INDUSTRIAL FASTENERS INSTITUTE®

“Clean” Military Hardware - Webinar

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Salim Brahimi P.Eng., Ph.D.

- ❖ IFI Technical Director
- ❖ President and Principal Engineer - IBECA Technologies
- ❖ Adjunct Professor - McGill University, Co-Director McGill HE Facility

  ➔ Over 33 years of experience in the fastener industry

Highlights of Current and Past Contributions to Industry Standards Development

- Chair - Research Council on Structural Connections (RCSC)
- Chair - ASTM F16 (Fasteners) and ASTM F07 (Aerospace & Aircraft)
- Developed ASTM F1941/F1941M and ISO/TR 20491
- Head of Delegation for Canada - ISO TC2 Committee on Fasteners
- ASME Committee B18 (Fasteners), and B01 Threads
- SAE Fastener Committees
- Recipient of ASTM Fred F. Weingruber Award
- Recipient of IFI Soaring Eagle Technology Award

INDUSTRIAL FASTENERS INSTITUTE

IFI Headquarters
6363 Oak Tree Blvd
Independence, OH 44131 USA
www.indfast.org

IFI is ***the*** association of North American ***fastener manufacturers***
Mandate to actively engages with:

- ✓**Suppliers**
- ✓**Customers**
- ✓**Government**
- ✓**Public at large**

to advance the ***competitiveness***, ***products***, and ***innovative technology*** of its members and North American fastener manufacturing in a global marketplace.

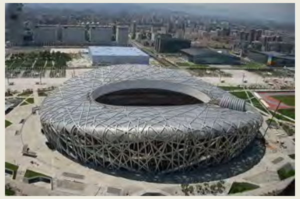
IFI currently has ~ 160 member companies and is continuing to grow!

Membership by Industrial Sector

Division I - Industrial Products





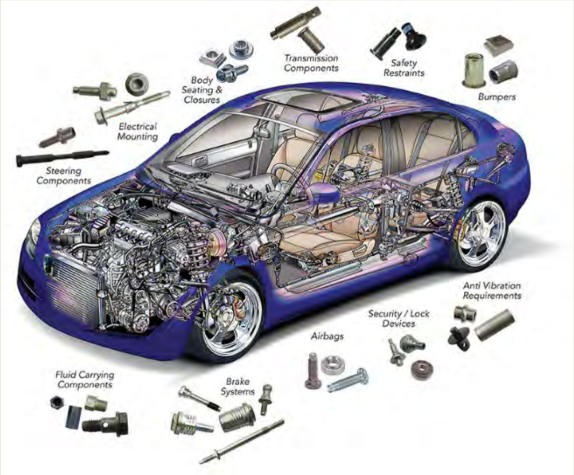


Division II – Aerospace




Division III - Automotive





Membership by Industrial Sector

INDUSTRIAL FASTENERS INSTITUTE®

ASD: Associate Suppliers Division

Materials, machinery, equipment, and/or services

Technical Activities

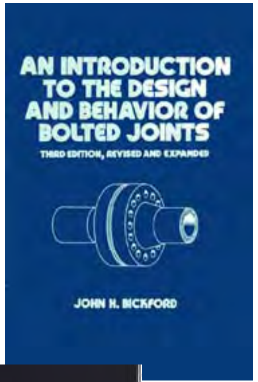
IFI STANDARD® Published and issued by the Industrial Fasteners Institute of Independence, OH	QUALITY ASSURANCE REQUIREMENTS FOR FASTENER TESTING LABORATORIES	IFI-139 Page 1 of 13 Issued: January 1991 Revised:

Fastener **standards** development

- IFI Standards

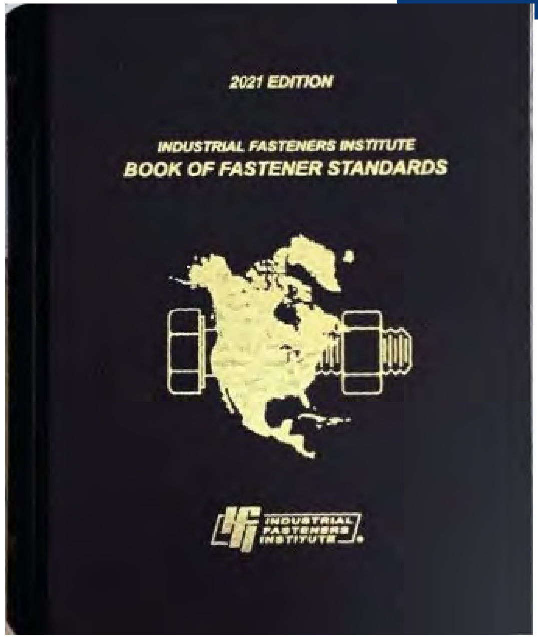
Active in **consensus standards organizations**:

- ISO, ASTM, ASME, SAE, RCSC



Provision of **technical resources**

- Standard
- Publications
- Books
- Technical bulletins



TECHNICAL REPORT

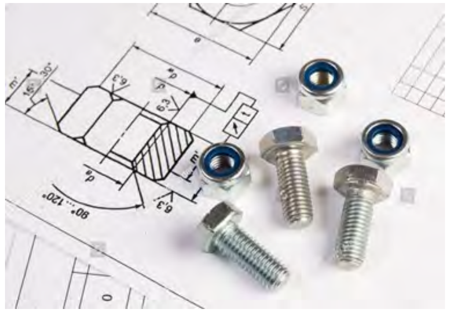
ISO/TR 20491

First edition
2019-02

Fasteners — Fundamentals of hydrogen embrittlement in steel fasteners

Fixations — Principes de la fragilisation par l'hydrogène pour les fixations en acier

Technical and engineering **support**



Training & Education

Members Only Training

Technical classes for members only ([IFI MOT]())

Education and training for industry at large

- Collaboration: **[Fastener Training Institute (FTI)]()**

Emphasis on **practical** and **hands-on** training

- Workshops
- Case studies
- How to read the standards
- Testing and measurement
- Plant visits

FASTENER TRAINING INSTITUTE

Other sponsored programs

- Fastener Education Foundation
- [Rock Valley College - Cold Forming Apprenticeship]()
- [ECC Compton Center – Compton College]()

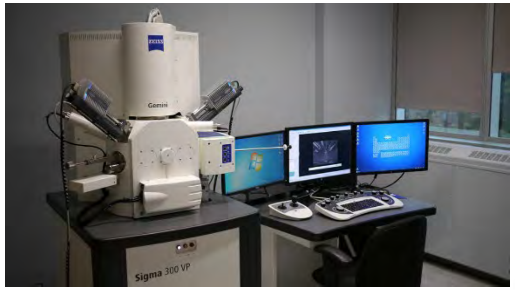
EL CAMINO COLLEGE

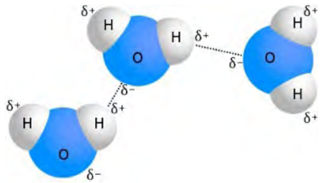
RockValleyCollege

Research & Development

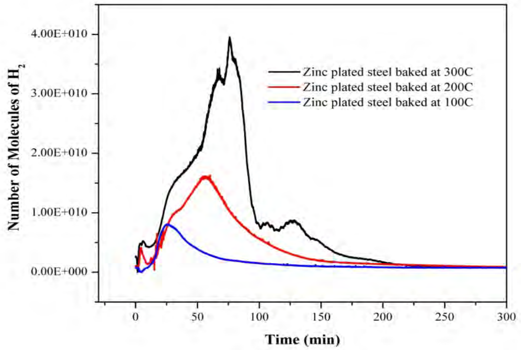
Sponsorship of **Research & Development**

- Bolting Technology Council (ASTM F16.96)
- Research Council on Structural Connections (RCSC)
- McGill Hydrogen Embrittlement Facility

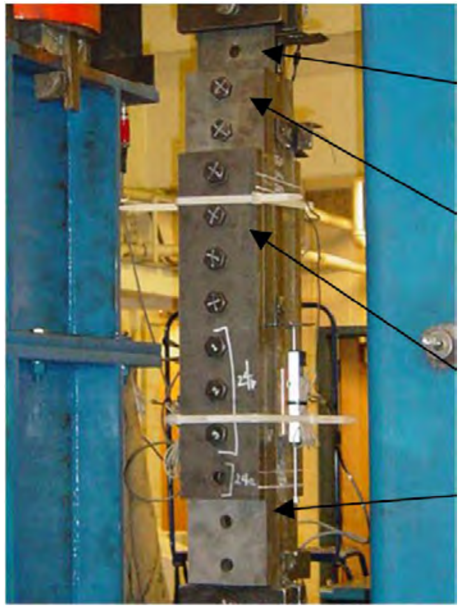




McGill Hydrogen Embrittlement Facility



Rajagopalan, Brahimi, Yue, 2010



Technical Presentation

Why replace cadmium (Cd) ?

Cadmium is used as a sacrificial coating for steel applications (fasteners, aerospace, military)

- Several beneficial properties, e.g, OCP close to steel.
- Electroplating: was predominantly based on Cyanide chemistry – less today.
- Long term exposure & cadmium poisoning ➔
  - Complications include cough, anemia, and kidney failure and increases risk of cancer

Why hexavalent chromium (Cr^{6+}) ?

Hex chrome used a s a passivation layer to protect sacrificial coatings (e.g., Zn, AL, Cd)

- Hexavalent chromium compounds are genotoxic carcinogens.

Environmental regulations e.g., EU RoHS (2003) and REACH (2007)
➔ Hard deadlines for replacing Cd with more environmentally friendly options, such as Zn-Ni and Al and eliminating Cr^{6+}

REPORT

Joint Projects
funded by

NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL OF CANADA (NSERC)

REPLACEMENT OF CADMIUM COATINGS FOR AEROSPACE APPLICATIONS

(CRDPJ 424990 – 11)

Héroux-Devtek
Pratt & Whitney Canada
Safran Landing Systems*

* formerly Messier-Bugatti-Dowty

EFFECT OF MATERIAL CHARACTERISTICS OF ZINC BASED COATINGS ON HYDROGEN EMBRITTLEMENT OF STEEL FASTENERS

(CRDPJ 428422 – 11)

Boeing
Canadian Fasteners Institute

Principle Investigator
Prof. Stephen Yue

Department of Mining and Materials Engineering

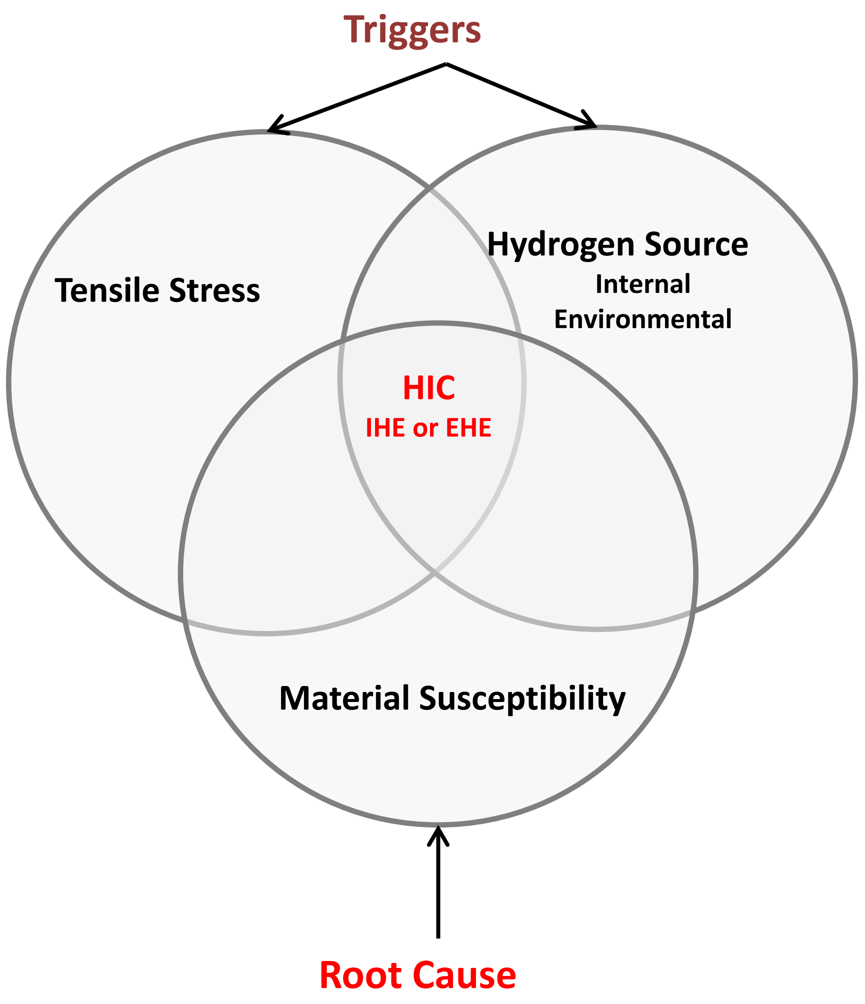
McGill University

2012-2017

- Tribological studies: comparisons between Cd, Al and Zn-Ni coatings
- Corrosion studies: Cd, Al and Zn-Ni coatings in neutral, acidic and alkaline environments
- Effect of baking on aerospace grade electroplated Zn and Cd on high strength steel
- Quantification of hydrogen uptake in steels due to corrosion of sacrificial coatings

Hydrogen Embrittlement defined

Hydrogen Embrittlement (HE) — a permanent loss of ductility in a metal or alloy caused by hydrogen in combination with stress, either externally applied or internal residual stress. Source: ASTM F 2078



1. Susceptibility
2. Hydrogen
3. Stress

TIME!

Sources of hydrogen

IHE: Internal Hydrogen Embrittlement

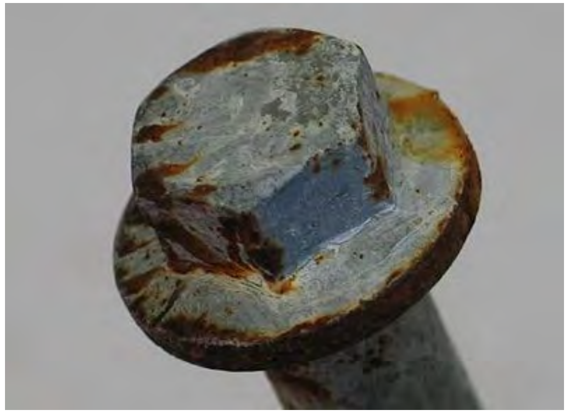
Residual H from processing

- Electroplating
- Acid Pickling

EHE: Environmental Hydrogen Embrittlement

H absorption during service – principally **corrosion**

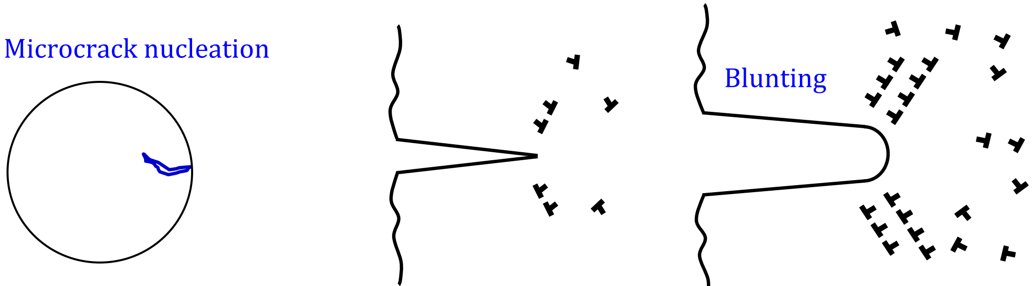
- Stress corrosion cracking (SCC)
- Cathodic hydrogen absorption (CHA)



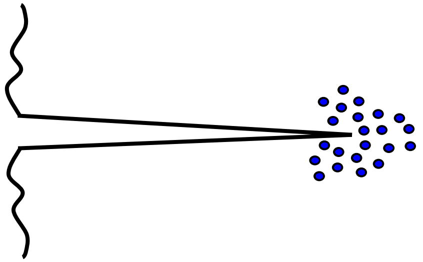
HE damage mechanism

- **Stress concentration** gradient
- **Transport & trapping** affected by microstructural characteristics
- **Hydrogen damage** ➔ crack initiation/growth
  - **Decohesion** of atomic bonds **(HEDE)**
  - **Hydrogen Enhanced Local Plasticity (HELP)**
  - **Dislocation pinning**

Ductile fracture

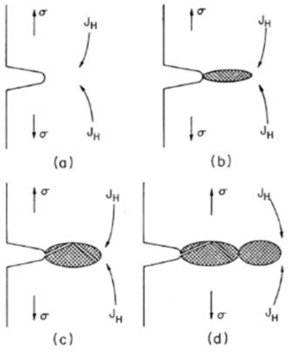


H induces a ***ductile-to-brittle*** *transition*

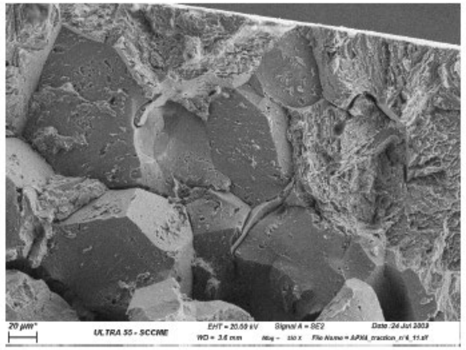


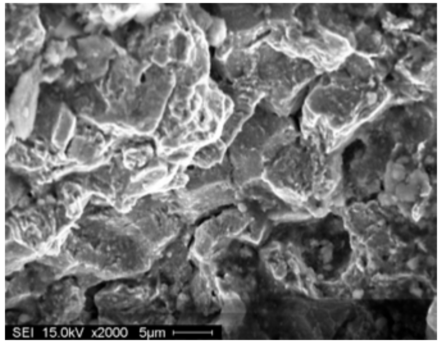
H atoms rearrange - repeat of sequence for crack propagation

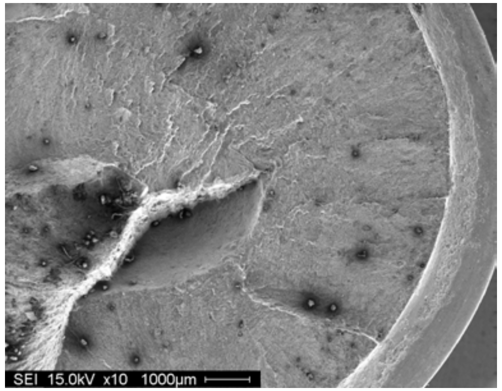
Sequential brittle fracture!



Crack propagation mechanism



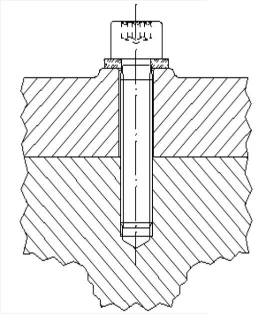


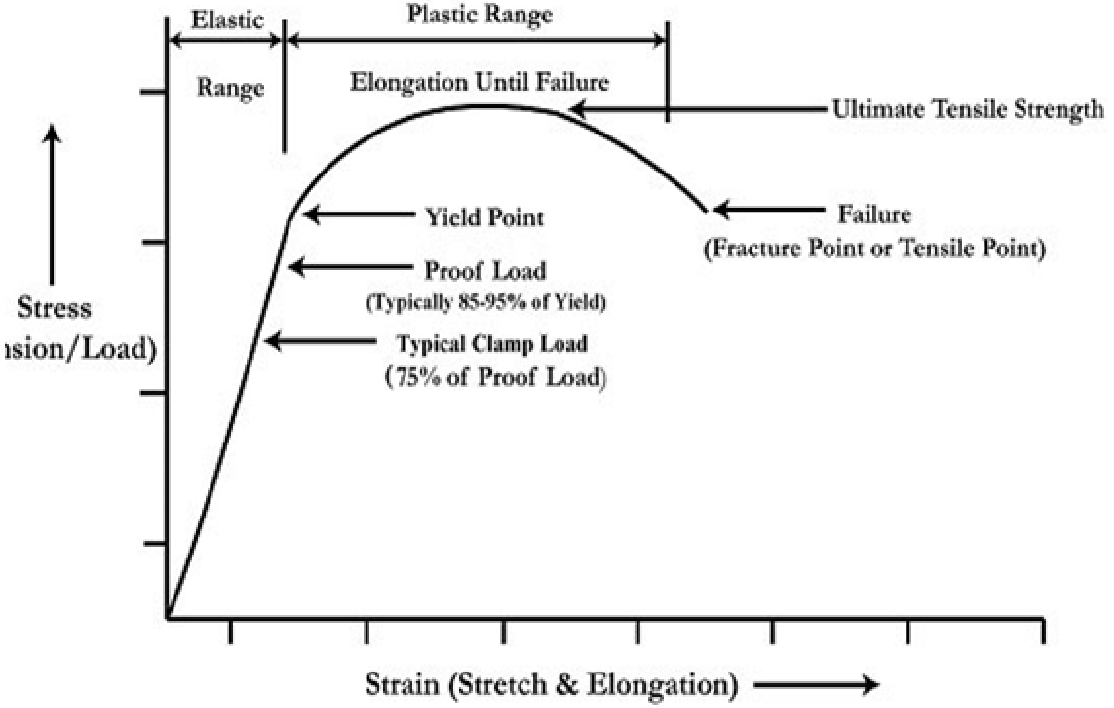


Bolt strength levels and mechanical behavior

- **400 MPa (PC 4.6) - 60 ksi (Gr. 2) -**
  - Plain carbon steel
  - Not heat treated
- **800 MPa (PC 8.8) - 120 ksi (Gr. 5)**
  - Plain carbon steel <u>or</u> alloy steel
  - Heat treated
- **1000 MPa (PC 10.9) - 150 ksi (Gr. 8)**
  - Alloy steel (<u>or</u> carbon boron steel for 10.9)
  - Heat treated
- **1200 MPa (PC 12.9) - 180 ksi**

  (39 HRC, 390 HV)
  - Alloy steel
  - Heat treated





Tensile Stress-Strain Diagram

High strength (>1200 MPa) ➔ high HE **susceptibility**

Critical applications ➔ high **stresses**

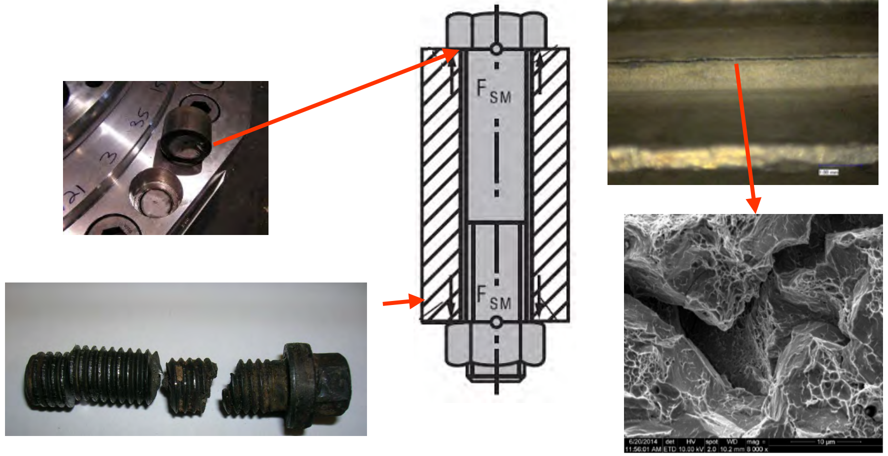
Coated ➔ potential for residual **hydrogen**

Used in corrosive environments ➔ **hydrogen** generation

Built-in stress concentration areas

- Threads
- Underhead fillet radius

Rajagopalan, Brahimi, Yue, 2010

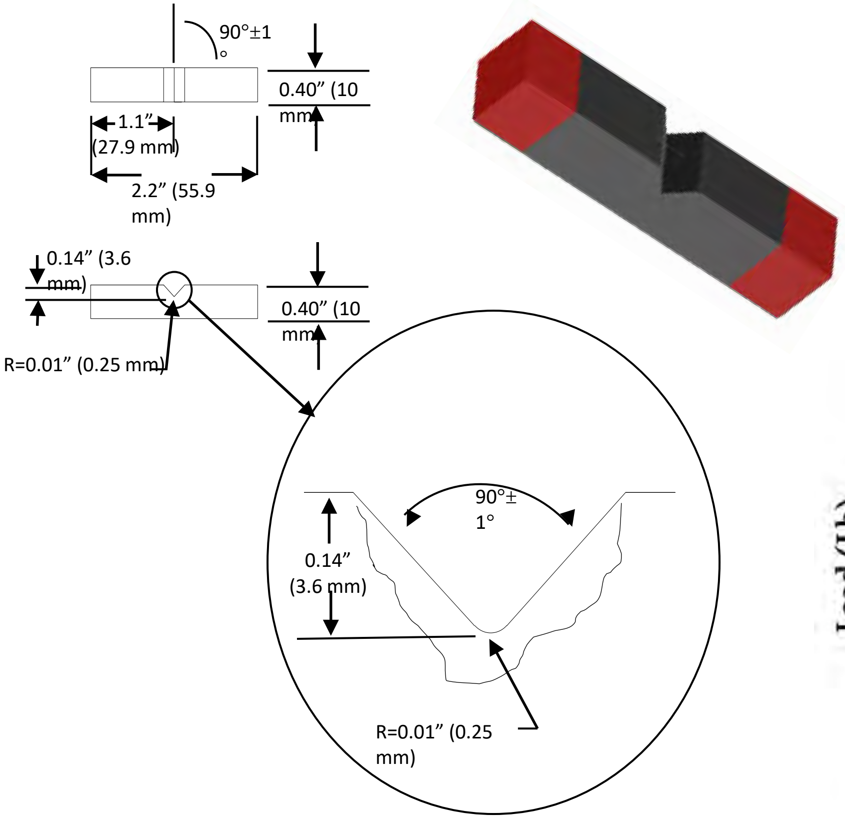


Coating process evaluation – test in air

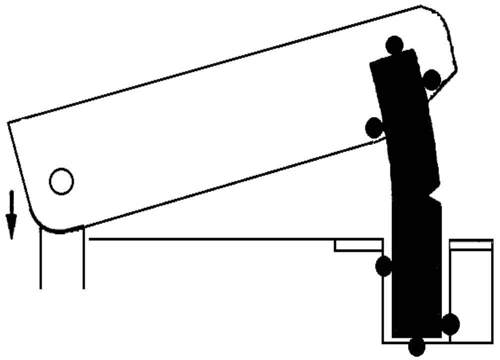
~60 process & processing conditions were evaluated

- Zn – acid chloride – barrel
- Zn – alkaline (non cyanide) – barrel
- Zn/Ni – acid chloride – barrel
- Zn/Ni – alkaline (non cyanide) – barrel
- Zn/Ni – alkaline (non cyanide) – rack
- Zn/Fe – alkaline (non cyanide) – barrel
- Cadmium – cyanide – barrel
- Zn phosphate – barrel
- Mechanical zinc – bulk drum
- Magni 555® – bulk dip spin
- Dacromet® – bulk dip spin

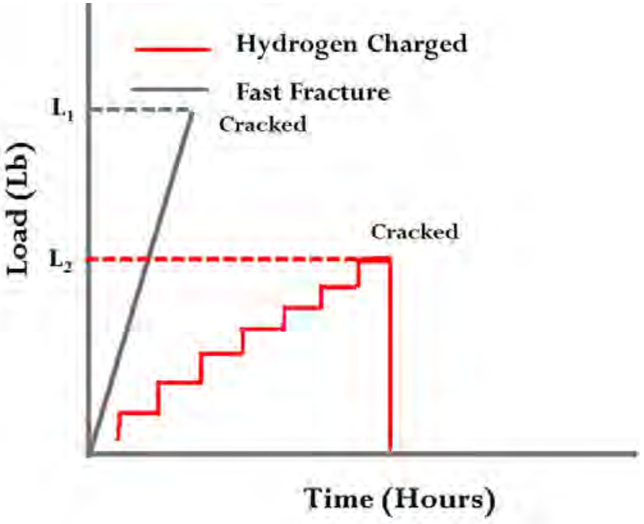
Notch bar ➔ 53 HRC ➔ worst case



Notched square bar – ASTM F519 type 1e
H introduced by electroplating (IHE)

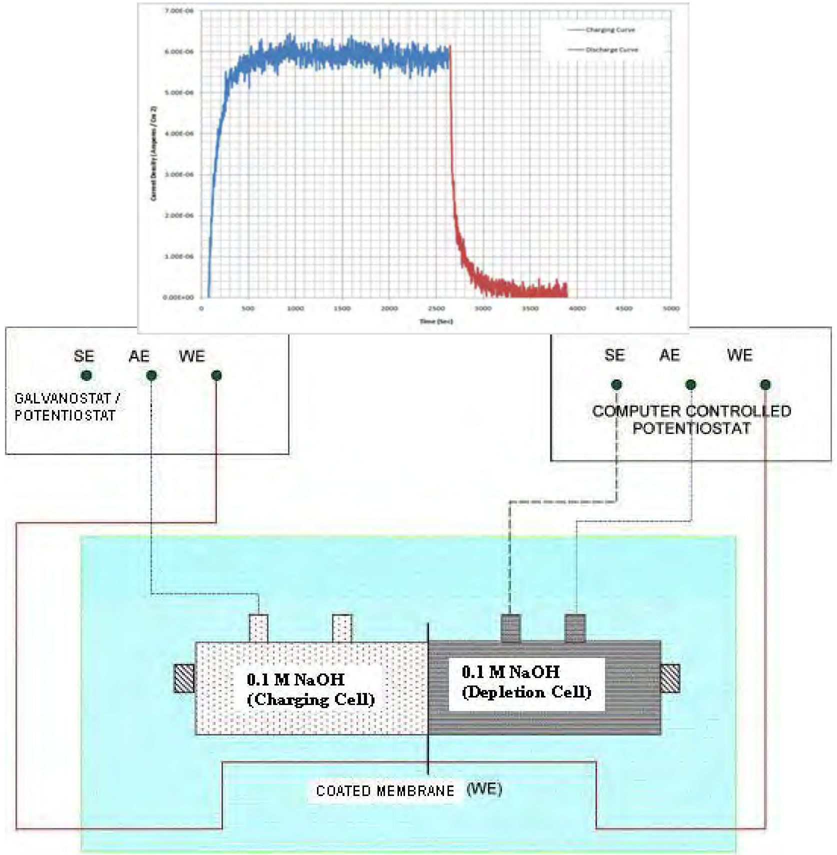


ASTM F1940 Loading protocol
24 h test

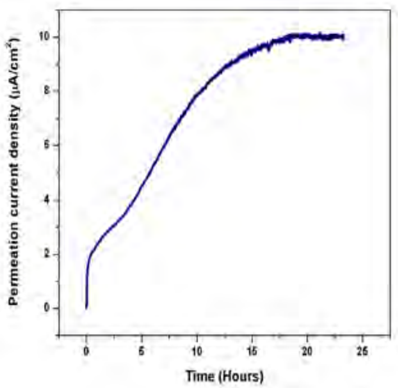


Brahimi, Yue, 2008

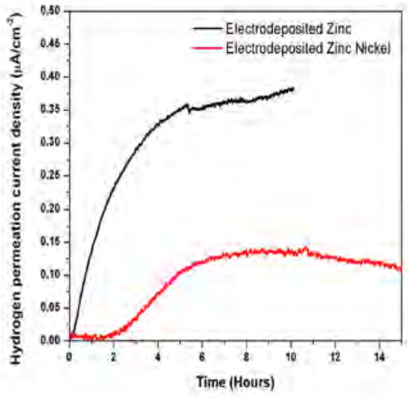
Other analytical techniques – Electrochemical permeation (EP)



Calculation of effective diffusion coefficient of the coating material



Permeation transients of low carbon steel shim

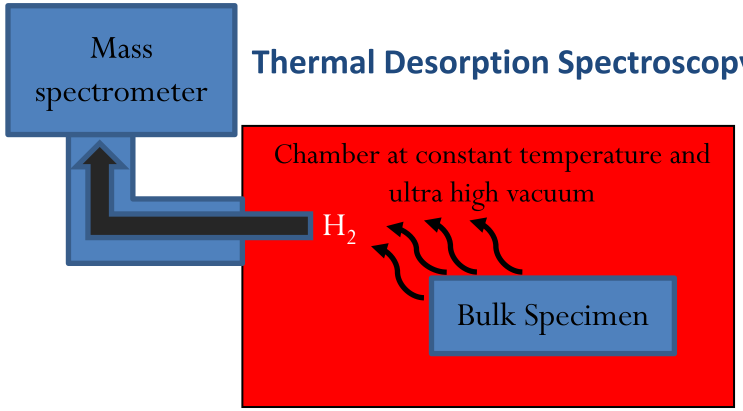


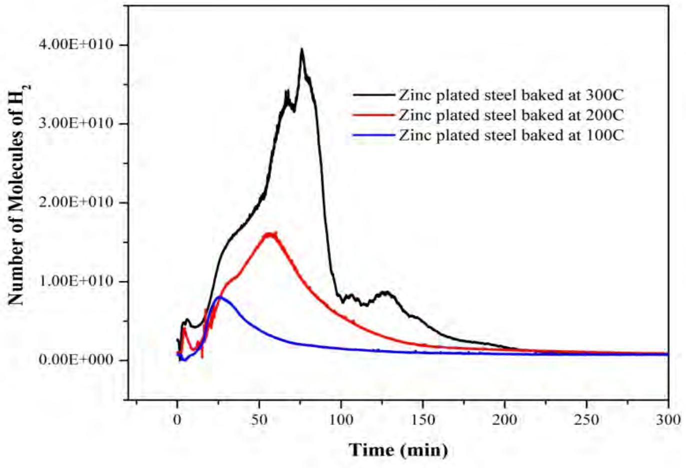
Permeation transients of Zn and Zn –Ni coatings on low carbon steel shim

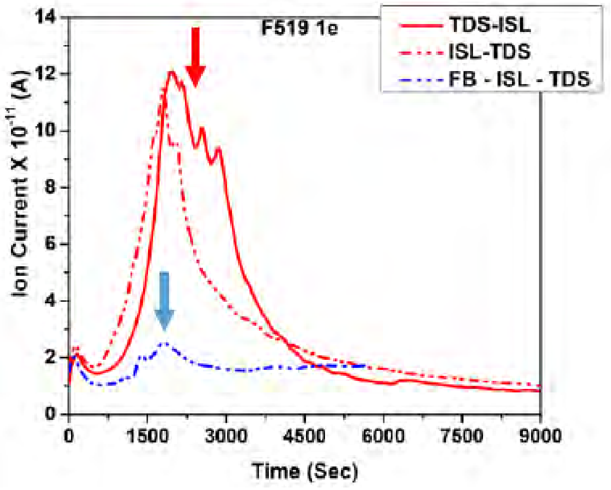
Material	Diffusion Coefficient D ($cm^2 s^{-1}$)	Subsurface hydrogen conc. C_0 (Mol cm^{-3})	Permeation flux J_{ss} (mol $s^{-1} cm^2$)
Bare steel	3.86E-07	2.70E-06	1.05E-10
Electrodeposited Zn	8.20E-09	5.38E-06	3.94E-12
Electrodeposited Zn-Ni	3.91E-09	2.89E-06	8.6E-13

Rajagopalan, Brahimi, Yue, 2010

Other analytical techniques – Thermal desorption spectroscopy (TDS)







Measure H discharge as a function of time and temperature

Rajagopalan, Brahimi, Yue, 2010

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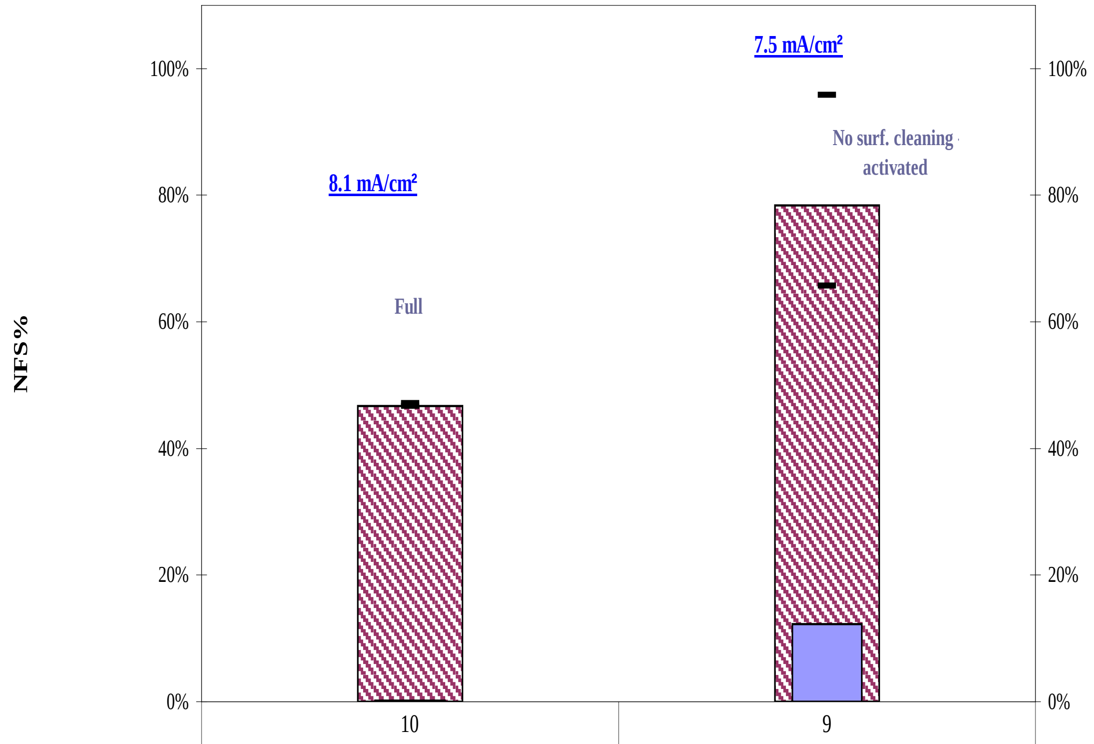
Zinc electroplating

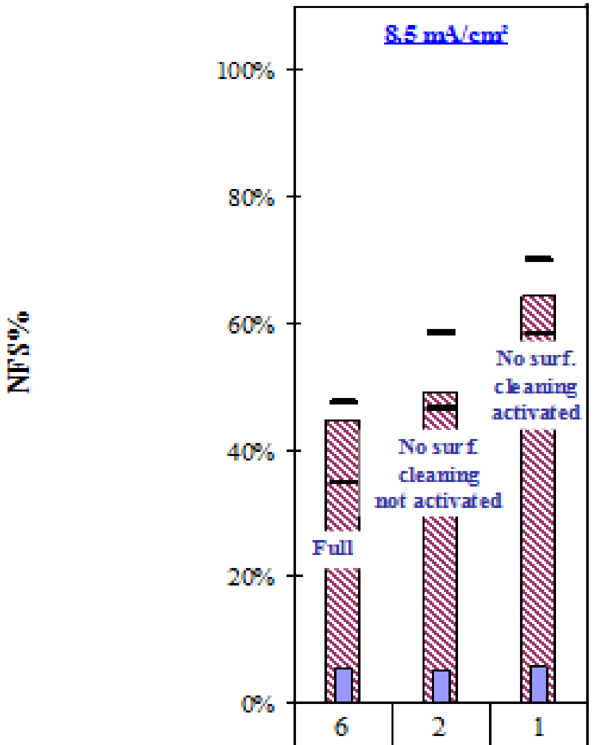
Effect of baking 200 °C (~400 °F)

Alkaline zinc
High efficiency 80-90%



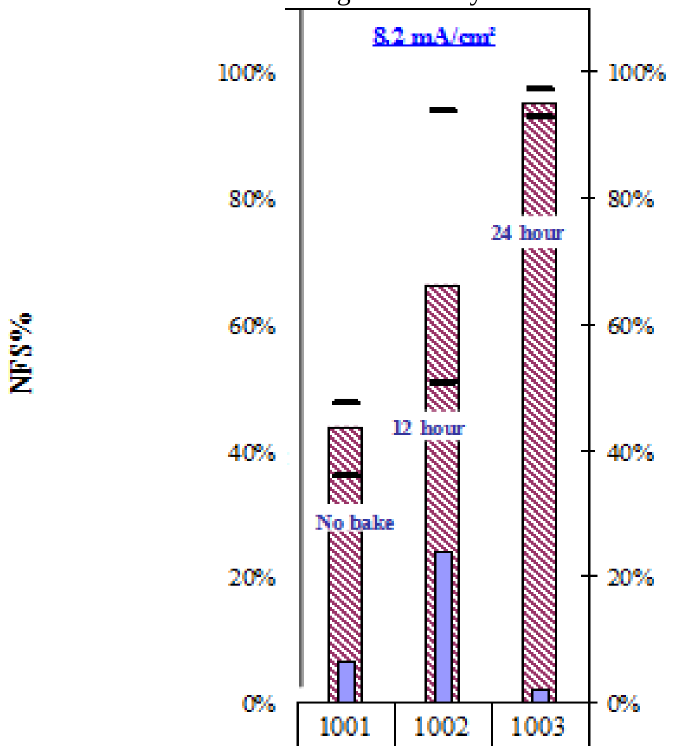
	10	9
Average	46.7%	78.4%
Standard deviation	0.15%	12.22%
Minimum	46.7%	65.7%
Maximum	47.1%	95.8%

Zinc - acid chloride
High efficiency 90-95 %



	6	2	1
Average	44.7%	49.1%	64.2%
Standard deviation	5.42%	5.26%	5.81%
Minimum	35.0%	46.7%	58.4%
Maximum	47.6%	58.5%	70.0%

Zinc - acid chloride
High efficiency 90-95 %



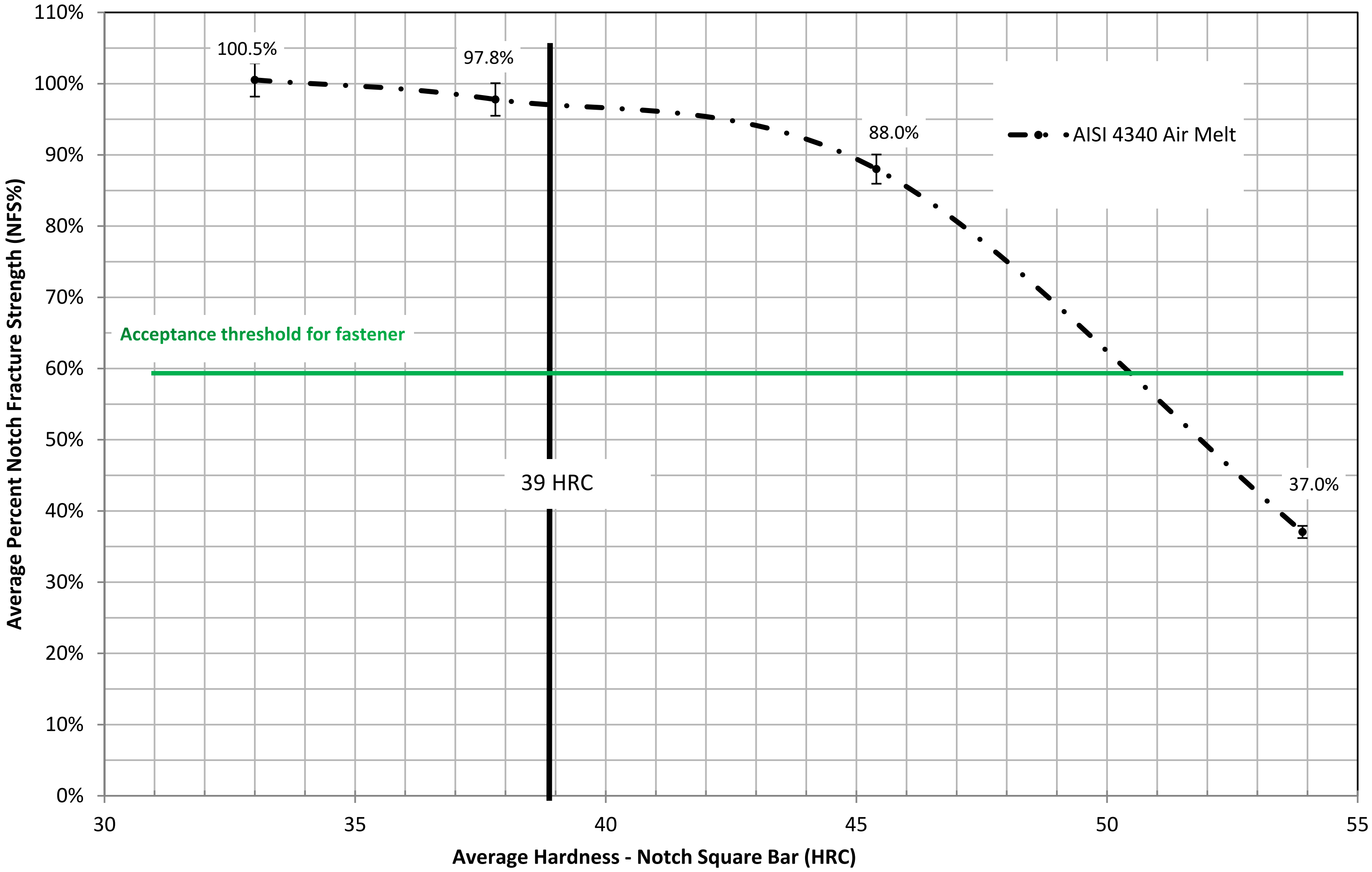
	1001	1002	1003
Average	43.8%	66.2%	95.0%
Standard deviation	6.69%	24.07%	2.17%
Minimum	36.0%	50.8%	92.9%
Maximum	47.6%	93.9%	97.2%

Brahimi, Yue, 2008

IHE – Worst case: Zn Electroplating

The susceptibility of steel fasteners increases significantly when the specified hardness is above 39 HRC (380 HV).

In other words, they can tolerate the presence of higher concentrations of hydrogen without any delayed degradation of their mechanical strength



Brahimi, Rajagopalan, Yue, 2015

Confusing electroplating technical standards

IHE avoidance – requirement for "baking"

Some standards have defined critical hardness limits for baking that are lower, ranging from 31 to 35 HRC. Examples: ASTM B633/ASTM B850 and ISO 2081/ISO 9588 – **these standards should NOT be used for electroplating fasteners.**

These values are largely unsupported by data → adopted primarily as a precaution against manufacturing errors.

It is appropriate to classify susceptible fastener products as those having minimum specified hardness above 39 HRC (390 HV).

This classification is based on both scientific research and longstanding fastener industry practice.

Standards suited for fasteners:

- → **ASTM F1941/F1941M**
- → **ISO 4042**

Summary findings

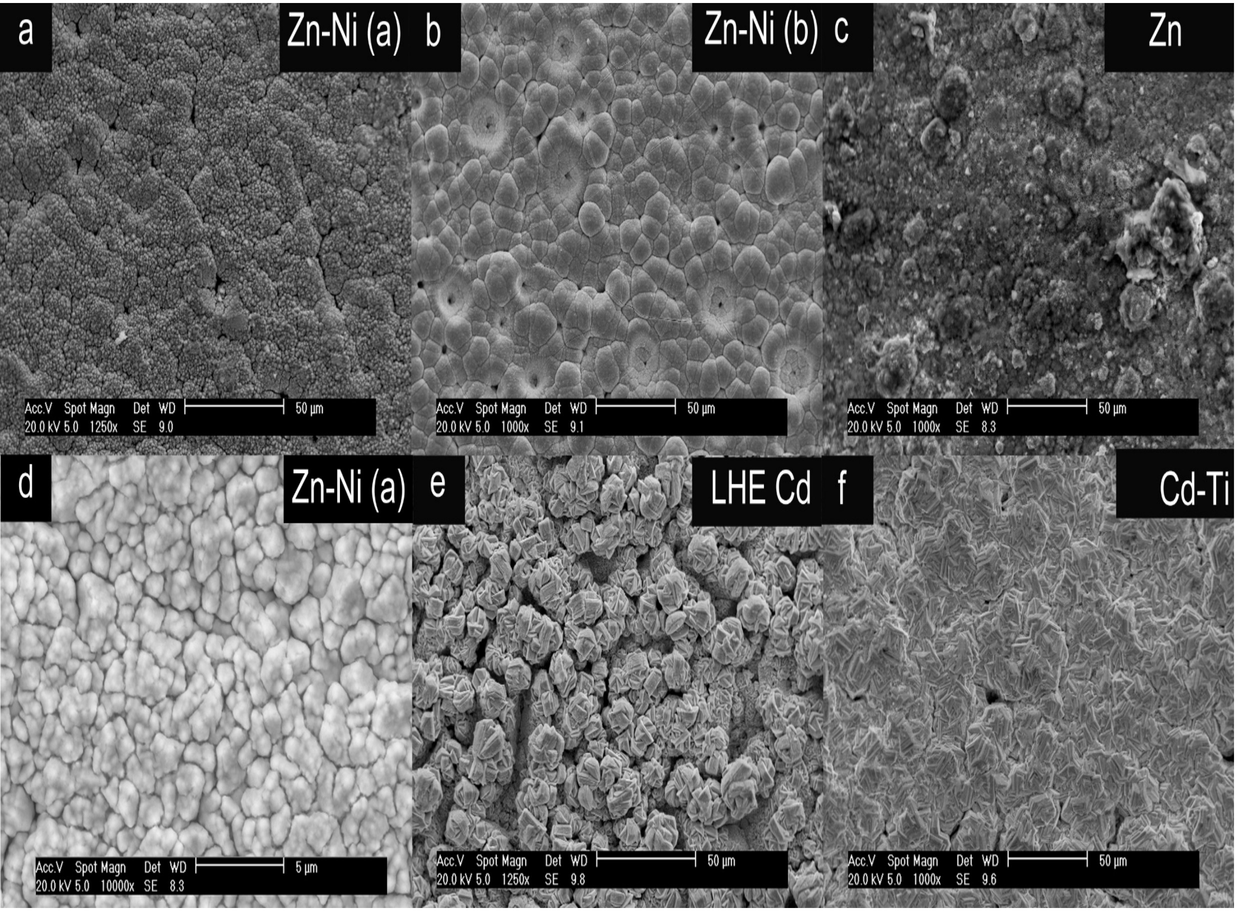
- Zinc acid chloride ➔ most embrittling
- Alkaline zinc ➔ slightly less embrittling
- Alkaline zinc-iron process ➔ moderately embrittling (86%)
- The least embrittling processes ➔ LHE zinc-nickel, alkaline and acid

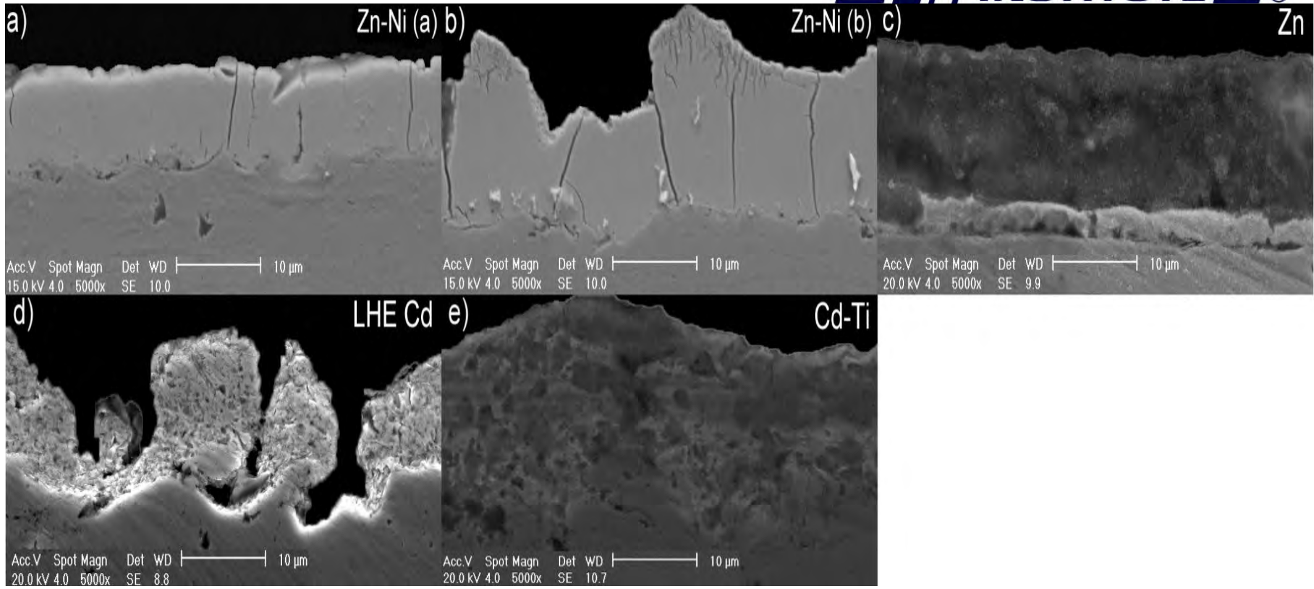
Results support grouping into two basic parameters affecting IHE:

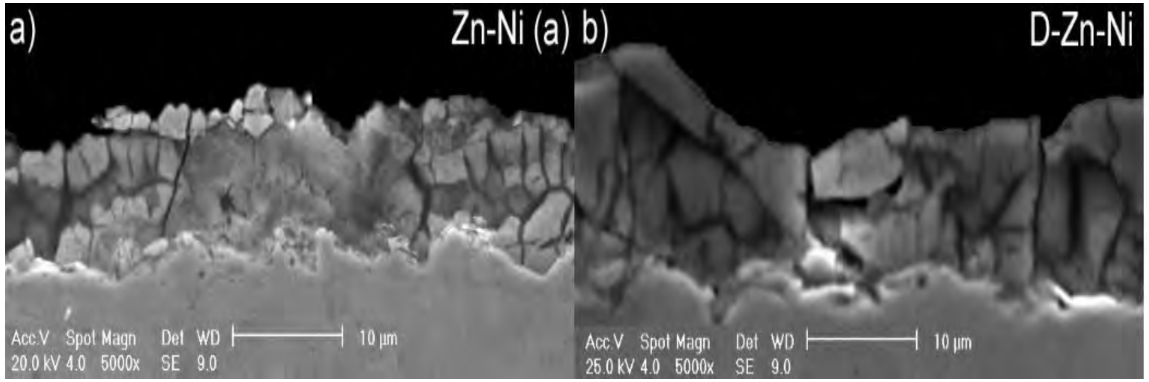
- (i) ***Coating permeability*** - first order effect,
- (ii) ***Quantity of hydrogen*** introduced by the process - second order effect

- Baking at min. 400 ° F (204 °C) can fully restore ductility
- However… baking response depends upon the permeability of the coating

  ➔ baking time must be adapted to the coating type
- **For Zn plated coatings, 4 h bake is a waste of time and money!**
- Zn-Ni Coatings will require less baking time than Zn ➔ **to be determined!**
- **Parts below 39 HRC are not embrittled –no baking required! ref. ASTM F1941**





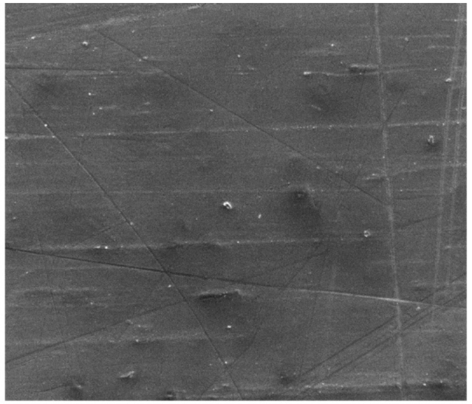


Sriraman, K. R., S. Brahimi, J. A. Szpunar, J. H. Osborne and S. Yue, Characterization of corrosion resistance of electrodeposited Zn-Ni, Zn and Cd coatings, ***Electrochimica Acta*, 105, 314-323, 2013**

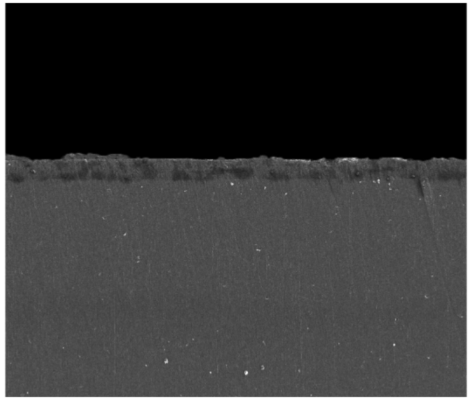
Comparison Zn vs Zn-Ni

Zn Coating

Surface

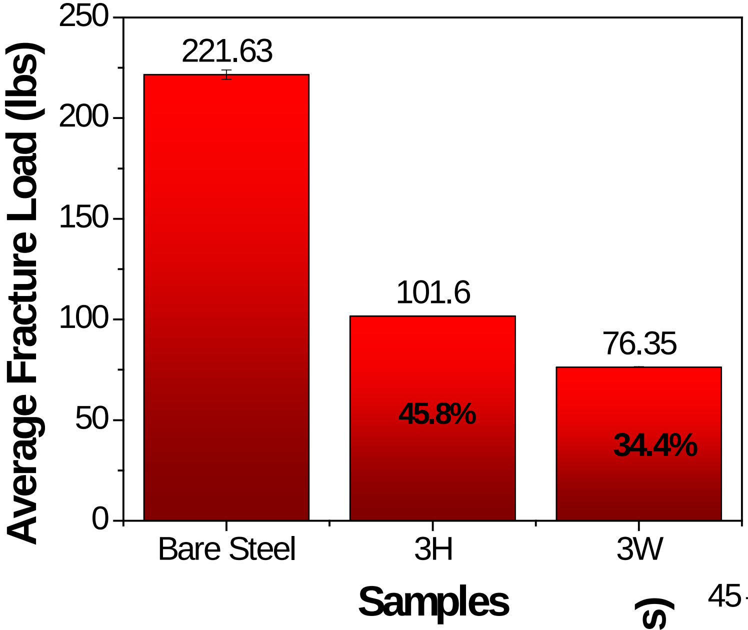


Cross-section

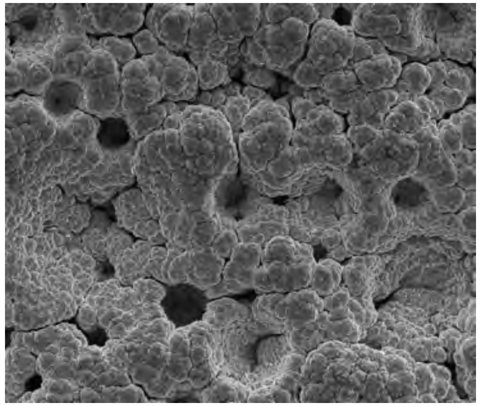


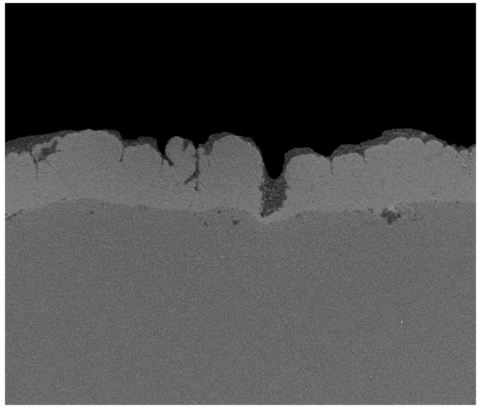
50 µm

5.9 ± 0.6 µm



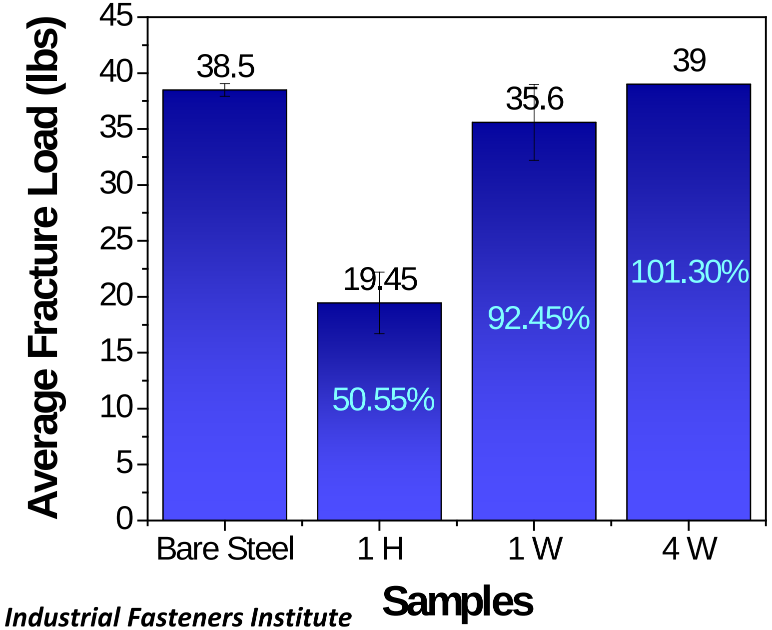
Zn-Ni Coating





50 µm

14.2 ± 3.8 µm



Barbosa de Melo, Rajagopalan, Brahimi, Yue, 2018

What is "LHE" Zn-Ni?

LHE Zn-Ni

- Low Hydrogen Embrittlement
- High H permeability
- Ni 12-16%
- Gamma Zn-Ni deposit
- No brighteners – dull appearance
- Cauliflower – columnar structure
- Coating has through cracks
- Cracks more with baking

Bright Zn-Ni

- Low H permeability
- Less than 10% Ni
- Brighteners - shiny and esthetic
- Platelet structure
- Uniform and continuous (defect free)

Zinc Nickel Specifications

Aerospace

- **AMS2461** Plating, Zinc-Nickel Alloy (12 to 16% Ni) Issued 2020-11 **(LHE) (Fasteners and Standard Parts)**
- **MIL-DTL-32648** (USAF) ZINC NICKEL Plating, Low Hydrogen Embrittlement Electro Deposition **(LHE)**
- **prEN 4826** (ASD-STAN STANDARD) Aerospace series Zinc-nickel (12-16% Ni) plating of steels with specified tensile strength ≤ 1 450 MPa, copper, copper alloys and nickel alloys and aluminium alloys for parts and fasteners **(LHE)**

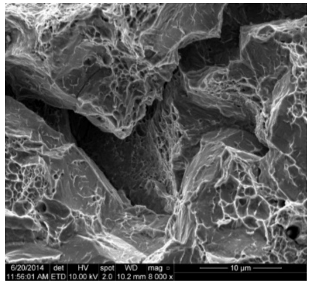
Non-Aerospace

- **MIL-PRF-32647** Performance Specification ZINC-NICKEL Electroplating for Fasteners **(Fastener specific)**
- **ASTM B841-18** Standard Specification for Electrodeposited Coatings of Zinc Nickel Alloy Deposits
- **ASTM F1941 / F1941M** – 16 Standard Specification for Electrodeposited Coatings on Mechanical Fasteners, Inch and Metric **(Fastener specific)**
- **ISO 4042 Fasteners** — Electroplated coating systems **(Fastener specific)**

JUST RELEASED! ISO TR 20491:2019

Fundamentals of hydrogen embrittlement in steel fasteners

- 4-5 years of development in ISO TC 2
- Significant milestone for the fastener industry
- Will serve as basis for discussions related to fastener hydrogen embrittlement
- Will inform the evolution of fastener standards and practices around the world
- *Available at the IFI Web Store.* Or ISO Online Collection



TECHNICAL REPORT

ISO/TR 20491

First edition
2019-02

Fasteners — Fundamentals of hydrogen embrittlement in steel fasteners

Fixations — Principes de la fragilisation par l'hydrogène pour les fixations en acier

Publications

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THANK YOU!