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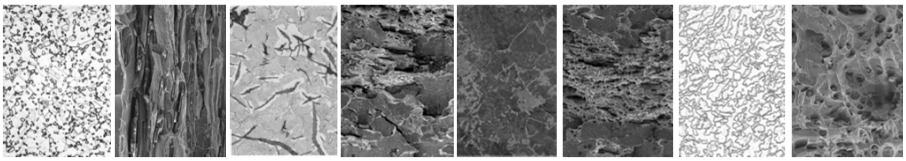

METALLOGRAPHY AND FRACTOGRAPHY OF IRON AND STEEL

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METALLOGRAPHY

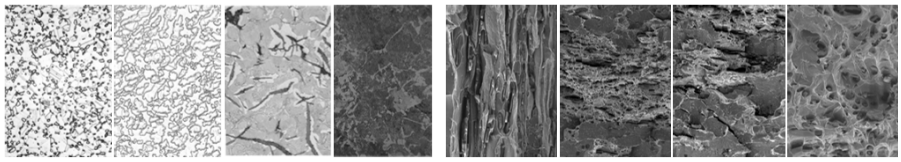
Study of the microstructure of metals. It also gives information concerning the properties and processing history of ferrous materials.

- **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**



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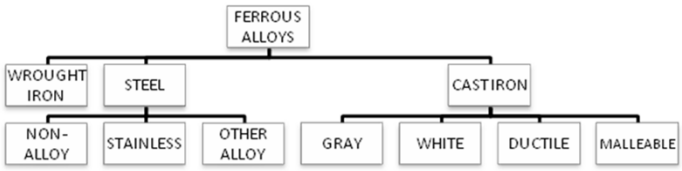
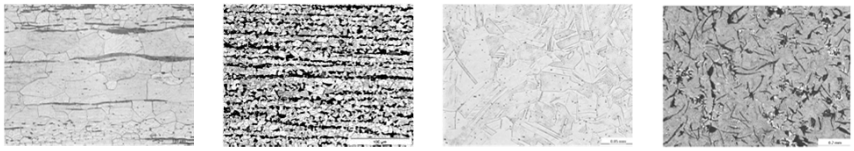
FERROUS ALLOYS





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 %

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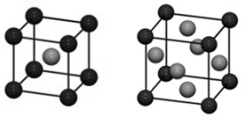
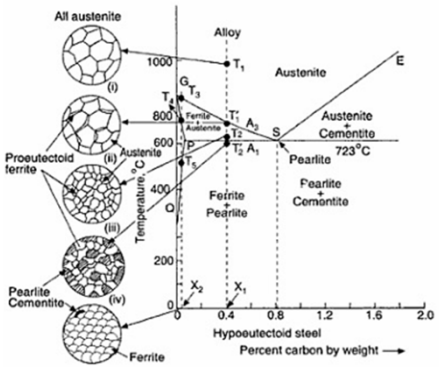
FERROUS PHYSICAL METALLURGY

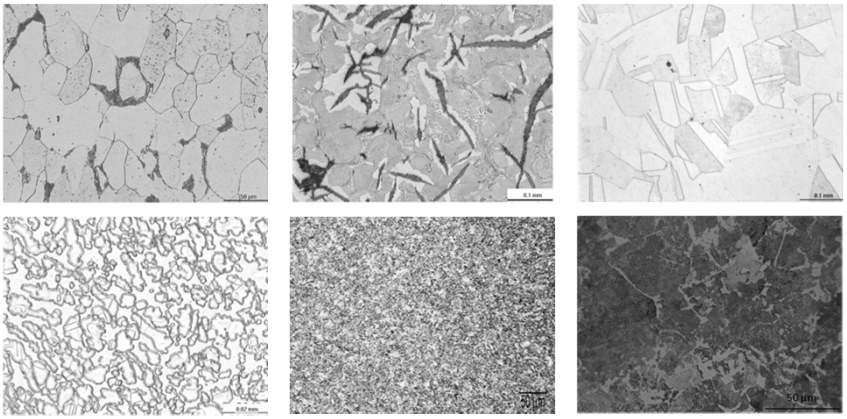
- **iron-carbon phase diagram**
  - Stability regions of the phases in ferrous materials at near equilibrium conditions
    - Ferrite
    - Austenite
    - Cementite
    - Graphite
  - Allotropic changes of iron
    - FCC (face centered cubic crystal) austenite
    - BCC (body centered cubic crystal)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





- e.g.: slow cooling of a hypoeutectoid steel with 0.4% C
  - austenite until 785 ºC
  - 785 ºC -727 ºC transformation of austenite to ferrite
  - at 727 ºC the remaining austenite transforms through the eutectoid reaction to ferrite + cementite (pearlite)

MAJOR CONSTITUENTS OF FERROUS ALLOYS



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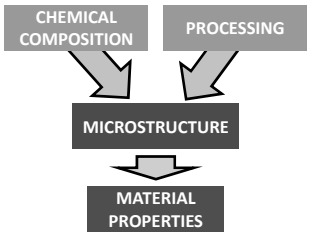
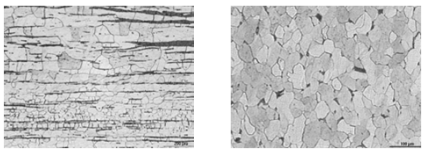
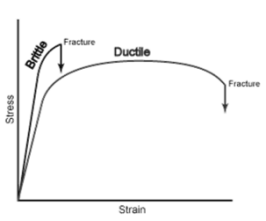
MICROSTRUCTURE – MATERIAL PROPERTIES

- 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







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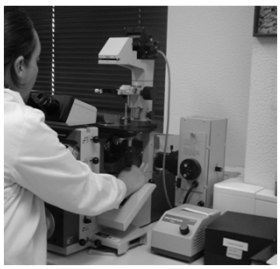
METALLOGRAPHIC LABORATORY

- **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 commom chemical etchants
- **examination**

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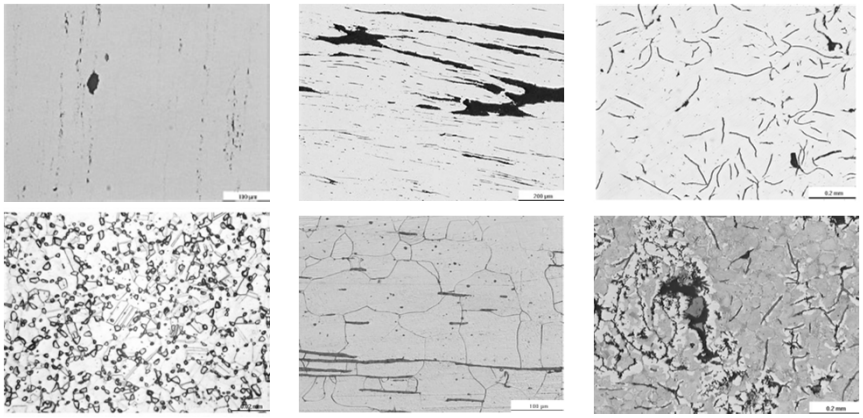
MICROGRAPHIC EXAMINATION



BS EN 10247:2007 – Micrographic examination of the non-metallic inclusion content of steels using standard pictures.
BS EN ISO 945-1:2008 - Microstructure of cast irons. Part 1: Graphite classification by visual analysis.
BS EN ISO 643:2003 - Steels — Micrographic determination of the apparent grain size.

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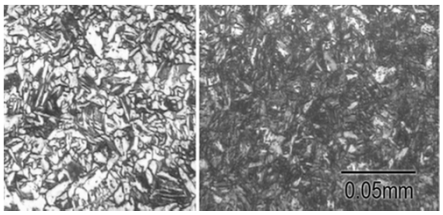
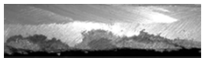
CHANGES IN MICROSTRUCTURE

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

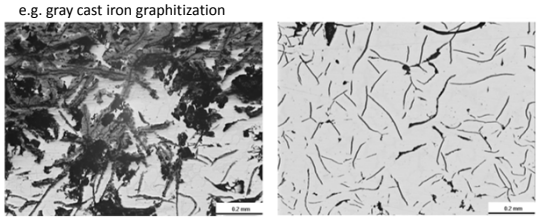
e.g. thermomechanical treatment: core – ferrite+perlite; rim - tempered martensite



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



e.g. gray cast iron graphitization



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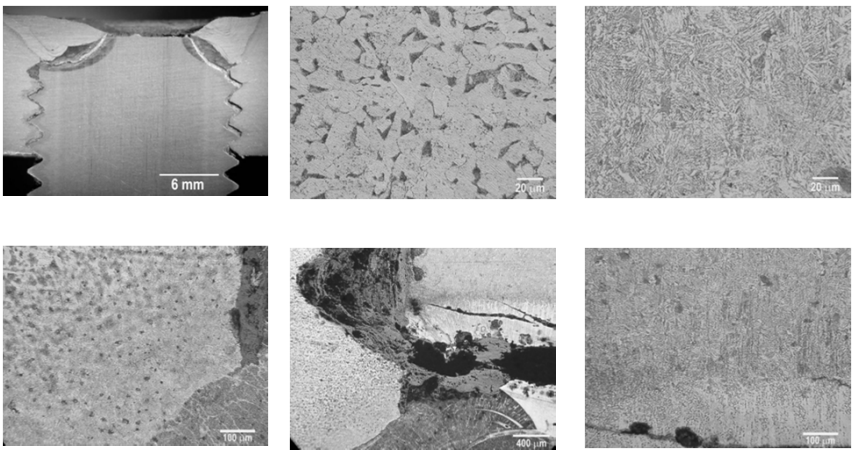
MACROGRAPHY|MICROGRAPHY



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

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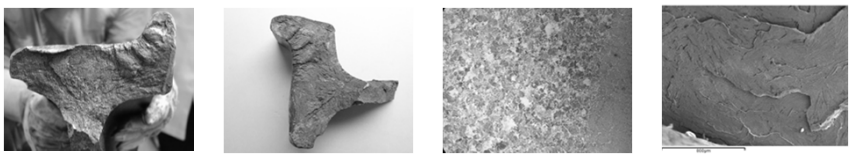
FRACTOGRAPHIC PROCEDURES



- **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**

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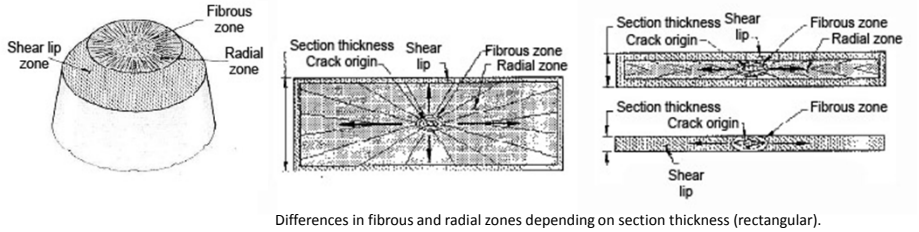
FRACTURE MORPHOLOGY

- 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).

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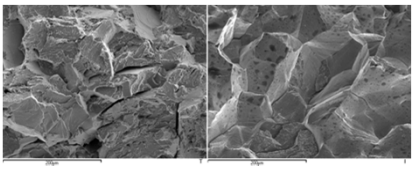
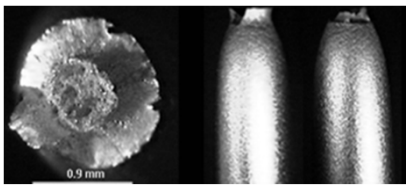
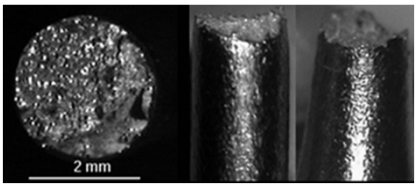
FRACTURE CLASSIFICATION

- 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,** …







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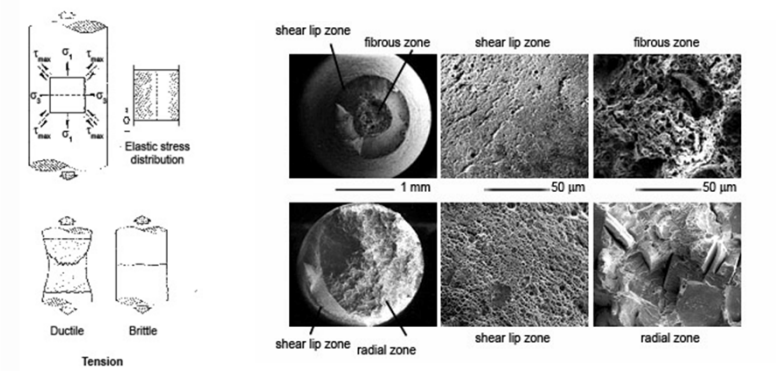
CHARACTERISTIC DUCTILE AND BRITTLE FRACTURES

- 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.



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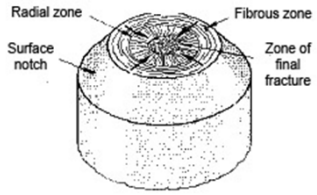
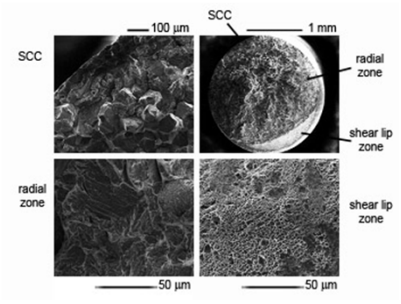
CRACK ORIGIN

- 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





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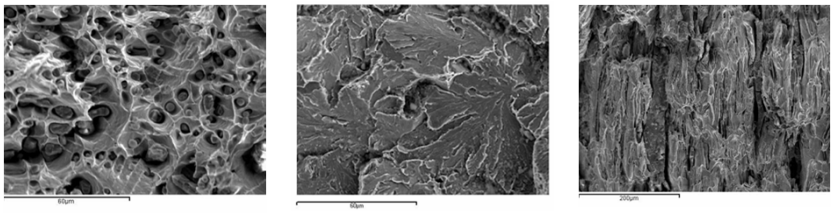
MICROSCOPIC FEATURES



- 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

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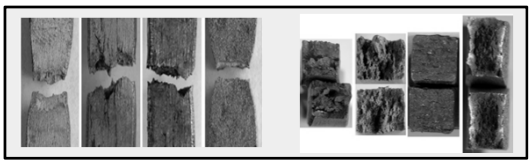
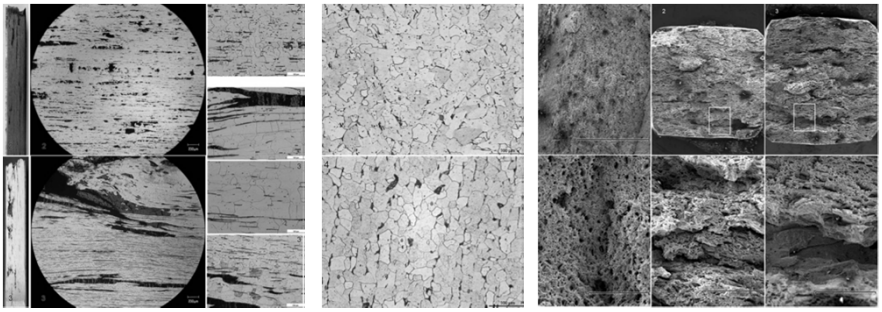
PRACTICE





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