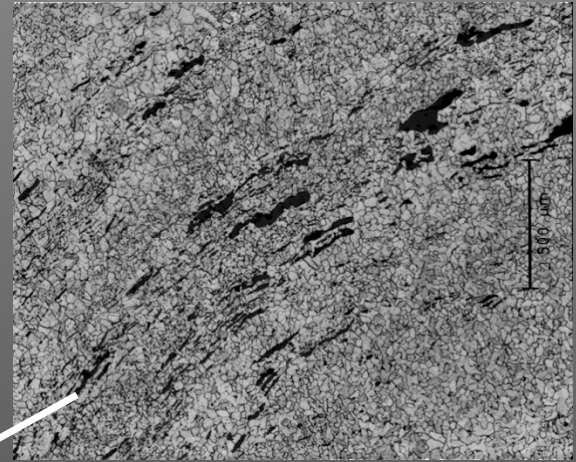


Slag stringers parallel to rivet shaft



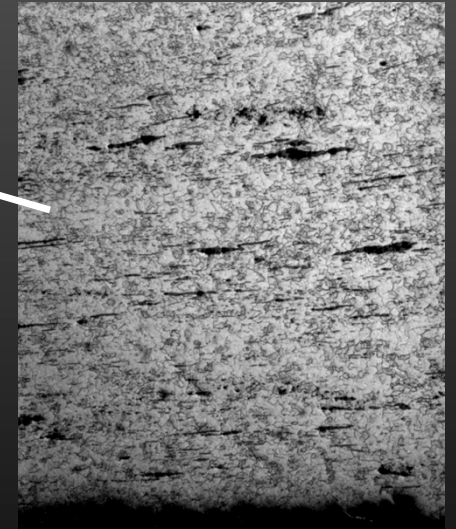
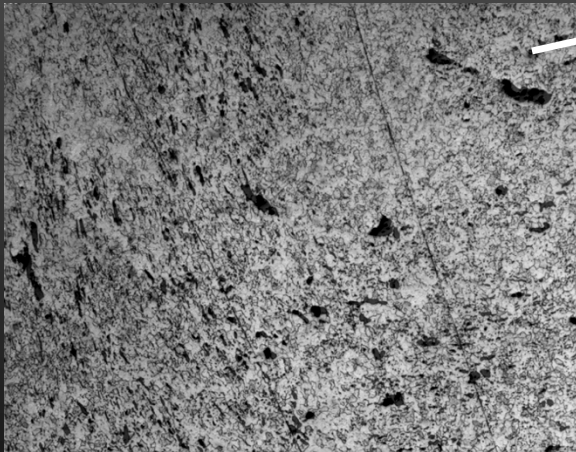
500 μm
(micrographs)

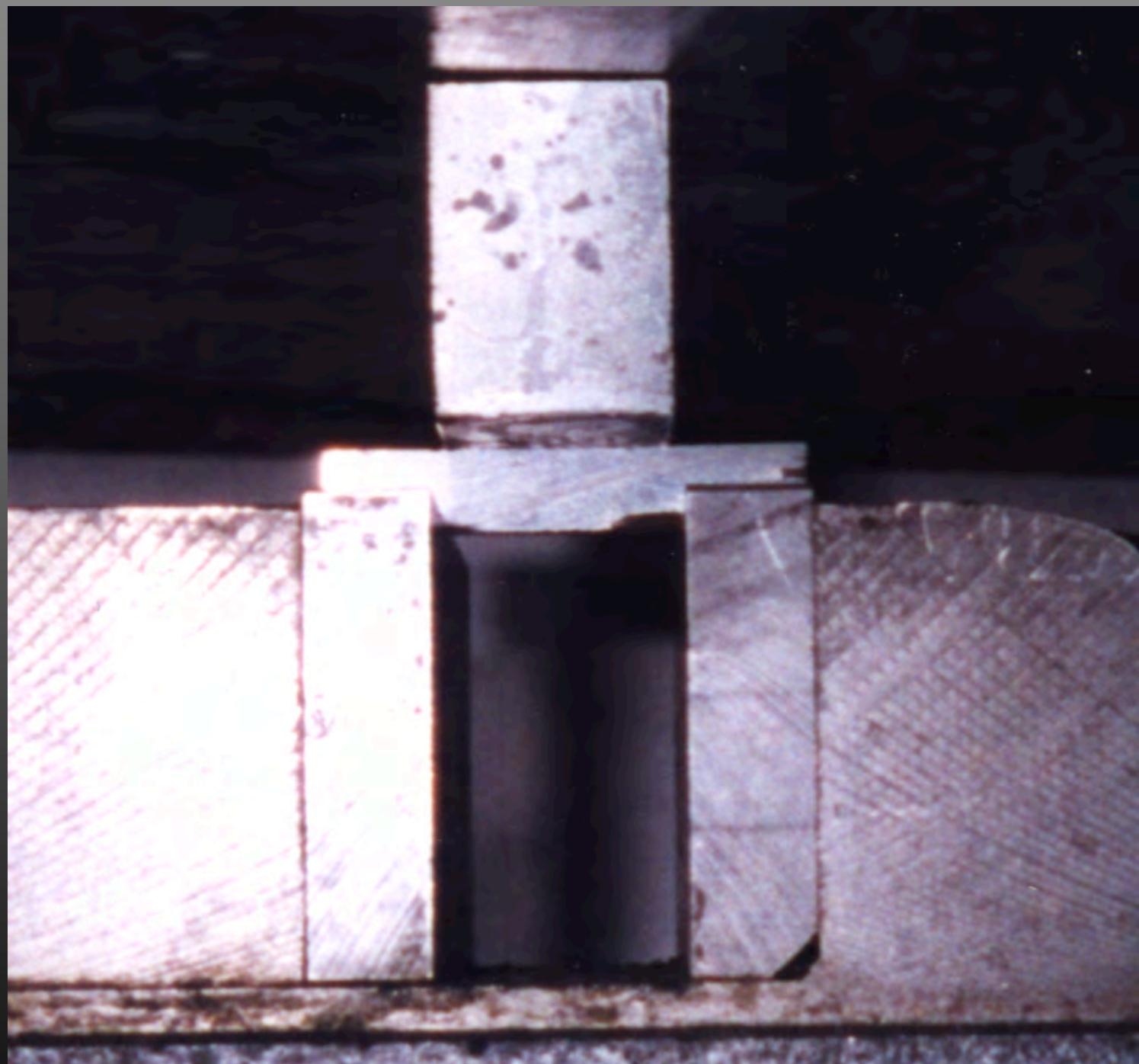
1 cm

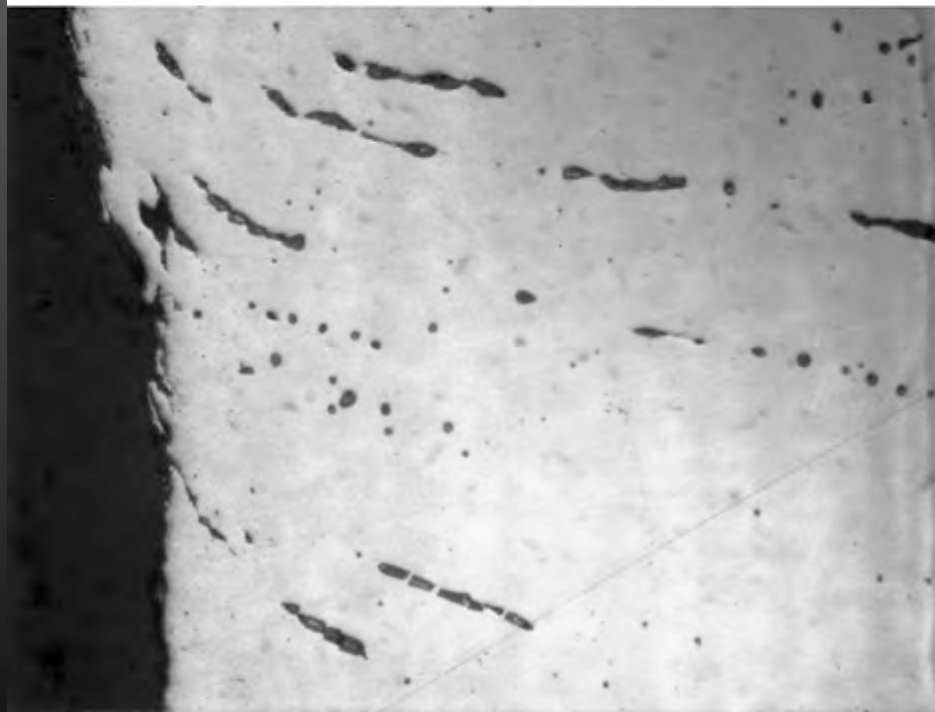
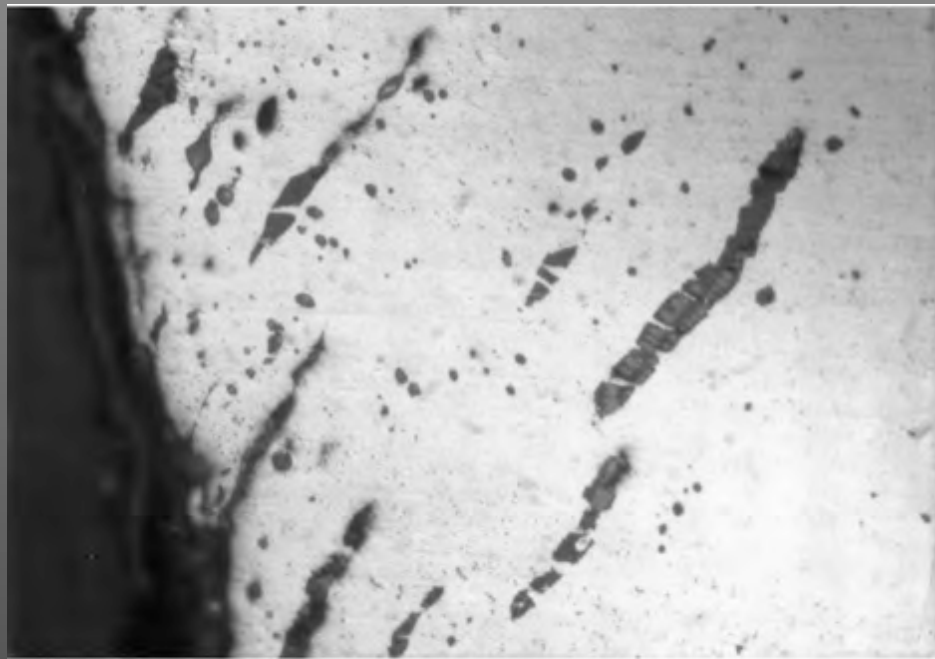


Slag stringers perpendicular to rivet shaft

Missing a head





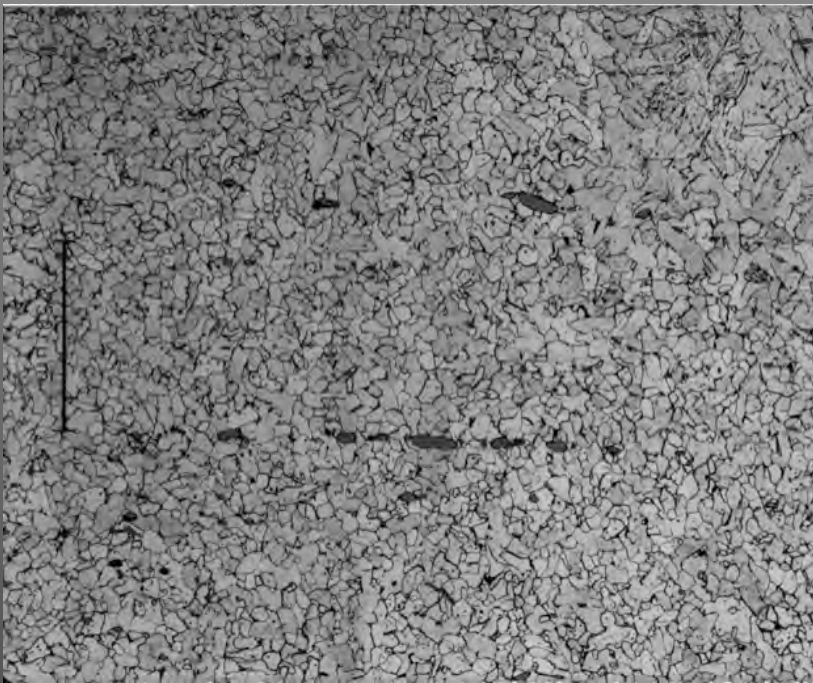


Wrought Iron Comparison

Farmers Bank Building (1903)
Pittsburgh, PA

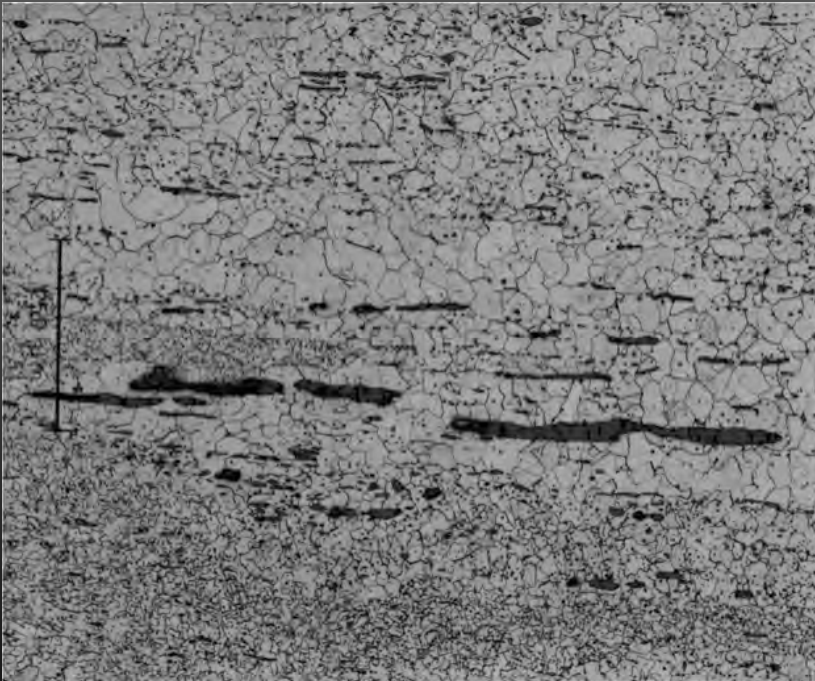
(Courtesy D. Rees-Evans, Nucor-Yamato Steel)

12 rivet average: 1.9% slag



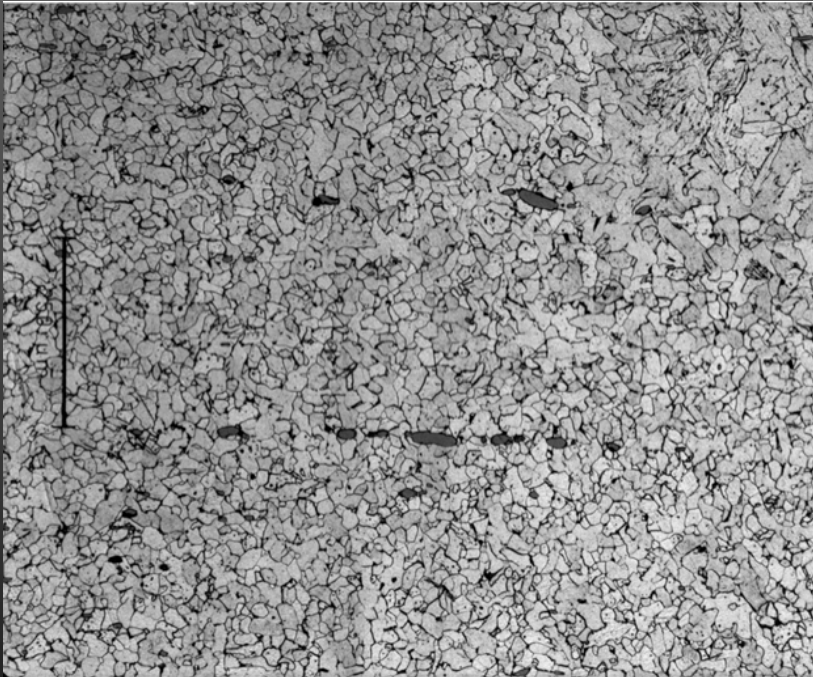
RMS Titanic (1911)

48 rivet range: 2 - 17% slag

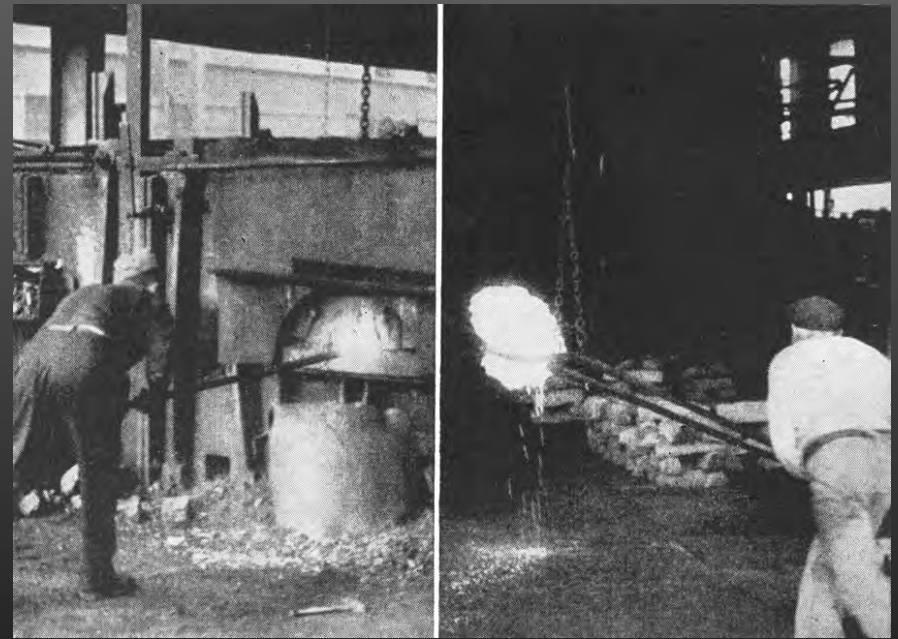


Wrought Iron Rivets

- Commercially pure iron with 1-4% incorporated slag (iron silicate)
- Puddled, extruded into a bar, and formed into rivets

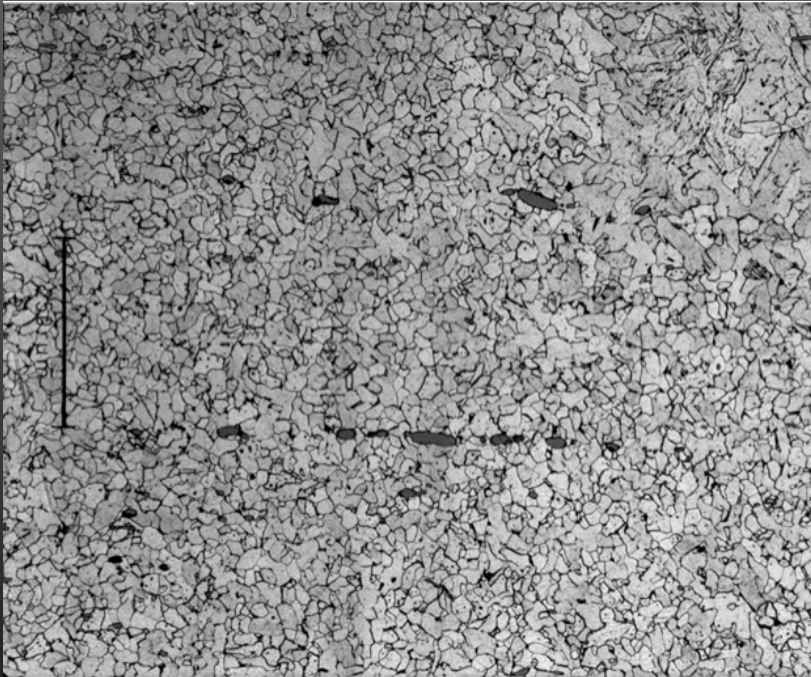


100 μm

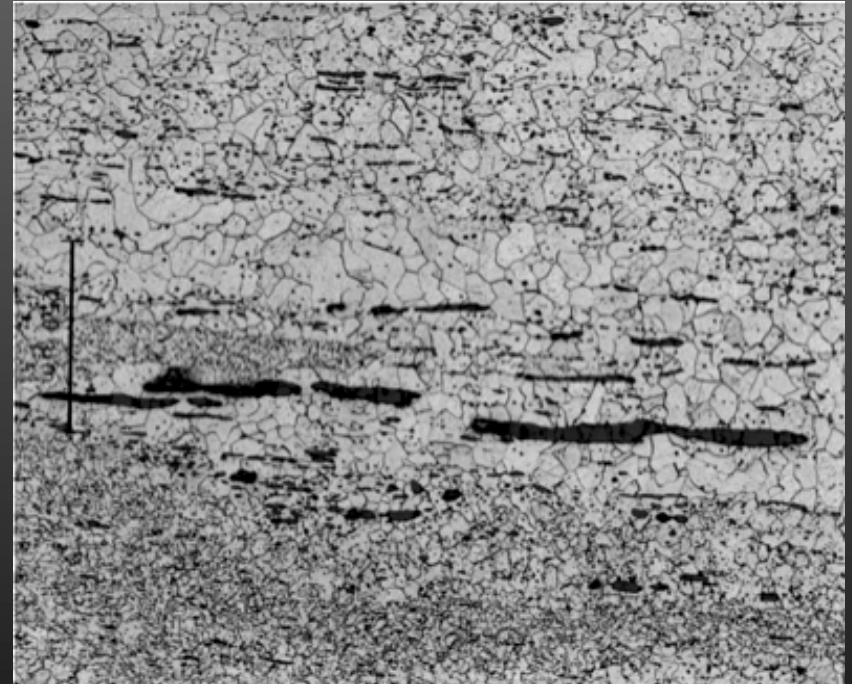


Wrought Iron Rivets

- Commercially pure iron with 1-4% incorporated slag (iron silicate)
- Puddled, extruded into a bar, and formed into rivets



100 μm

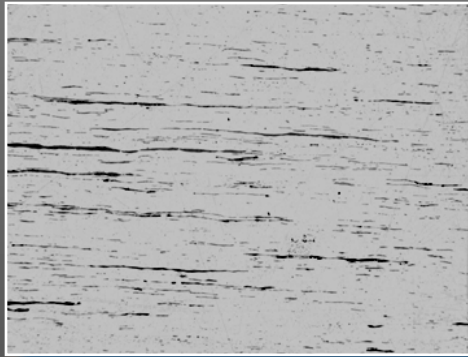


100 μm

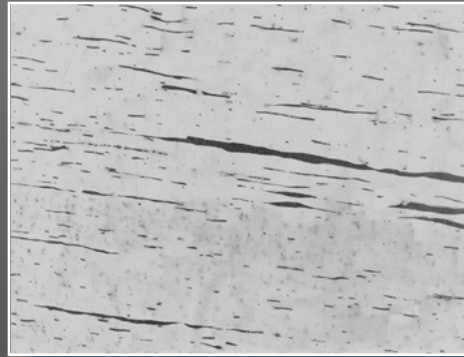
Hypothesis:

Did the re-orientation of large slag stringers in the wrought iron rivets in the impact zone cause the rivet heads to fail prematurely?

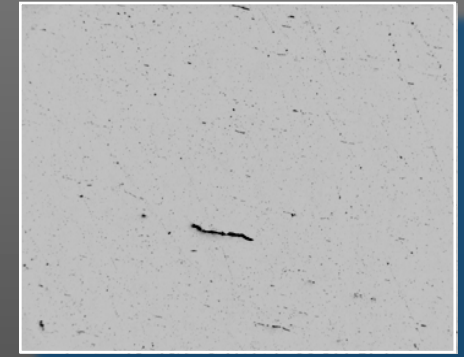
Wrought Iron Comparison



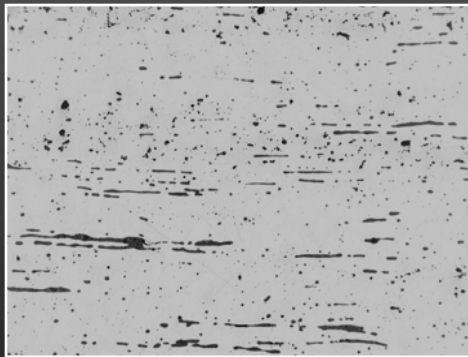
Wheeling Custom House
West Virginia (1857)



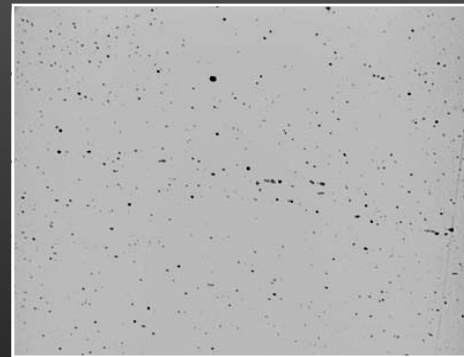
Domestic Candelabra
Ulster, N. Ireland
(late 19th century)



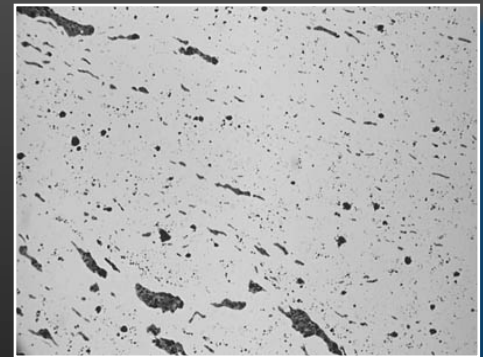
SS Peking Rivet
Hamburg, Germany (1911)



Barkentine Elissa Chain plate
Galveston Harbor, Manchester (1872)



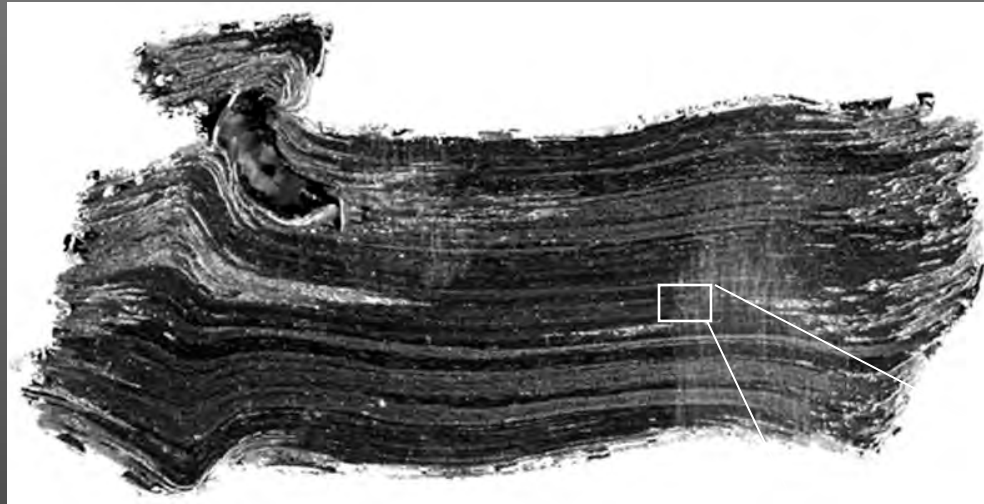
Farmer's Bank Building Rivet
Pittsburgh, PA (1903)



RMS Titanic Bulkhead Rivet
Belfast, N. Ireland (1911)

Microstructural Analysis

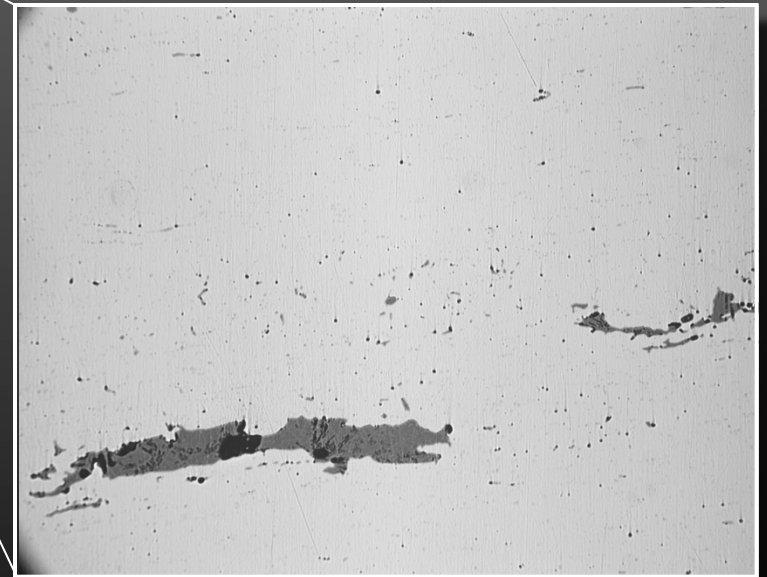
Quantitative Metallography



head

shaft

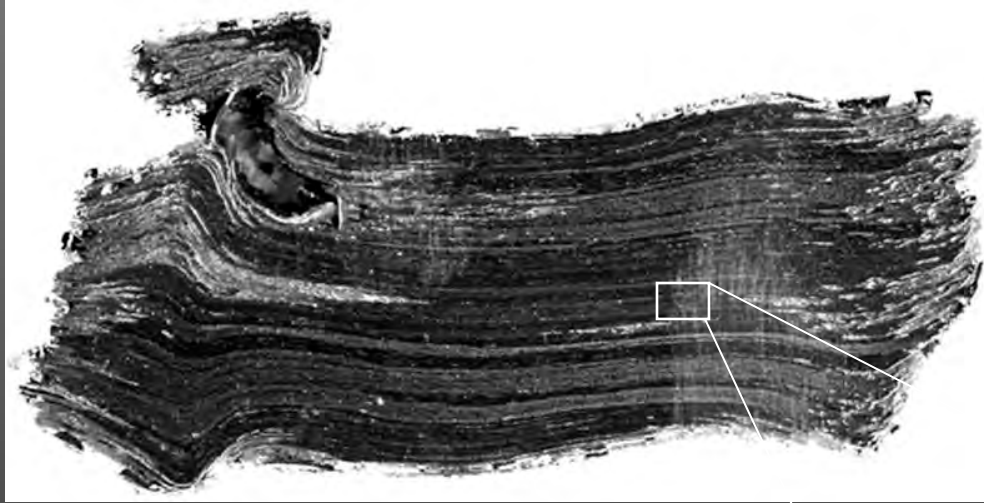
Polished cross-sections were digitally imaged at 100X to create a mosaic of each rivet's surface (100-1200 per rivet).



300 μ m

Microstructural Analysis

Quantitative Metallography



head

shaft

Measurements include:
Slag area percent, aspect
ratio, orientation and
particle size

Images were analyzed using
software that selects slag
regions using an automated
sequence based on greyscale
values.

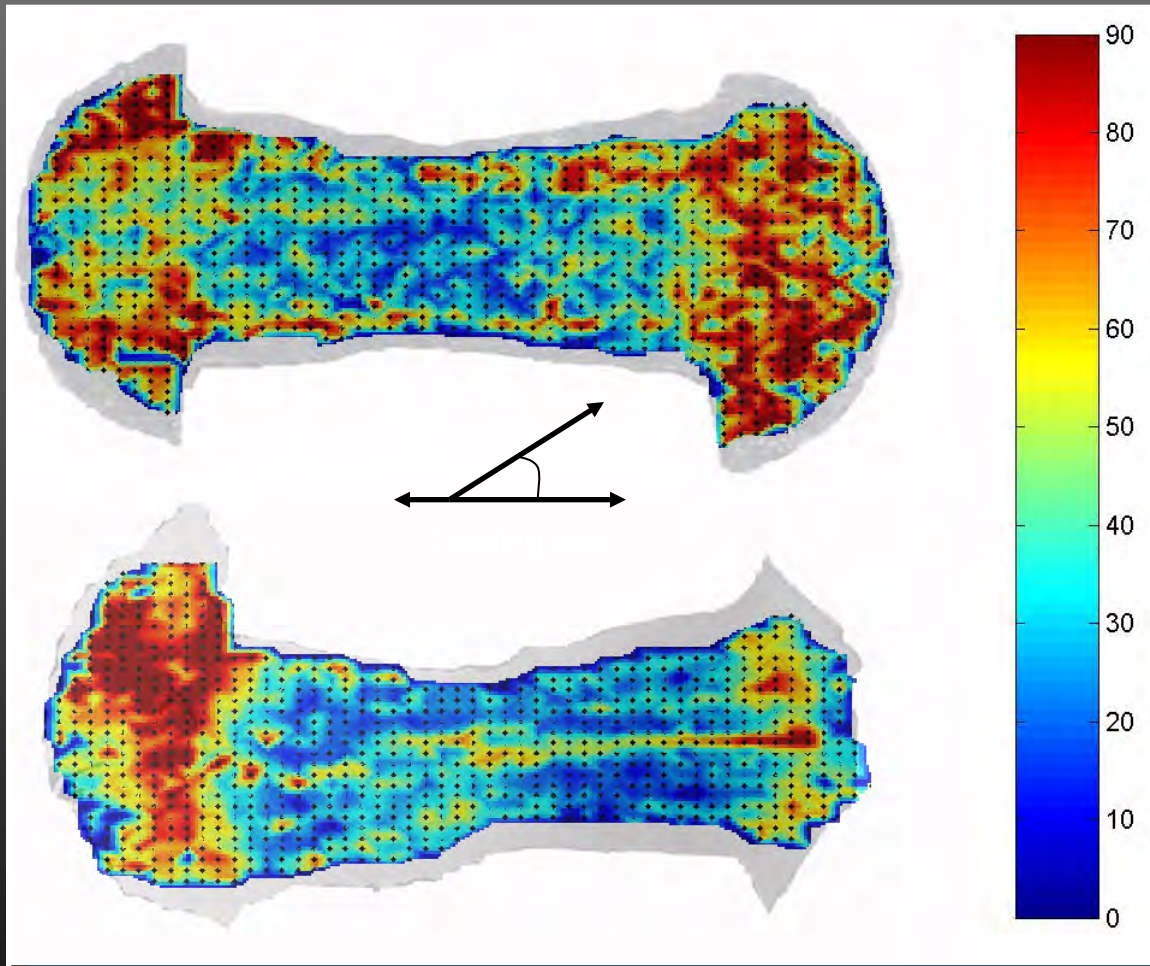


300 μ m

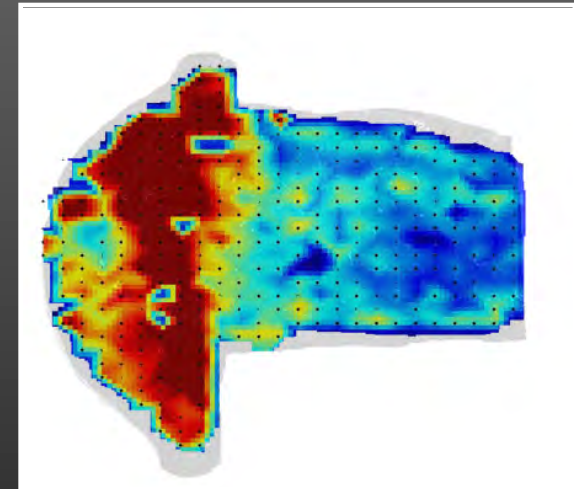
Orientation

Titanic Hull Rivets

Degrees (θ)



Farmer's Bank Rivet

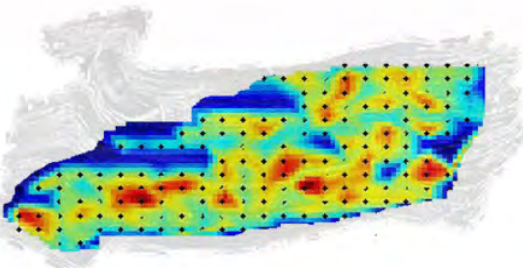


Area Percent of Particles

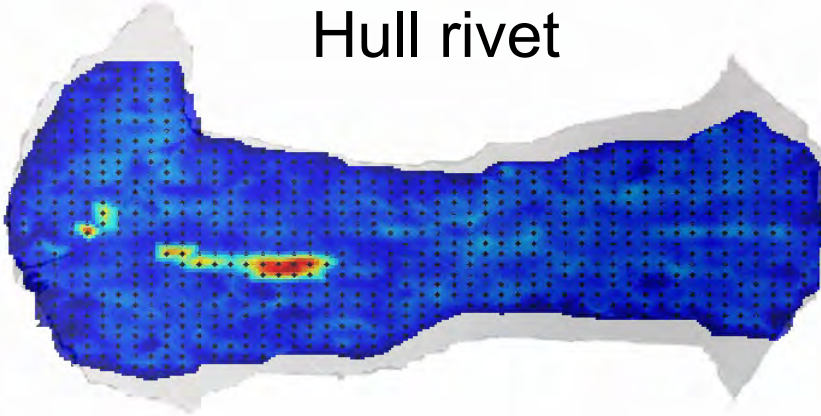
Titanic Rivets

Area %

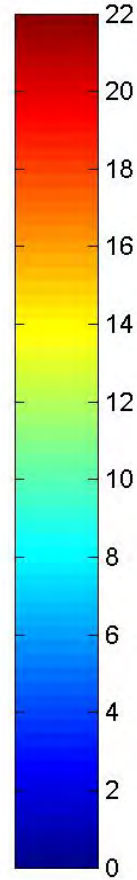
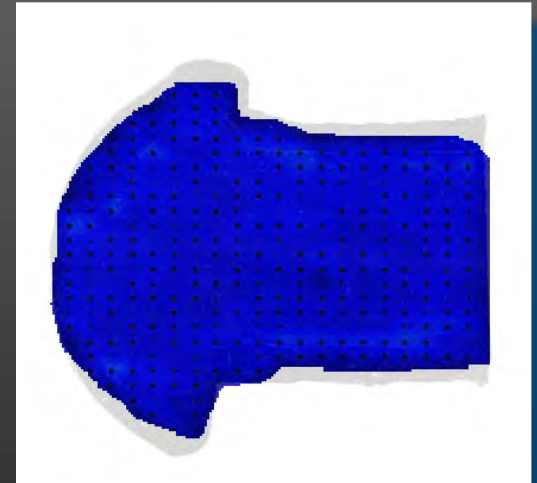
Bulkhead rivet



Hull rivet



Farmer's Bank Rivet



Good Titanic Hull Rivet



- 1.9% slag
- fine fibers
- well distributed

Good (?) Titanic Hull Rivet



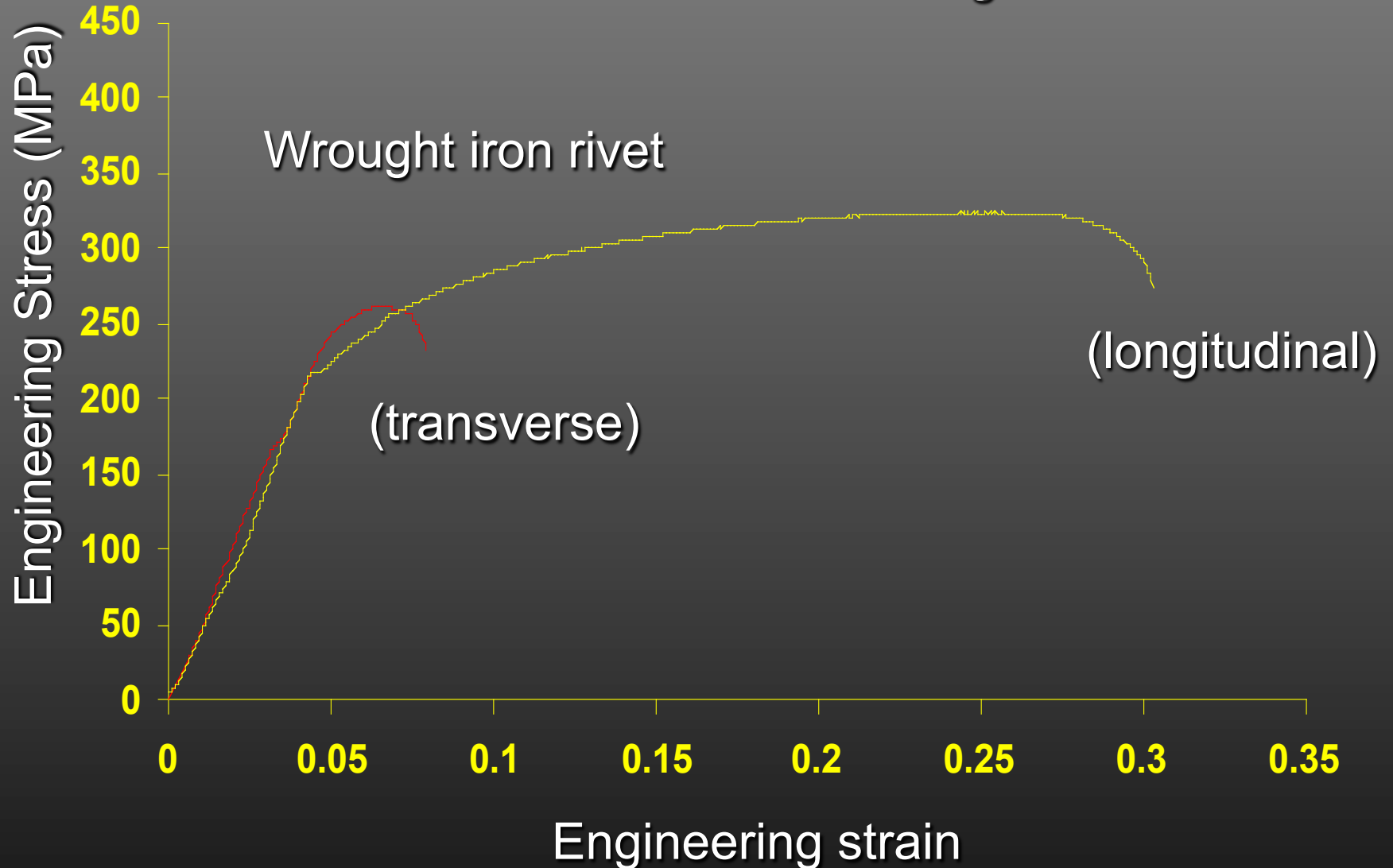
Mechanical Testing

Variations among Titanic wrought iron, Titanic rivet steel and comparison material were studied as a function of:

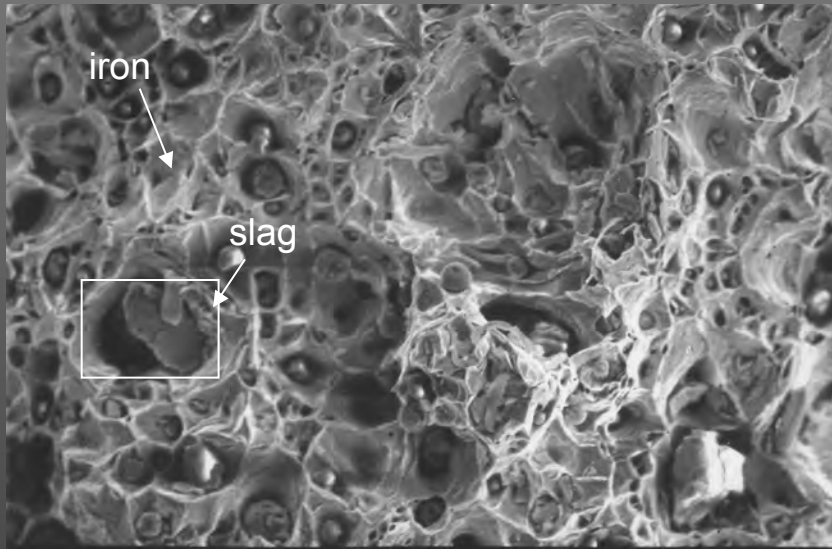
- material
- orientation
- slag area percent
- slag aspect ratio

Rivet Mechanical Properties

Uniaxial Tensile Testing



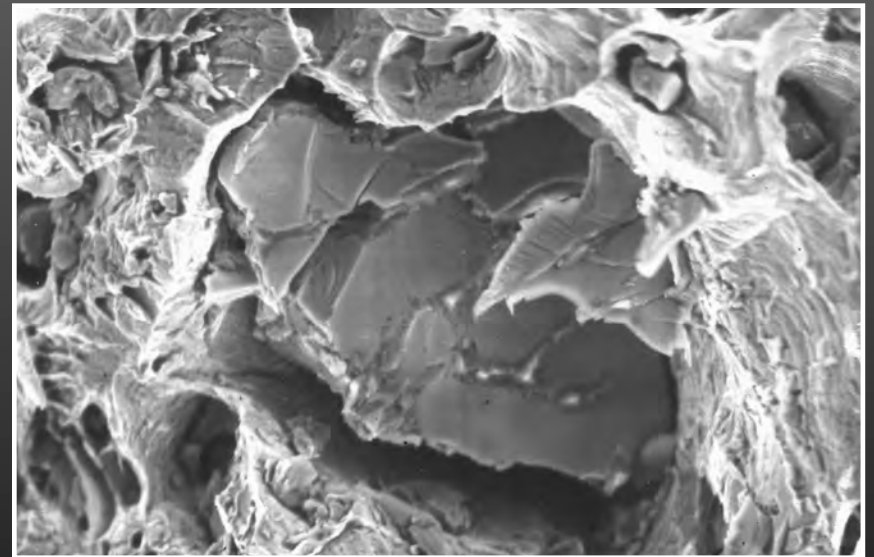
Rivet Mechanical Properties



— 10 μ m

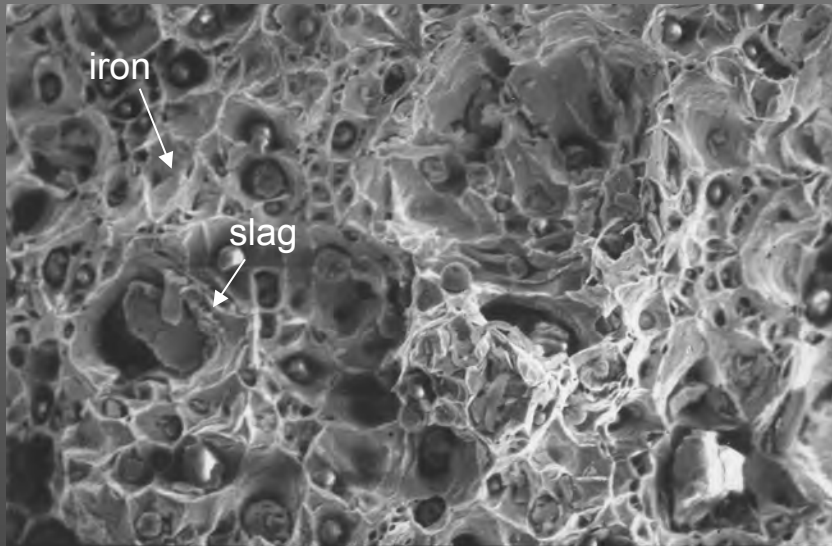
Longitudinal Orientation

Wrought Iron



— 10 μ m

Rivet Mechanical Properties

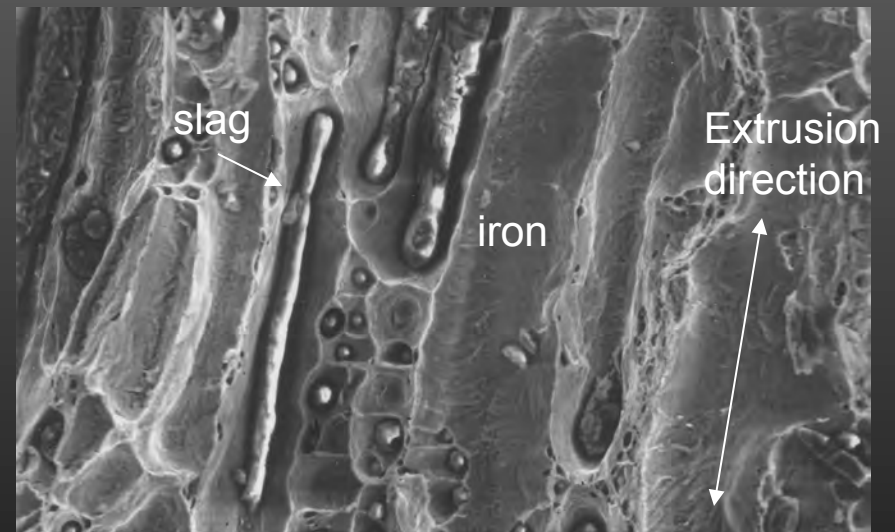


— 10 μ m

Longitudinal Orientation

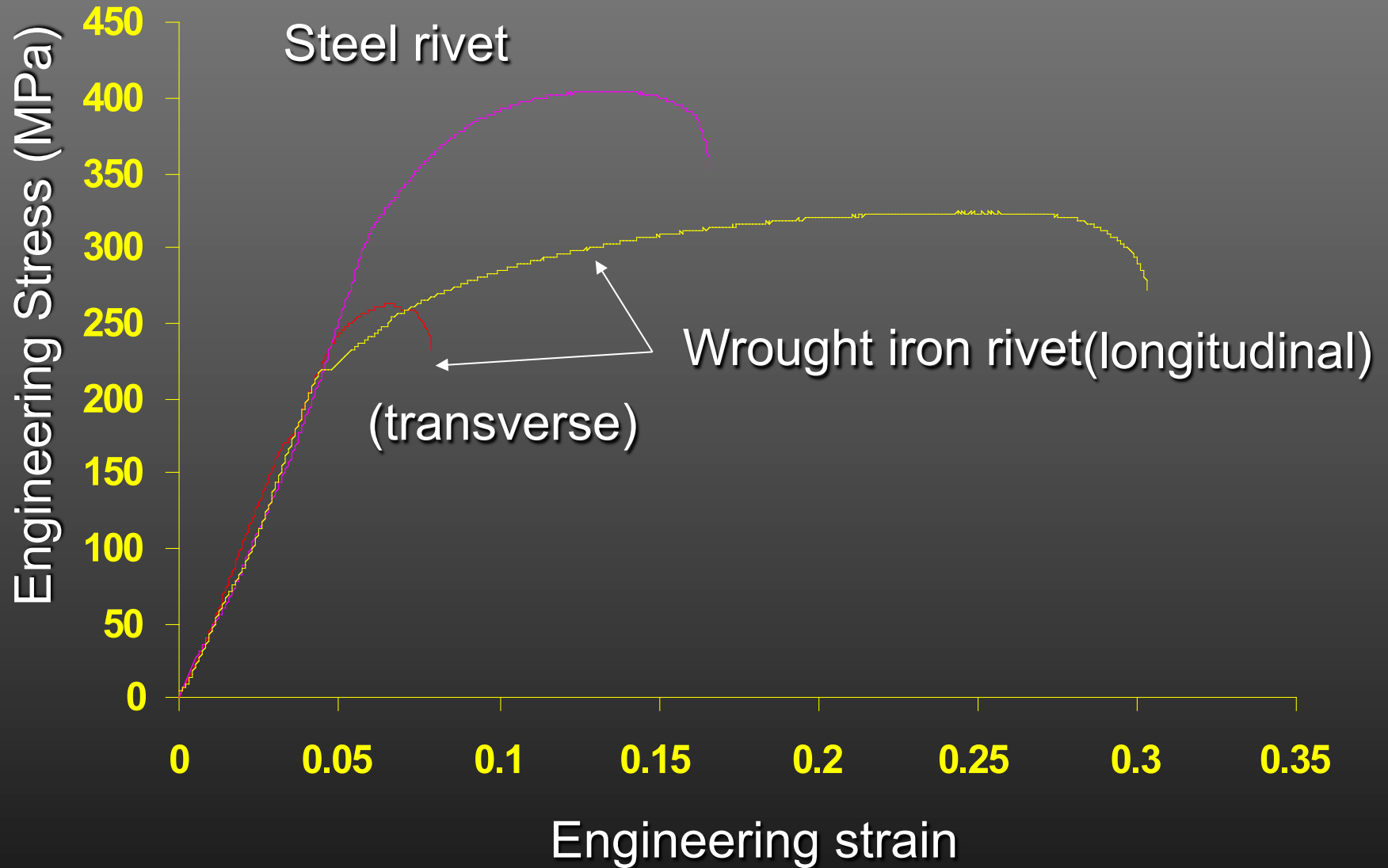
Wrought Iron

Transverse Orientation

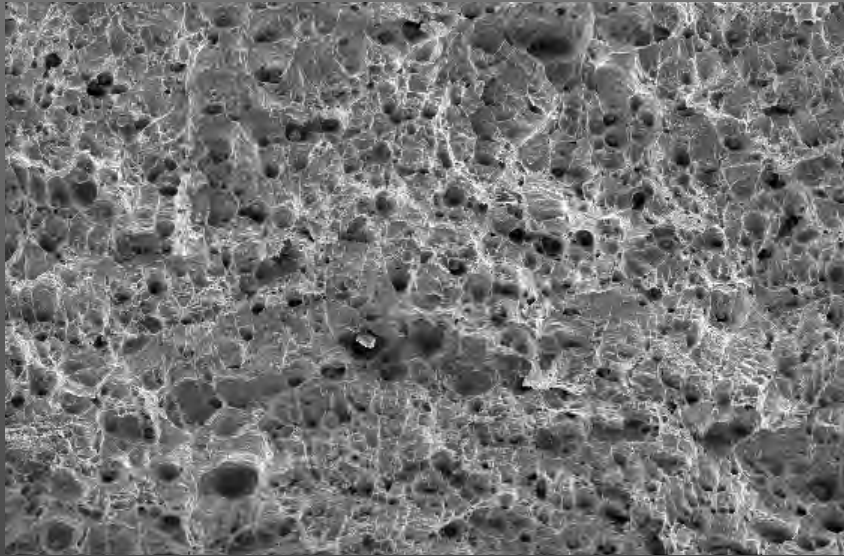


— 10 μ m

Rivet Mechanical Properties



Rivet Mechanical Properties



100 μ m

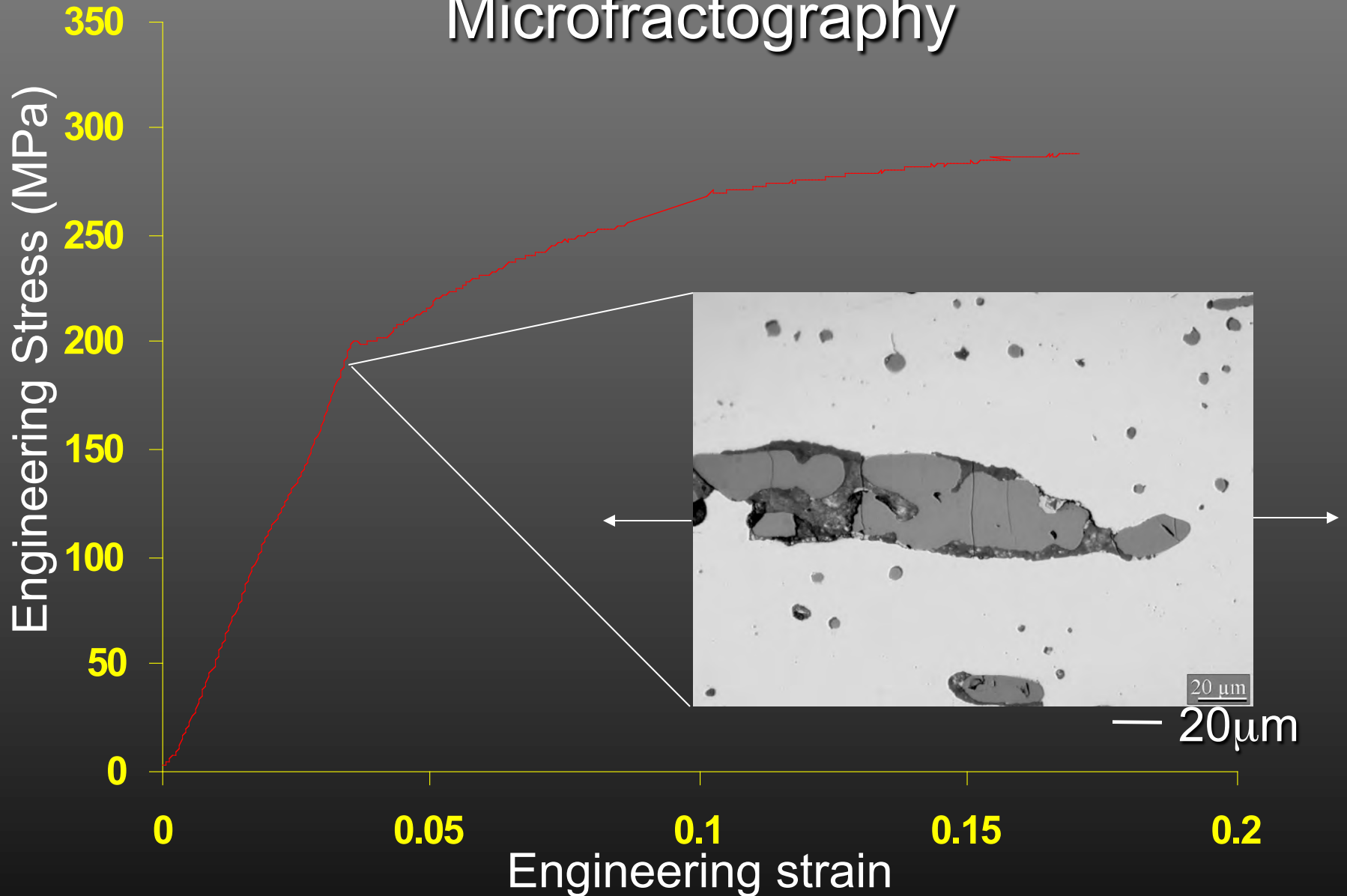
Low-carbon steel



10 μ m

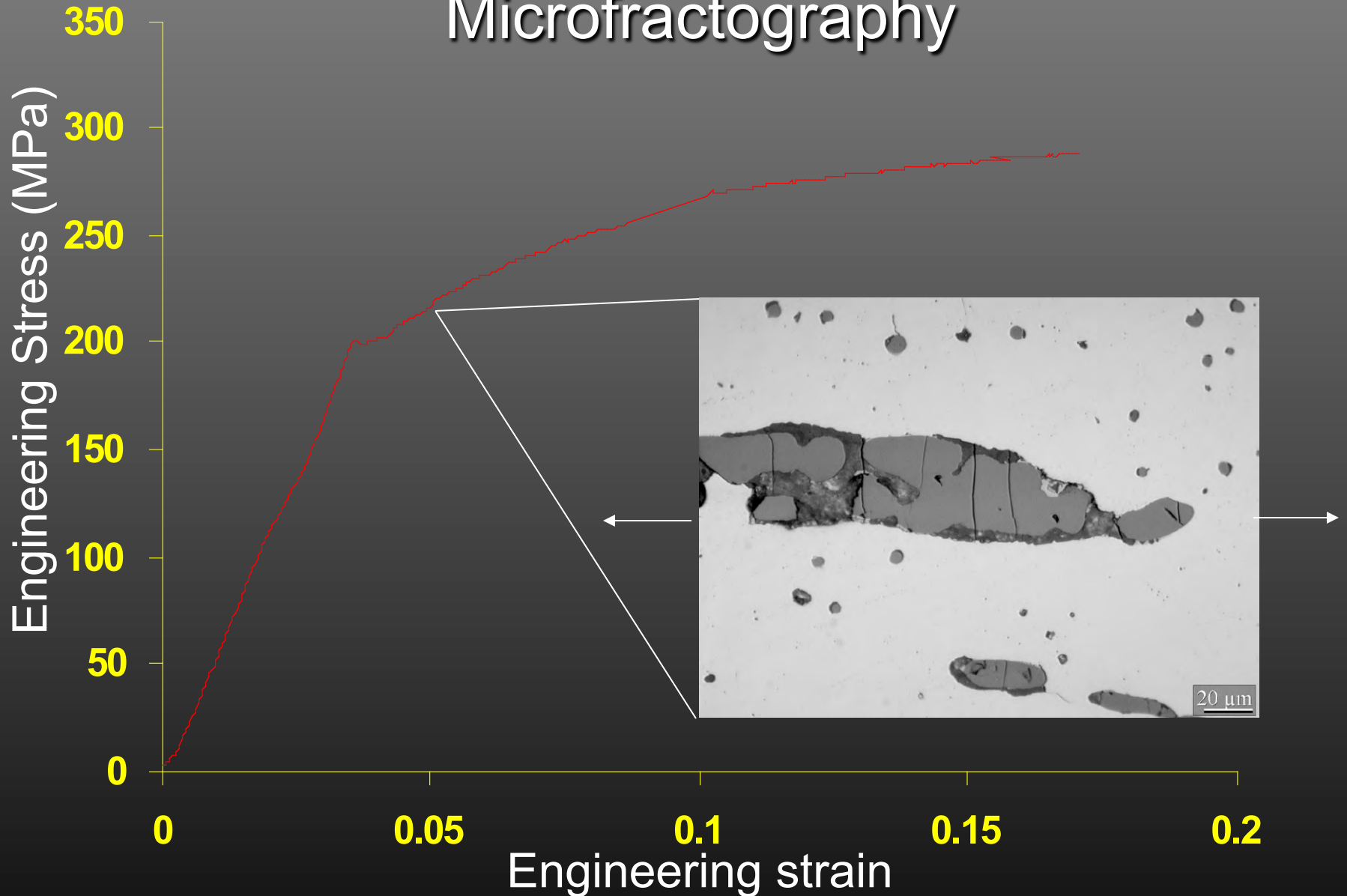
Fracture Strength of Slag

Microfractography



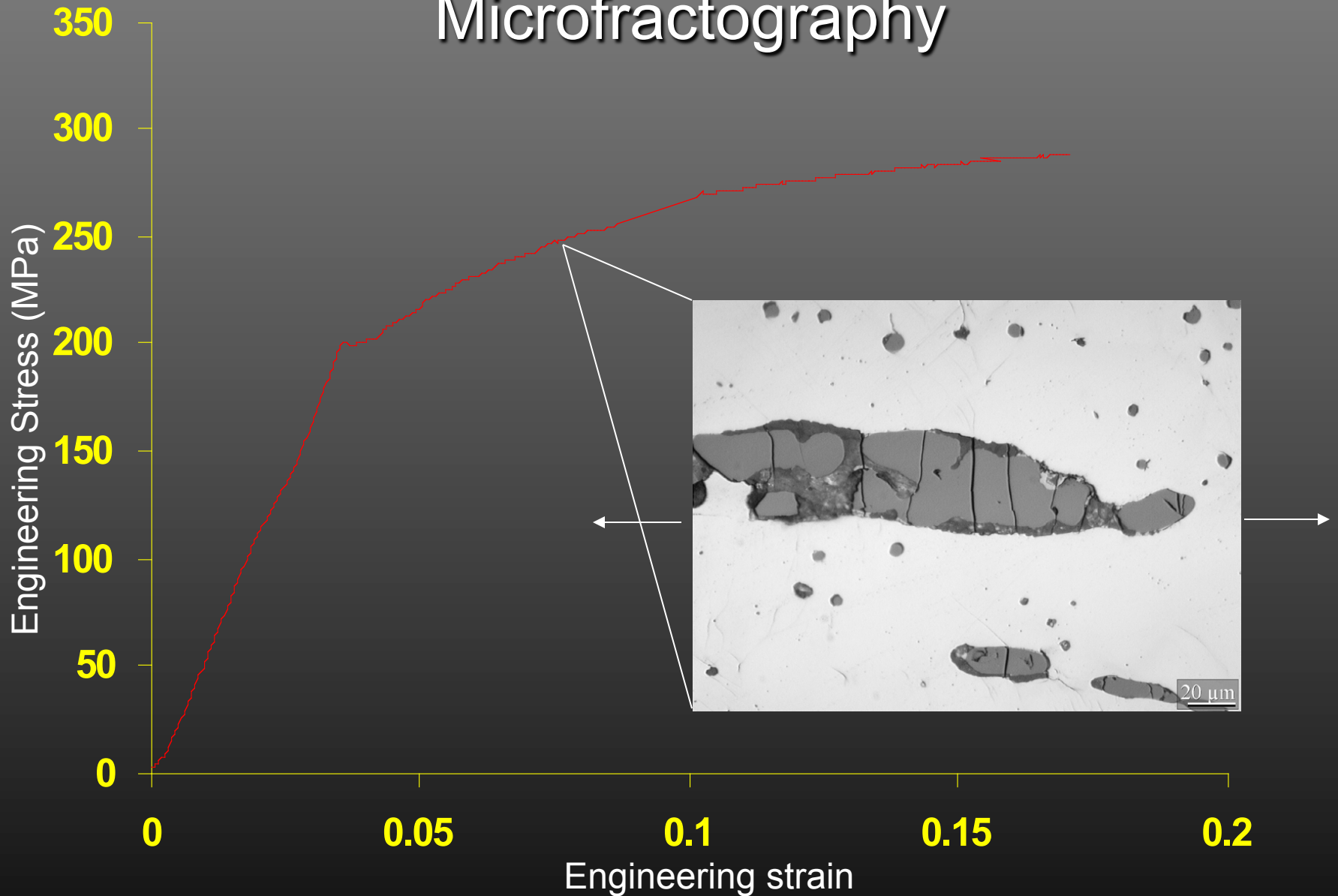
Fracture Strength of Slag

Microfractography



Fracture Strength of Slag

Microfractography



Fracture Strength of Slag

Microfractography

