CHARTER STEEL

Charter Steel

Technical Services Laboratory

1

1

CHARTER STEEL

Technical Services (TS) Lab

- **In Operation Since June, 2013**
- **Our Mission:**
  - Provide a lab service dedicated to our customers
  - Provide enhanced technical services to our customers
  - Reduce time to resolve customer claims and other customer technical issues

2

2

CHARTER STEEL

TS Lab Capabilities

Charter Steel's Technical Services Laboratory employs a staff of 8 including 2 degreed metallurgists with over 50 years of combined experience. We provide a full array of testing capabilities and investigative services to our customers. Capabilities include:

- **Scanning Electron Microscopy**
  - Tescan MIRA (Acquired in 2023):
    - Field Emission, Variable Pressure, Bruker® EDS, RJ Lee IntelliSEM® Automated Inclusion Analysis, EBSD (planned for 2025) and WDS (planned for 2026)
- **Optical Microscopy:**
  - 2 Keyence VHX 7000 digital microscopes, 1 Olympus DSX digital microscope, 1 BX51M optical microscope, 1 Zeiss stereo-microscope
  - Image analysis software (Keyence, Olympus, Clemex, Pax-It)
    - Image Stitching, Image Stacking, 3D Rendering, Automated Measurements
- **Mechanical Testing:**
  - Automated Microhardness (HV & HK) with Mapping, Rockwell (B, C and superficial)
  - Accredited production labs provide chemistry, tensile, and other routine tests.
- **Sample Prep:**
  - Full suite of metallographic equipment (sectioning, mounting, grinding, polishing, and etching)

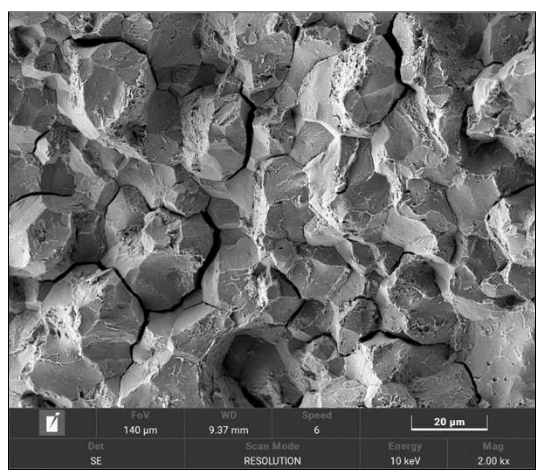
3

3

CHARTER STEEL

Electron Microscopy (Fractography)

- **The scanning electron microscope allows for detailed examination of fracture surfaces at magnifications over 10,000X.**
- **The features on the surface allow us to determine the failure mode (ductile overload, fatigue, etc.)**



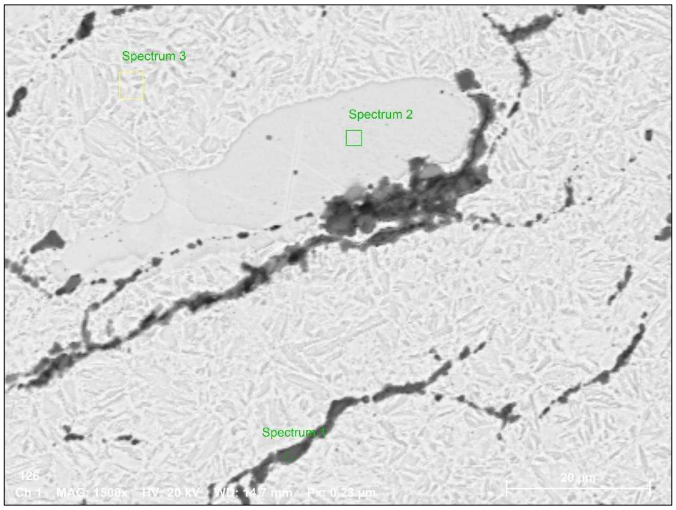
Fracture surface taken on Tescan

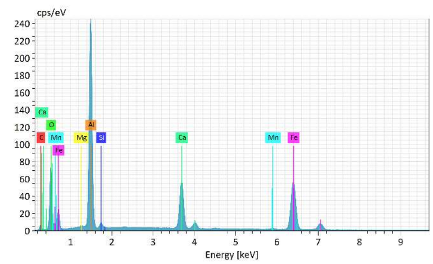
4

4

CHARTER STEEL

Electron Microscopy (Energy Dispersive X-Ray Spectroscopy (EDS))





- **Energy dispersive x-ray spectroscopy.**
- **Determines the composition of the material at sub-micron resolution.**

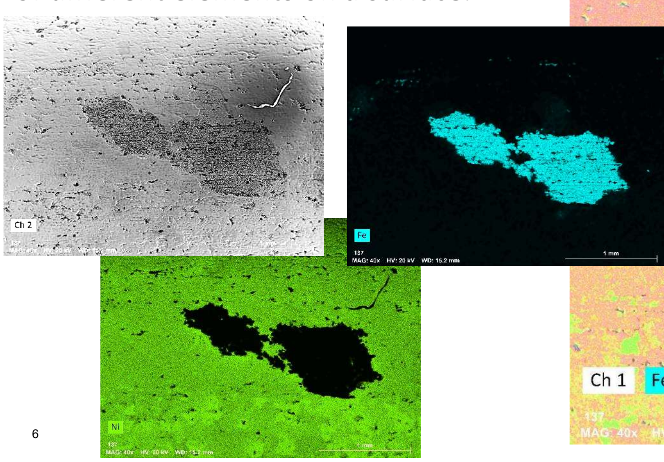
5

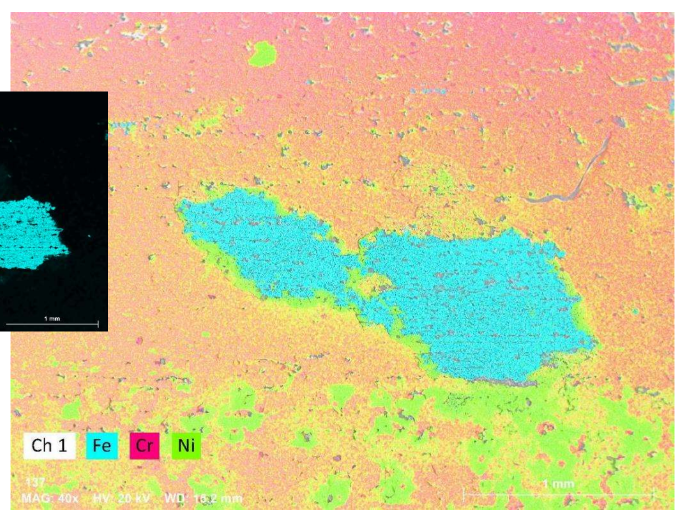
5

CHARTER STEEL

Electron Microscopy (EDS Mapping)

Uses EDS to map out the distribution of different elements on a surface.





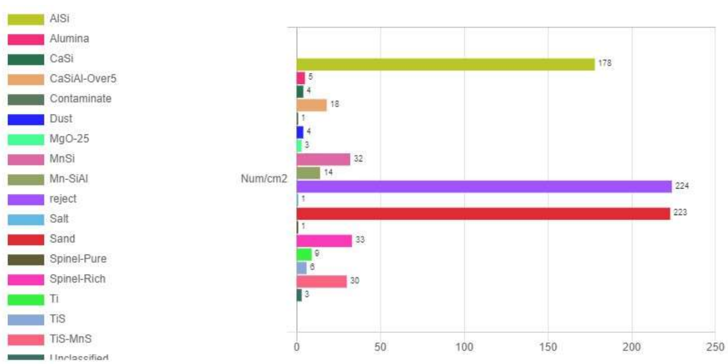
6

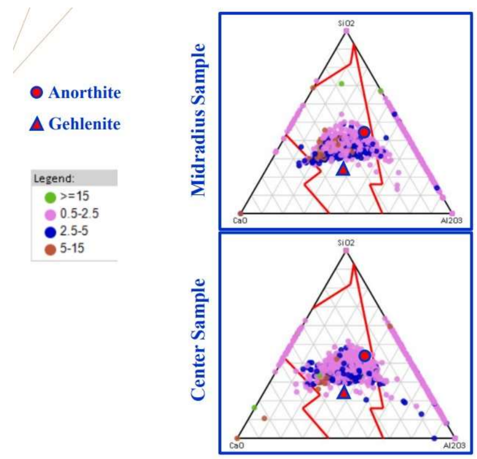
6

CHARTER STEEL

Electron Microscopy (Automated Inclusion Analysis)

Uses EDS to identify, measure, count, and determine the composition of non-metallic inclusions.





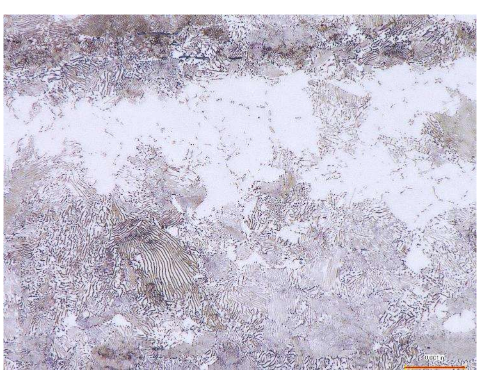
7

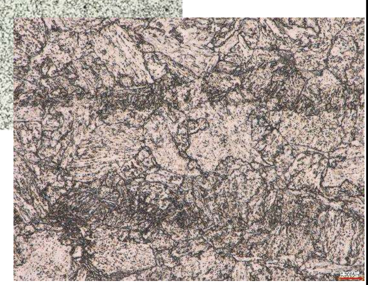
7

CHARTER STEEL

Light Microscopy

Standard Metallography reveals the microstructure of the steel.



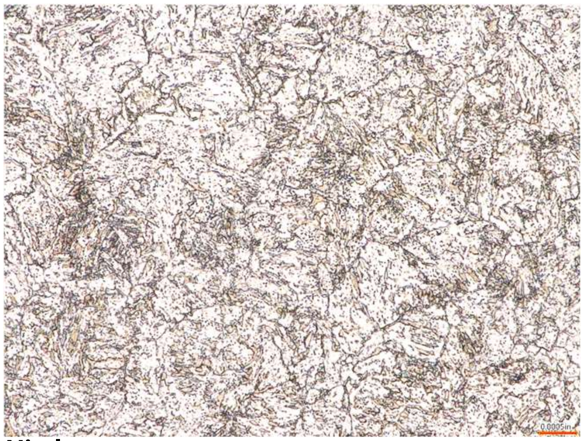


8

8

Light Microscopy

Different etchants reveal different details.

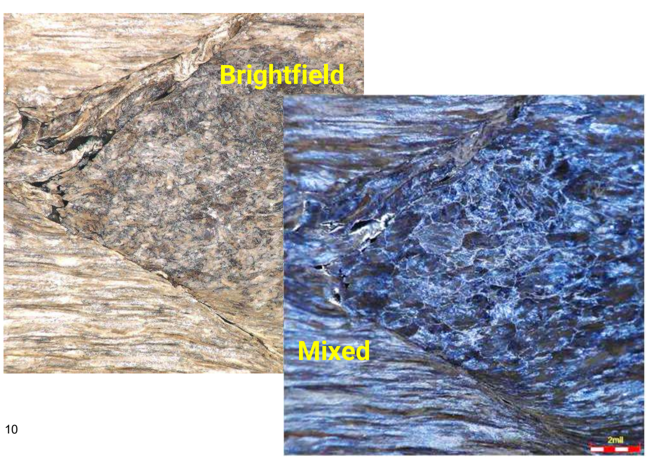


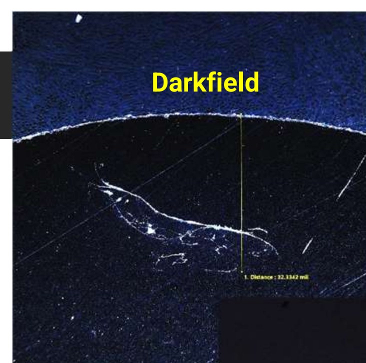
9 **Nital** **Picral**

9

Light Microscopy

Different lighting methods reveal different details.





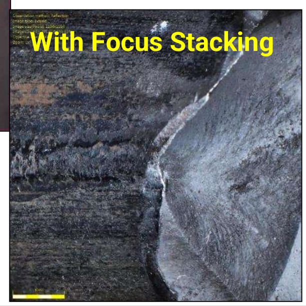
10

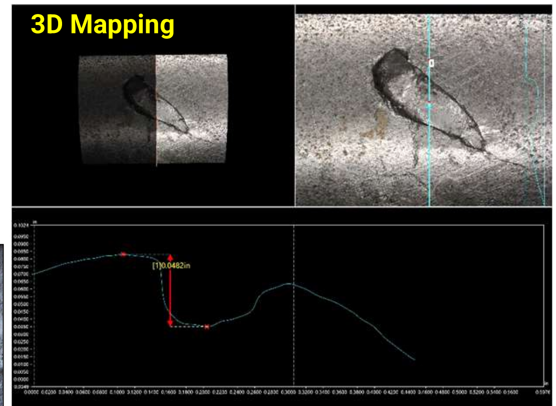
10

CHARTER STEEL

Digital Light Microscopy (Keyence VHX and Olympus DSX)

Focus stacking allows for imaging and 3D mapping of surfaces.





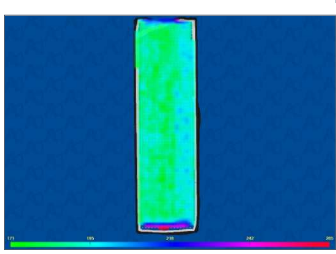
11

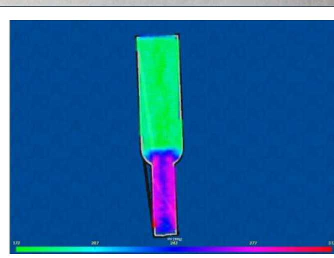
11

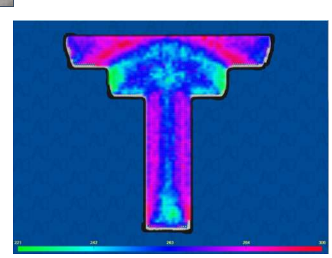
CHARTER STEEL

Automated Microhardness Mapping (Heading Progression Example)

Automated Vicker's and Knoop microhardness allows for high resolution measurement and mapping of changes in hardness.





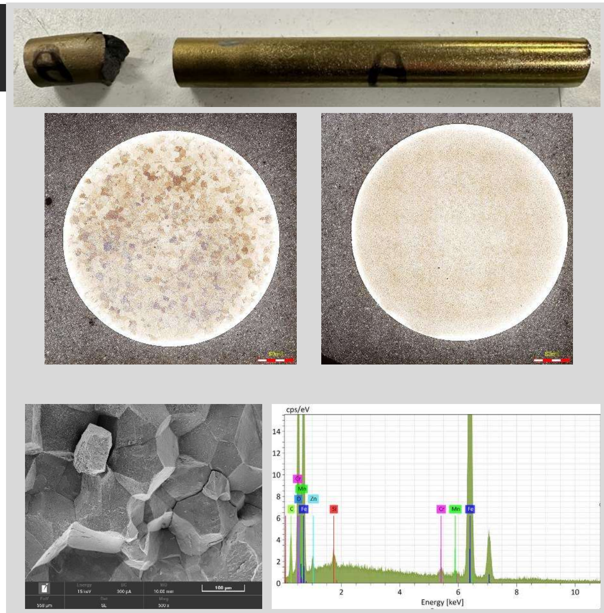


12

12

CHARTER STEEL

Customer Support – Case 1



Issue: Fractures during bending of zinc coated wire.

Visual: Un-broken end was shiny/smooth while broken end was dull with "orange peel" texture.

Mechanicals: Hardness was approximately 30-32 HRC.

Microstructure: Significant grain coarsening was observed in broken end area.

SEM/EDS: Fracture origin exhibited brittle intergranular failure. Zinc was detected on the fracture surface.

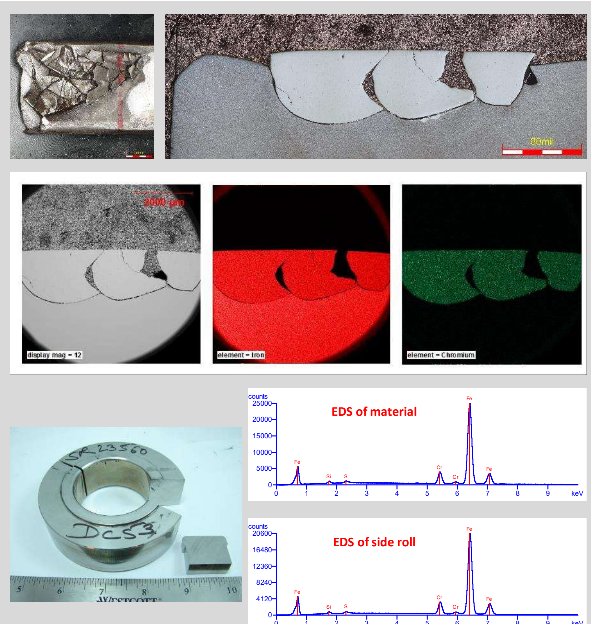
Conclusion: The fracture was the result of liquid metal embrittlement caused by localized heating of the steel after the application of the zinc-chromate coating.

13

13

CHARTER STEEL

Customer Support – Case 2



Issue: Material cracked/broke during cold rolling.

Visual: The break occurred at an area of rolled-in material/particles.

Microstructure: Grain deformation showed material was rolled-in at some point after annealing. Material did not etch indicating it was not 1043 (parent material).

SEM/EDS: Rolled-in material exhibited 8.7% Cr. Later EDS analysis of a side roll (provided by customer) showed nearly identical chemistry.

Conclusion: The break was the result of material from a broken side roll being cold rolled on to the raw material surface at the customer.

14

14

CHARTER STEEL

Customer Support – Case 3

Issue: Spring broke during testing.

Visual: The fracture origin was located at the surface along the inside diameter of the spring.

Microstructure: Heavy grain deformation resulting an adiabatic martensite layer from damage prior to powder coating was observed at the fracture origin. There was also foreign material embedded at the area of damage.

SEM/EDS: The foreign material exhibited ≈12.4% Mn and ≈1.6% molybdenum. Customer later submitted a sample which contacts spring during forming, and chemical analysis (via OES) matched EDS findings.

Conclusion: The break was the result of mechanical damage imparted on the spring surface during manufacture.

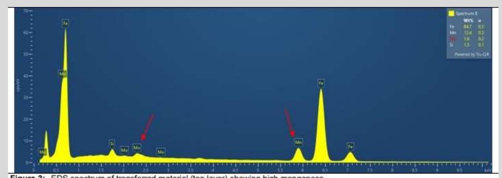


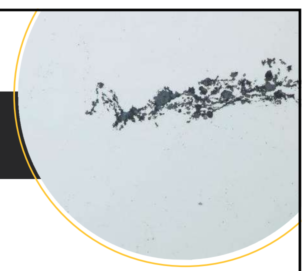
Figure 3: EDS spectrum of transferred material (top layer) showing high manganese.

15

15

CHARTER STEEL

Research and Development (Clean Steel)
(One of several studies)



- Samples: 4 bars from 4 different steel sources
- Number of sections: 2 longitudinal sections from each bar (8 total)
- Number of fields evaluated: 6 fields per section (48 total)
- Total area evaluated: 10,696 mm^2 (16.6 in^2) or ≈ 223 mm^2 per field
- Total SEM/EDS evaluation time: ≈ 206 hours (4.3 hours per field)
- Total individual time (prep, setup, evaluation, etc.): ≈ 100 hours
- Total number of inclusions detected/analyzed (≥ 1 micron): 482,848
- Information gathered:
  - How Charter compares to its competitors in terms of steel cleanliness
  - Distribution of deformable vs. non-deformable inclusions
  - Size/shape of inclusions in relationship to surface
  - Mineralogical classification of inclusions (oxides, sulfides, nitrides)
  - Oxide Ternary Diagrams (gehlenite, anorthite, etc.)
  - Statistics of Extreme Values (SEV) – ASTM E2283

16

16

CHARTER STEEL

Looking to the Future – Industry Technical Challenges

- UHS Fasteners
  - Resistance to IHE/EHE
  - Enhanced formability
  - Phosphate-free coatings
- Sustainability/Carbon Footprint
  - Microalloy development/advancement
  - Thermo-Mechanical Rolling (TMR)
  - Replacing BOF with EAF
- Increased Fatigue Strength in Springs
  - Cleaner steel (enhanced inclusion evaluation)
  - Casting practices (larger reductions, acid slag)

17

17

18