METALLOGRAPHY AND FRACTOGRAPHY OF IRON AND STEEL

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**METALLOGRAPHY**

Study of the microstructure of metals. It also gives information concerning the properties and processing history of ferrous materials.

- Fundamentals
- Equipment
- Procedures

**FRACTOGRAPHY**

Morphologic study of fracture surfaces for interpreting and identifying the causes of fracture.

- Fundamentals
- Basic procedures
- Fracture morphology
- Crack origin
- Microscopic features
Major types of ferrous alloys (based on carbon content):

- wrought iron with less than 0.08% of carbon
- steel with carbon content less than 2%
- cast irons with carbon content higher than 1.7%

FERROUS PHYSICAL METALLURGY

- Iron-carbon phase diagram
  - Stability regions of the phases in ferrous materials at near equilibrium conditions
    - Ferrite
    - Austenite
    - Cementite
    - Graphite
  - Allotropic changes of iron
    - FCC (face centered cubic crystal) austenite
    - BCC (body centered cubic crystal) α-ferrite

- Kinetics of phase transformations
  - Departure from near equilibrium

Example:
- Slow cooling of a hypoeutectoid steel with 0.4% C
  - Austenite until 785 °C
  - 785 °C - 727 °C transformation of austenite to ferrite
  - At 727 °C the remaining austenite transforms through the eutectoid reaction to ferrite + cementite (pearlite)
MAJOR CONSTITUENTS OF FERROUS ALLOYS

- Cementite (hard; brittle) - wear resistance
- Pearlite - strength and hardness (but degrade toughness and formability)
- Martensite - strength (partially lost during tempering to restore ductility)
- Bainite – strength and toughness
- Austenite - ductility

MICROSTRUCTURE – MATERIAL PROPERTIES
COURSE
Testing techniques for structures inspection 29th and 30th May 2012

METALLOGRAPHIC LABORATORY

• Specimen preparation area
  • equipment to cut or shear, ...
• Polishing/etching area
  • mounting press, grinding devices, ...
• Observation area
  • metallurgical microscope, other equipments, such as SEM, TEM, ...

• METALLURGICAL MICROSCOPE: upright or inverted – specimen below or upside down above the objective
  • Mechanical – moving the specimen or focusing the image (stage and scales, and the coarse- and fine-focus knobs)
  • Optical – objective (controls magnification, numerical aperture, resolving power, depth of field, and working distance) and ocular (magnify the image produced by the objective)
  • Illumination – light source, condenser lens, and half-mirror

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METALLOGRAPHIC PROCEDURES

• information gathering including the history and chemical composition of a material
• sectioning to extract appropriate size specimens for analysis
• mounting in a polymeric material or in a metal clamp
• grinding to remove the plastic deformation induced by sectioning
• polishing to remove all traces of deformation
• etching to reveal the microstructure (surface relief - changes in light reflectivity)
• Nital, picral and respective variations – most common chemical etchants
• examination
### Changes in Microstructure

- **Intentionally altered**
  - heat treatment
  - deformation (hot and cold working)

- **Unintentionally changed**
  - improper heat treatment (e.g. decarburization, sensitization)
  - service conditions (e.g. corrosion effects such as graphitization, hydrogen damage)

### BS EN 10247:2007 – Micrographic examination of the non-metallic inclusion content of steels using standard pictures.


### BS EN ISO 643:2003 – Steels — Micrographic determination of the apparent grain size.
MACROGRAPHY | MICROGRAPHY

e.g. corrosion and welding effects: plate - ferrite+pearlite; bolt - bainite

FRACTOGRAPHIC PROCEDURES

- Information gathering concerning service conditions, material characteristics, and fracture incident details
- Preliminary visual examination of fracture surfaces and adjacent areas
- Selection, preservation, and cleaning of fracture surfaces
- Macroscopic examination of fracture surfaces, secondary cracking, and surface condition
- Selection and preparation of specimens for further examination and testing
- Microscopic examination
- Complementary testing: nondestructive testing, and mechanical and chemical testing
- Identification of failure mechanisms
- Testing to simulate failure
- Data analysis, formulation of conclusions, and reporting
FRACTURE MORPHOLOGY

- Fracture sequence: crack initiation, crack propagation, and fast fracture
- Revealing marks enable differentiating the different areas and, therefore, identify the conditions leading to fracture
  - fibrous zone
  - radial zone
  - shear-lip zone

- Fracture surface features result from various factors, such as:
  - specimen shape and size
  - microstructure
  - mechanical properties
  - environmental and stress conditions

Differences in fibrous and radial zones depending on section thickness (rectangular).

FRACTURE CLASSIFICATION

- different criteria
  - macroscopic plastic strain significant or small - ductile or brittle
  - crack propagation path along grain boundaries or through grains - intergranular or transgranular
  - microscopic mechanisms, such as: cleavage, microvoid coalescence, quasicleavage, ...

Differences in fibrous and radial zones depending on section thickness (rectangular).
CHARACTERISTIC DUCTILE AND BRITTLE FRACTURES

- In a ductile material, cracking in tension originates near the center of the specimen and propagates toward the surface, the shear stress causing considerable deformation prior to fracture.
- In a brittle material, a single overloaded fracture shows little permanent deformation and is roughly perpendicular to the tensile stress direction. In absence of a stress concentration, the stress distribution is uniform across the section and, thus, fracture can originate at any location.

CRACK ORIGIN

- Features that point to the crack origin
  - radial marks lie perpendicular to the crack front and thus radiate and point to the origin
  - apexes of the V-shape chevron patterns point to the fracture origin
  - origin on concave side of fibrous or beach marks
- Typical features related with crack propagation
- Reassembling the fragments - fracture sequencing (strain mismatch)
- Examination of the external surface for secondary cracks
- Surface notches - alter the position of the crack origin, the direction of crack growth, and the sequence of fracture-zone features
The most common categories of microscopic fracture features include:

- cleavage (tongues, microtwins, and crack origins) – transgranular path, crystallographic well defined
- quasicleavage (cleavage facets not clearly identified as crystallographic planes)
- dimples from microvoid coalescence - microvoids initiated at interfaces between the matrix and particles or discontinuities expand and coalesce to form the dimples
- fatigue striations
- separated grain facets
- mixed fracture features