrogen damage?
- Understand the processing of your bars
  - Look for areas where atomic Hydrogen may be introduced
- Understand the End Use
  - Will additional Hydrogen be introduced?
  - Will any Hydrogen problem be apparent before it becomes a liability issue?

What Makes Steel Suceptible?

Hardness/Strength is the Primary Driver

- All steels less than 30HRc (145ksi) are not suceptible
- All steels above 30HRc need to be evaluated
  - Not the case that all are suceptible,
  - Assumed unless otherwise proven

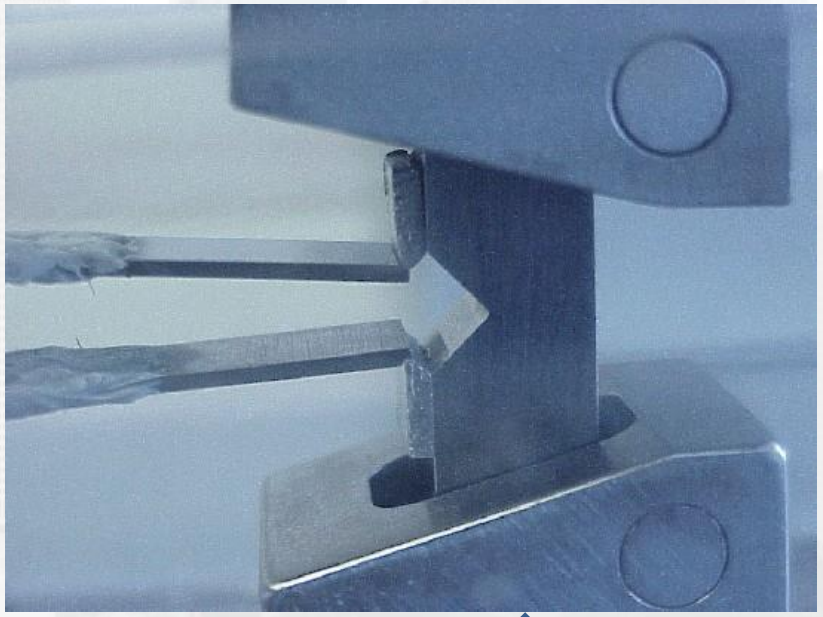
But Other Factors Play a Role

- Steel microstructure/processing
  - Quench&tempered martensitic bars are most suceptible[1]
  - Cold stressed & stress relieved bars (fully conforming A722)
  - Cold drawn wires (A416 strand)- rarely seen
- Thread geometry

[1]Hampejs, G.; Jungwirth, D.; Morf, U.; and Timiney, P., 1991, "Prestressing Materials and Systems: Galvanization of Prestressing Steels," Quarterly Journal of the Fédération Internationale de la Précontrainte

Is Your Steel Suceptible?

- Is the hardness over the 30HRc threshold?
  - Bars complying to A722 most likely are over
  - Strand is over
- Further evaluation can be done by advanced testing (bars only)
  - ASTM F1624: Standard Test Method for Measurement of Hydrogen Embrittlement Threshold
  - Bar is deliberately charged with hydrogen, then tested for any reduction in load capacity
- DSI has evaluated all A722 bars we sell



Note the test is done in bending!

http://www.fracturediagnostics.net/bending_frame.html

Steel Processing

- How is the bar made? Is a vacuum degasser used? How is it cooled?
- How big is the cross section?
  - DSI requires vacuum degassing over 2” bars
- How is any heat treatment done?
- Cleaning processes before coatings, particularly galvanize?
  - ASTM F2660: Standard Method for Qualifying Coatings… Relative to Hydrogen Embrittlement
  - DSI evaluates all coaters to ASTM F2660

Note: It is very difficult to measure quantities of Hydrogen in steel, and know the exact amount that results in embrittlement. Instead, best practices need to be established to minimize exposure. Critical steps should be evaluated and tested.

End Use

Environment

- Zinc coatings are known to react with grout and produce atomic Hydrogen
- Atmospheric and salt corrosion generally do not produce significant hydrogen
- Cathodic protection (anodes, impressed currents) can accelerate

Loading

- Bending loads, and their high surface stresses, are closely associated with hydrogen issues
- How does the loading change over time?

Conclusions

- Stress corrosion is a synergy of environment and stress on a suceptible steel
  - Corrodant lowers the threshold stress needed to propagate a crack
  - “Abnormally” brittle fracture- be sure to compare!
- Hydrogen damage is a subset of stress corrosion
  - Difficult to detect, effect may be delayed
- Prestressing applications need to consider:
  - Steel suceptibility, steel processing and end use
  - ASTM specifications are in place to help suppliers and users evaluate these concerns