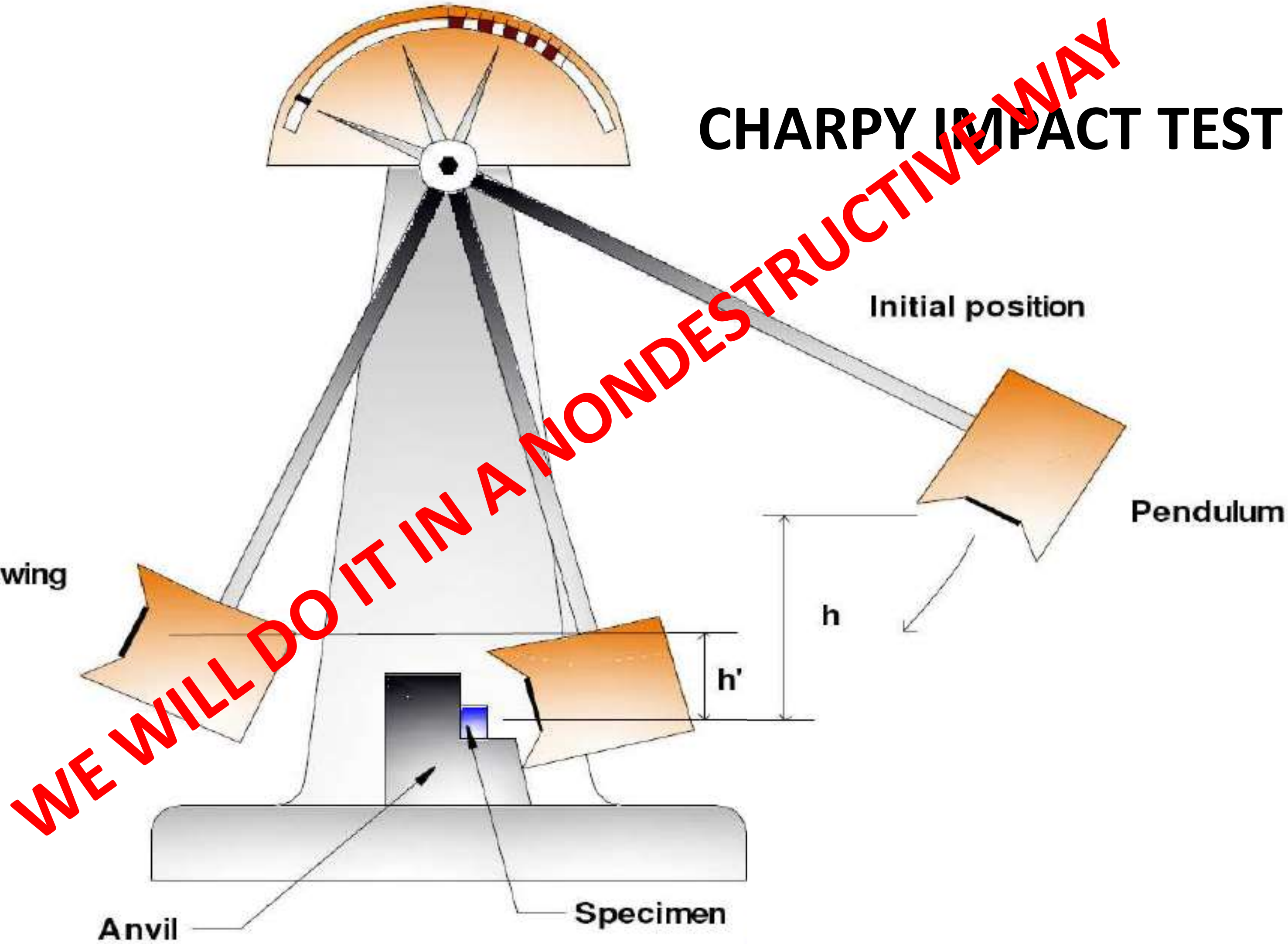
MATERIAL CHARACTERIZATION

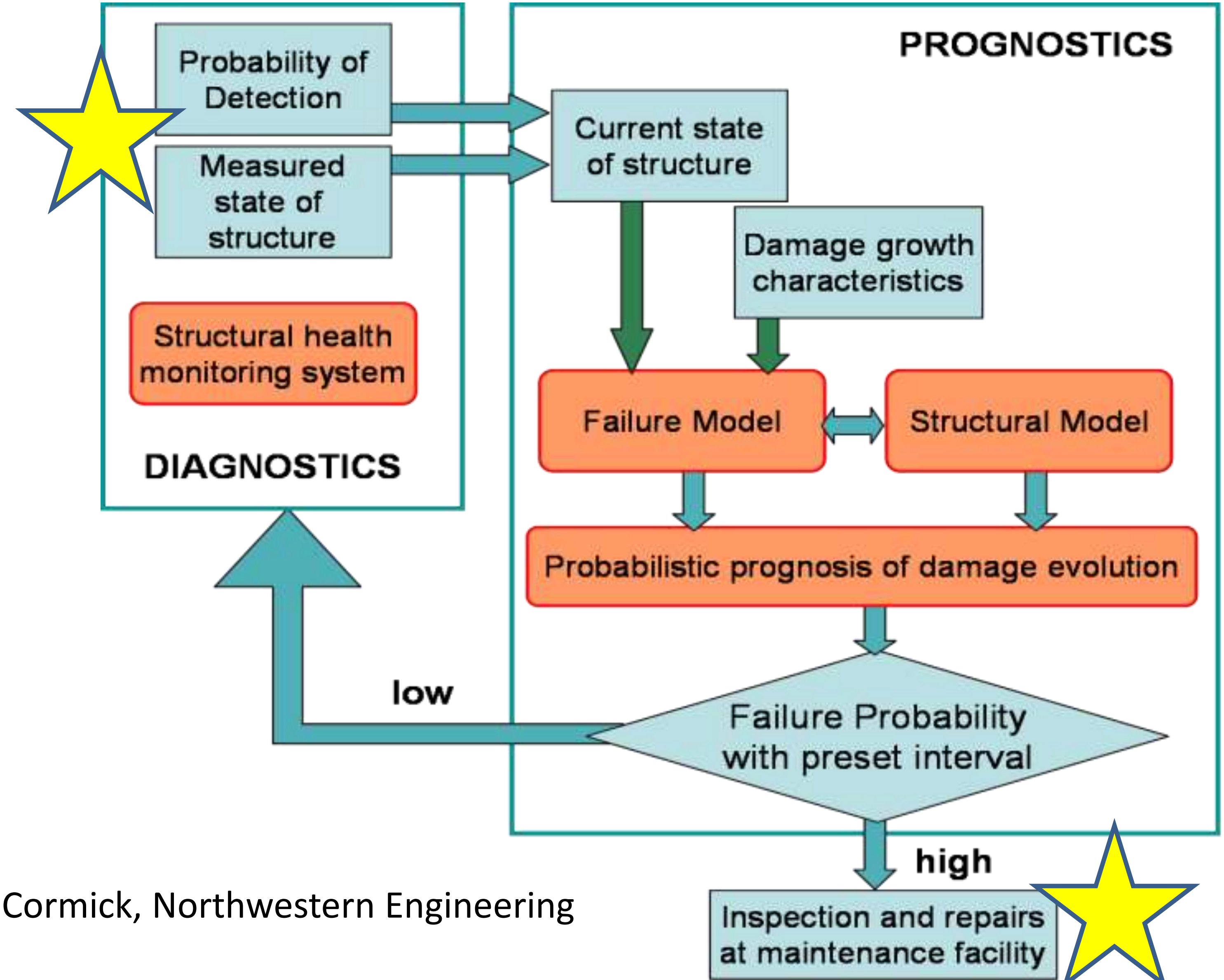
CHARPY IMPACT TEST



MATERIAL CHARACTERIZATION

4.	**Mitigation Strategies – The world is never perfect**
4.1.	Structure Design and NDT
4.2.	Application of NDT
4.3.	Limits of NDT
4.4.	Quantitative NDT
4.5.	Material Characterization
4.6.	Case Study – Inspection by Cause

Remaining Life



Mc Cormick, Northwestern Engineering

MATERIAL CHARACTERIZATION

NDT beyond the location and identification of defects:

Material Characterization – the Measurement of physical and mechanical properties of materials

NDC

Nondestructive Characterization of Materials

MATERIAL CHARACTERIZATION

ROUGH PROBLEM STRUCTURE

PHYSICAL PROPERTIES

Density
Magnetic Properties
Electric Properties
Thermal Properties
Optical Properties

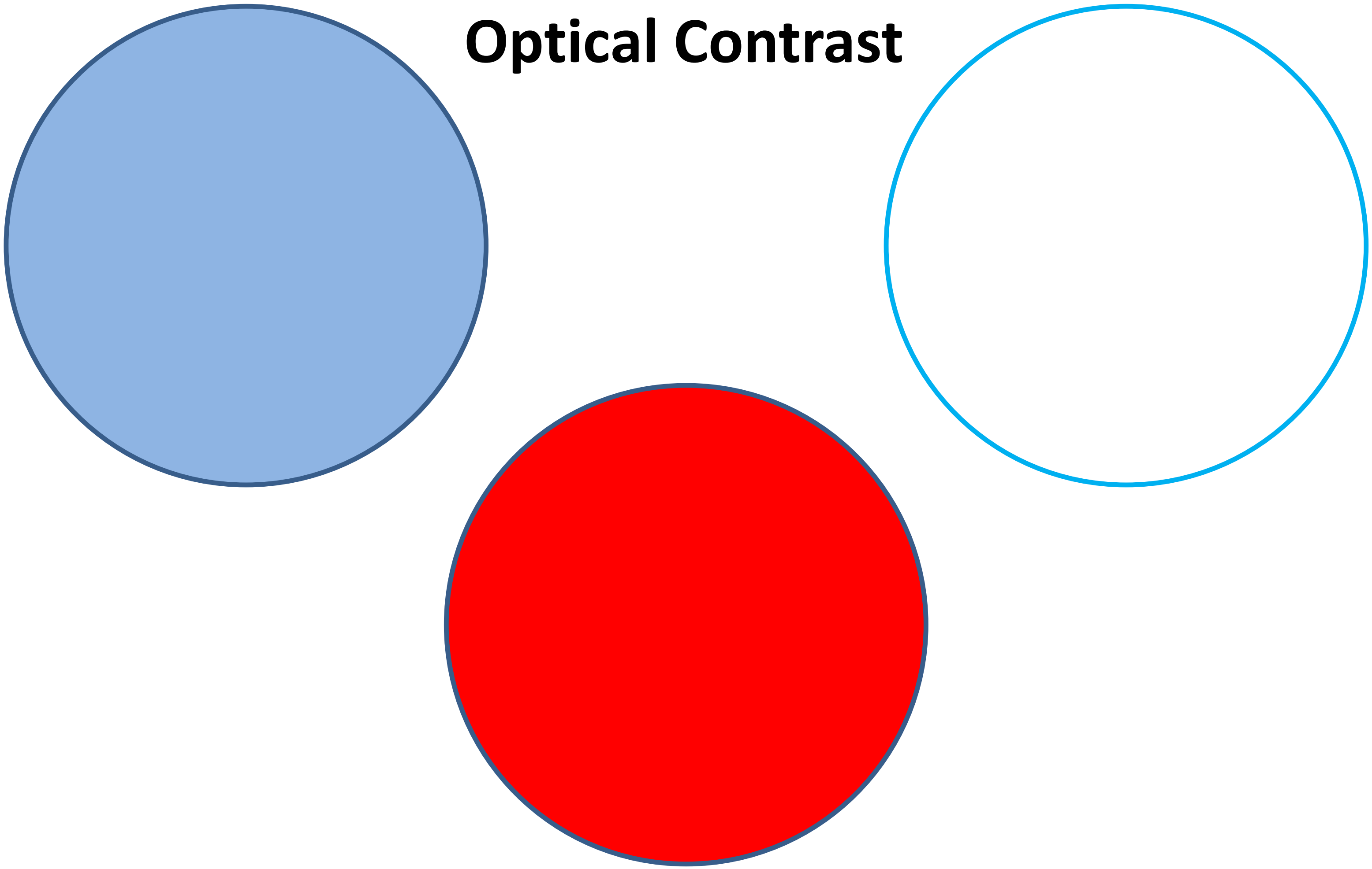
and many others

MECHANICAL PROPERTIES

Strength
Elastic Limit
Proportional Limit
Yield Strength
Ultimate Tensile Strength
True Fracture Strength
Ductility
Toughness
Fatigue Ratio
Loss Coefficient

PHYSICAL PROPERTIES

Optical Contrast



PHYSICAL PROPERTIES

BY DEFINITION,
NONDESTRUCTIVE TESTING MEASURES PHYSICAL PROPERTIES

There are many useful applications

- Material Identity Checks
- Sorting
- Waste Processing
- Dimension Control
-

However, it will become rather sophisticated when we need insight into the material structure

Optical Sorting Equipment (Waste Separation)

CP Manufacturing

MECHANICAL PROPERTIES

Strength; Hardness
Elastic Limit
Proportional Limit
Yield Strength
Ultimate Tensile Strength
True Fracture Strength
Ductility
Toughness
Loss Coefficient

DEFINED
BY
MECHANICAL TESTS
AS
STANDARDS
FOR
MATERIAL SPECIFICATIONS

PROBLEM DIMENSION

- **Nondestructive Methods measure physical properties**

- **Physical Properties Must correlate with Mechanical properties**

NDC CONCEPTS

RESOLUTION

Macroscopic Measurements
Meso-Methods
Microscopic Measurements

CONTRAST

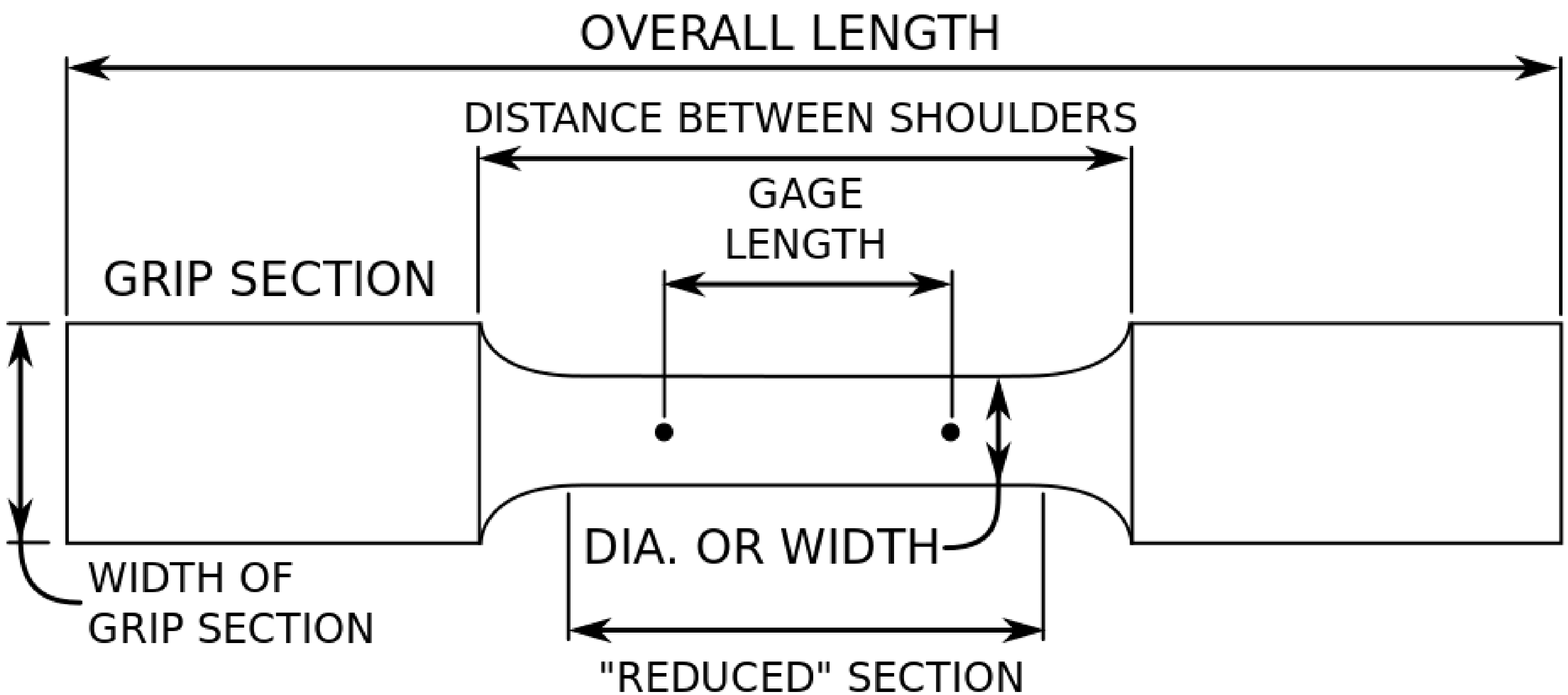
Local Changes of Properties
Meso-Methods
Uniform Properties

CORRELATION

Parameter Space
Statistics

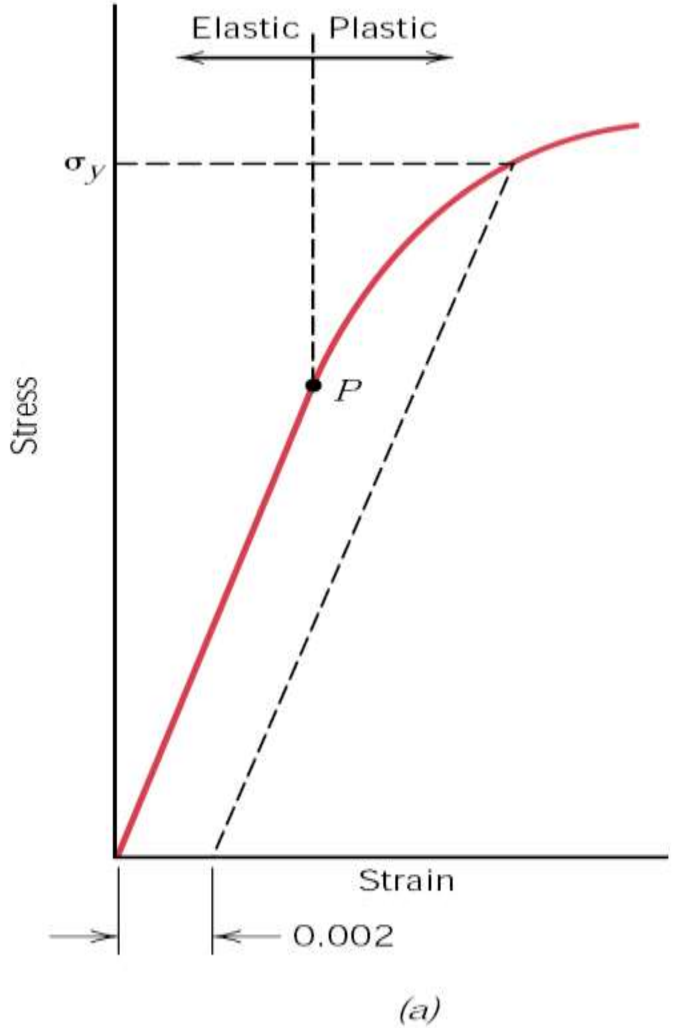
A Matter of Research

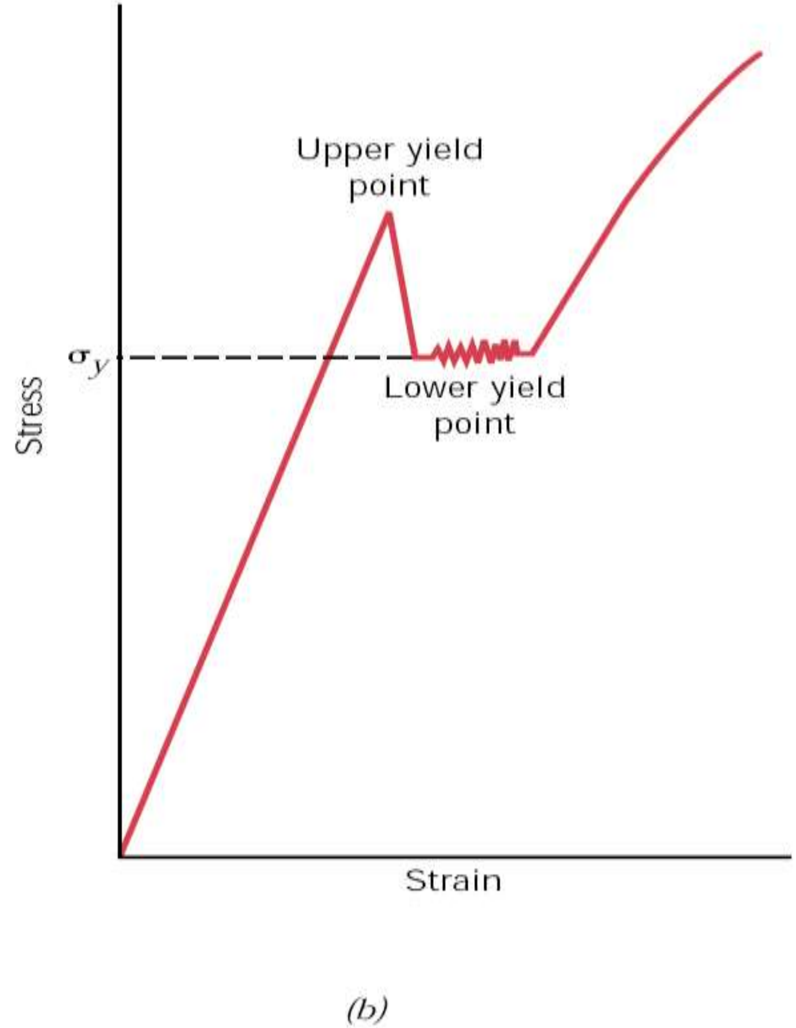
MECHANICAL PROPERTIES – TENSILE TEST



TENSILE TEST SPECIMEN

MECHANICAL PROPERTIES – TENSILE TEST

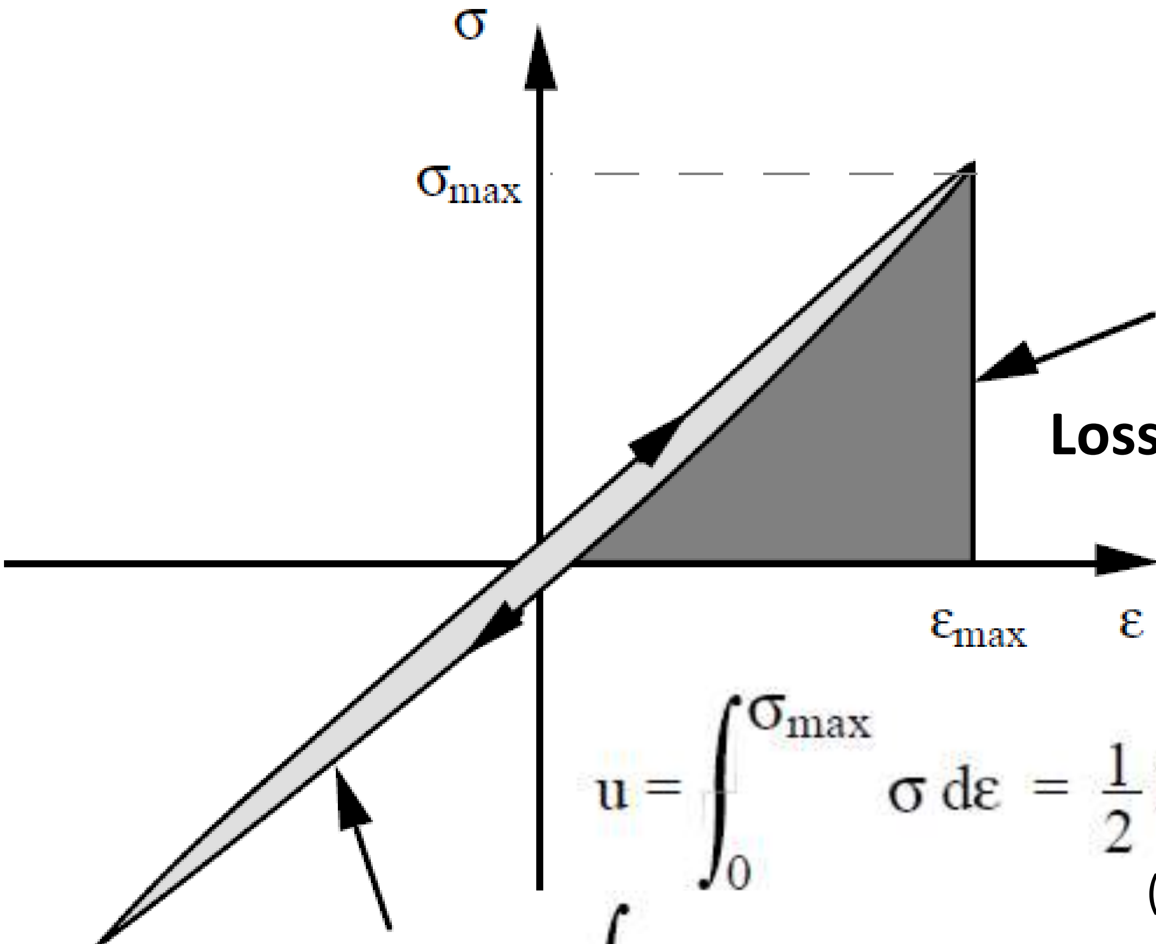




typical stress-strain curve for a metal.

Stress-strain curve for a material exhibiting the yield point phenomenon

MECHANICAL PROPERTIES – LOSS COEFFICIENT
MATERIAL DAMPING (Energy Dissipation)



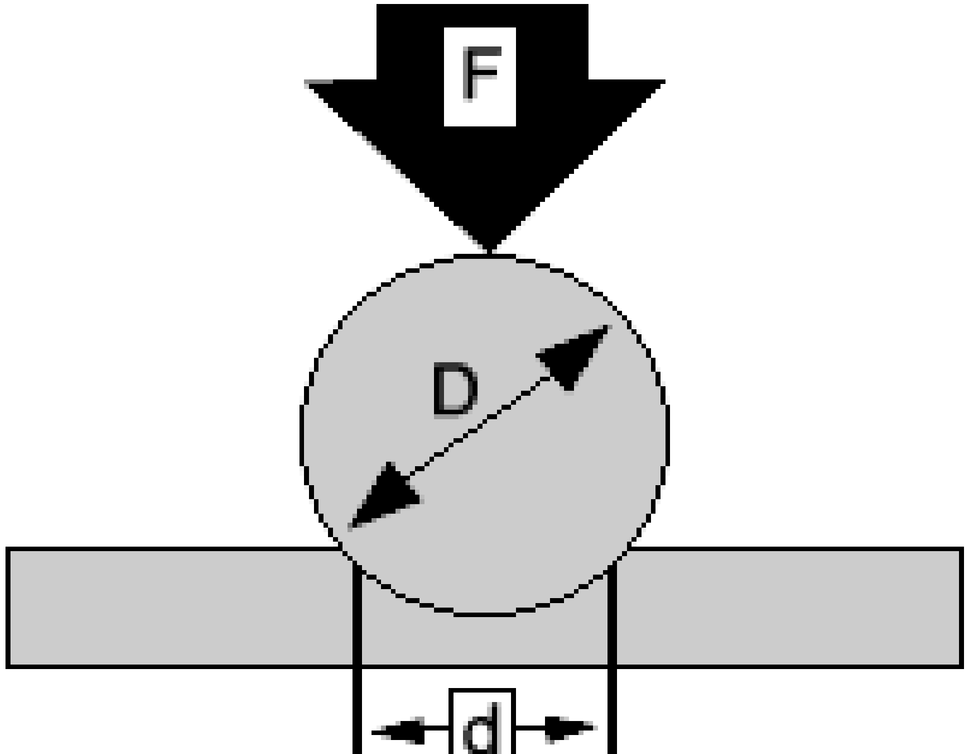
Loss Coefficient $\eta = \frac{\Delta u}{2\pi\, u}$

$$u = \int_0^{\sigma_{max}} \sigma \, d\varepsilon = \frac{1}{2} E \, \varepsilon_{max}^2$$

(E: Young’s modulus)

$$\text{Area} = \Delta u = \oint \sigma \, d\varepsilon$$

MECHANICAL PROPERTIES – HARDNESS TEST

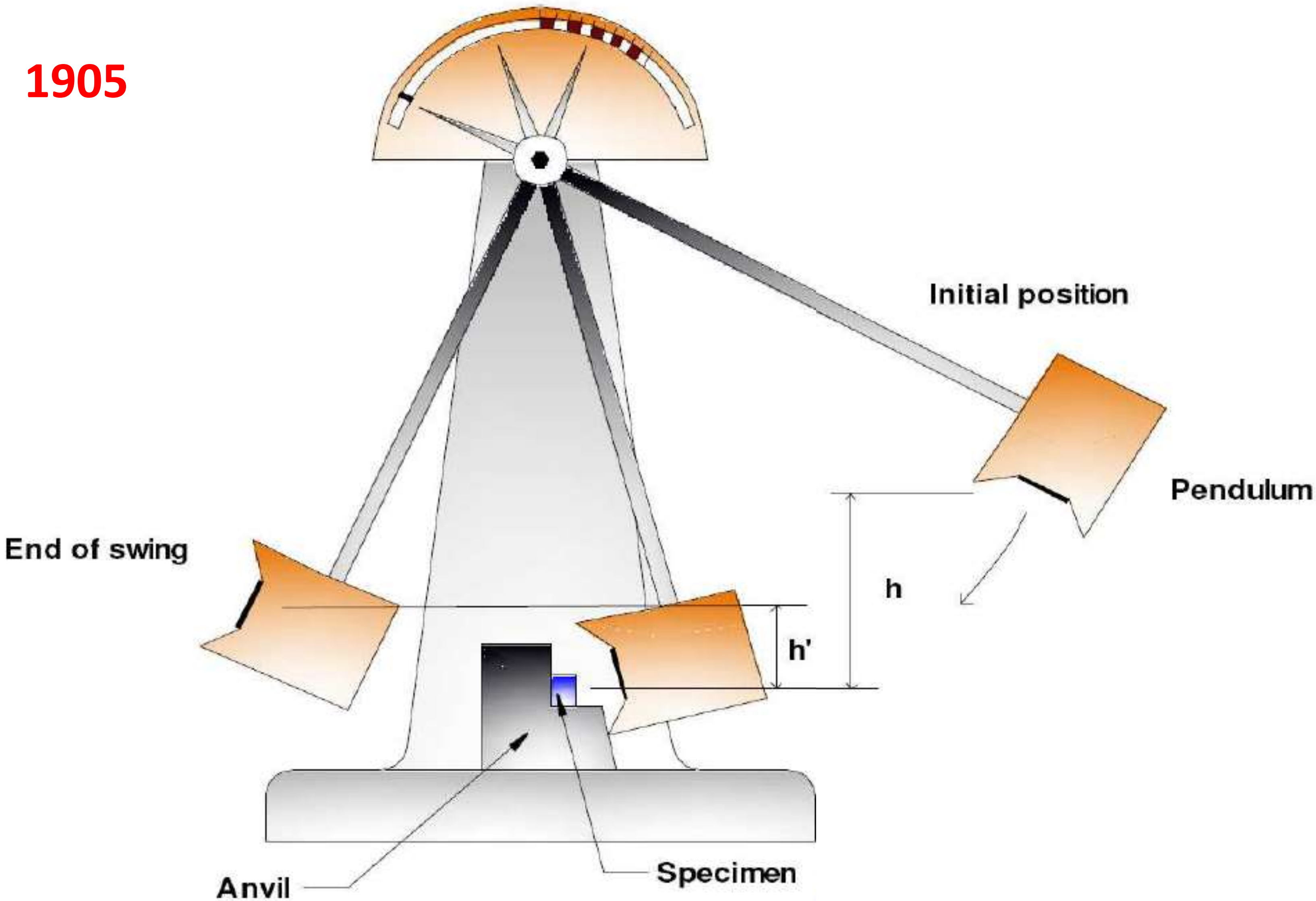


$$HB = \frac{2F}{\pi D\left(D - \sqrt{(D-d)}\right)}$$

MECHANICAL PROPERTIES – CHARPY IMPACT TEST

From 2

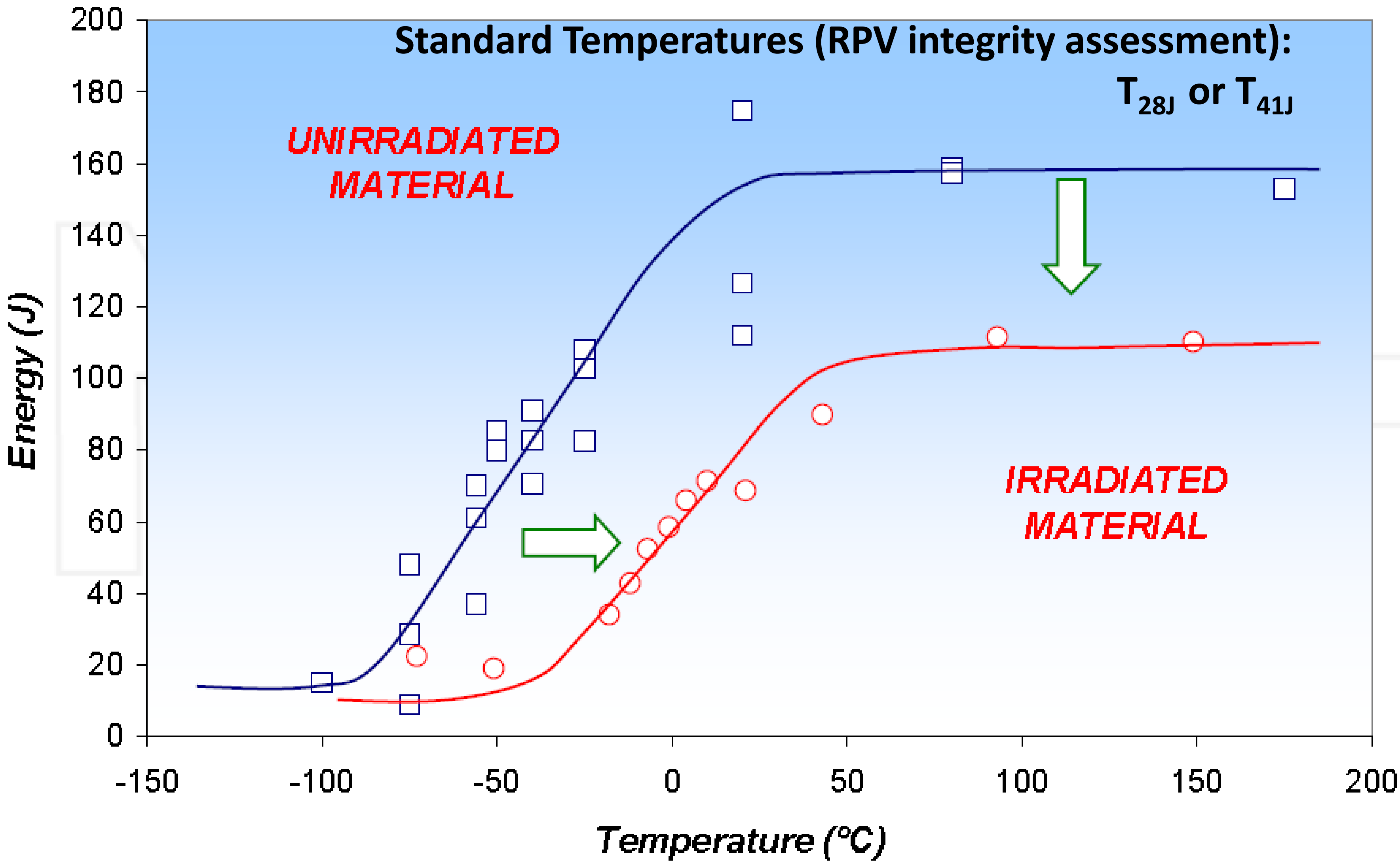
1905



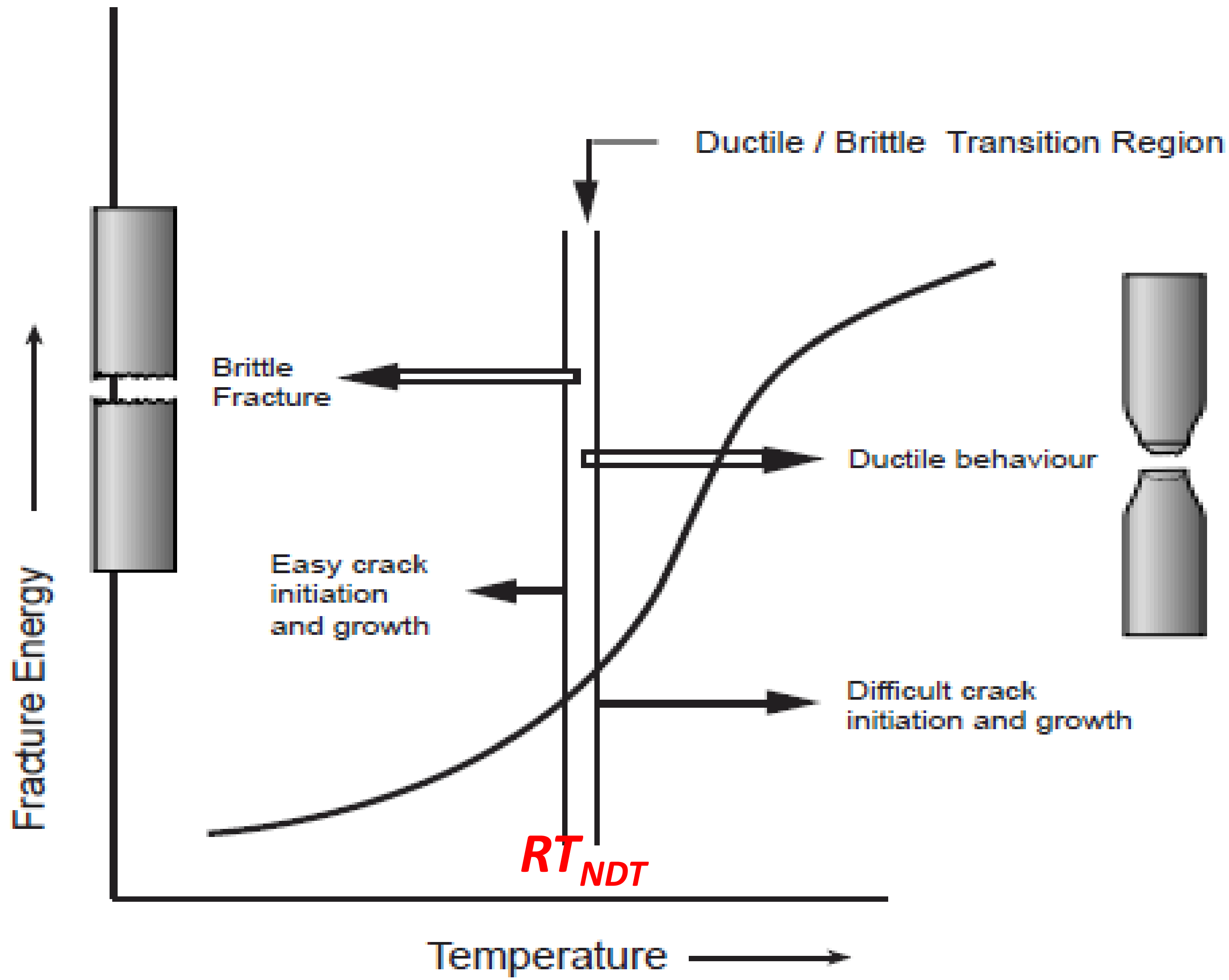
Sketch of the Charpy pendulum

MECHANICAL PROPERTIES – CHARPY IMPACT TEST

Effect of Irradiation on Charpy Curves



MECHANICAL PROPERTIES – REFERENCE TEMPERATURE



Strength

Strength has several definitions depending on the material type and application.
Material class and mode of loading are important when designing for strength.

For metals the most common measure of strength is the yield strength.

Strength, for ceramics however, is the compressive failure strength.
Failure in ceramics is highly dependent on the mode of loading.
The typical failure strength in compression
is fifteen times the failure strength in tension.

WHY?

Elastic Limit

The elastic limit is the highest stress at which all deformation strains are fully recoverable.

For most materials and applications this can be considered the practical limit to the maximum stress a component can withstand and still function as designed. Beyond the elastic limit permanent strains are likely to deform the material to the point where its function is impaired.

Proportional Limit

The proportional limit is the highest stress at which stress is linearly proportional to strain. This is the same as the elastic limit for most materials.

Some materials may show a slight deviation from proportionality while still under recoverable strain. In these cases the proportional limit is preferred as a maximum stress level because deformation becomes less predictable above it.

Yield Strength

The yield strength is the minimum stress which produces permanent plastic deformation. This is perhaps the most common material property reported for structural materials because of the ease and relative accuracy of its measurement. The yield strength is usually defined at a specific amount of plastic strain, or offset, which may vary by material and or specification. The offset is the amount that the stress-strain curve deviates from the linear elastic line. The most common offset for structural metals is 0.2%.

Ultimate Tensile Strength

The ultimate tensile strength is an engineering value calculated by dividing the maximum load on a material experienced during a tensile test by the initial cross section of the test sample. When viewed in light of the other tensile test data the ultimate tensile strength helps to provide a good indication of a material's toughness but is not by itself a useful design limit.

Conversely this can be construed as the minimum stress that is necessary to ensure the failure of a material.

True Fracture Strength

The true fracture strength is the load at fracture divided by the cross sectional area of the sample. Like the ultimate tensile strength the true fracture strength can help an engineer to predict the behavior of the material but is not itself a practical strength limit.

Because the tensile test seeks to standardize variables such as specimen geometry, strain rate and uniformity of stress it can be considered a kind of best case scenario of failure.

Ductility

Ductility is a measure of how much deformation or strain a material can withstand before breaking. The most common measure of ductility is the percentage of change in length of a tensile sample after breaking.

This is generally reported as % El or percent elongation. The reduction of area RA of the sample also gives some indication of ductility.

Toughness

Toughness describes a material's resistance to fracture.
The most common test for toughness is the Charpy impact test.
It is often expressed in terms of the amount of energy
a material can absorb before fracture.
Tough materials can absorb a considerable amount of energy before fracture
while brittle materials absorb very little.

Neither strong materials such as glass or very ductile materials such as taffy
can absorb large amounts of energy before failure.
Toughness is not a single property but rather a combination of strength and ductility.
The toughness of a material can be related to the total area
under its stress-strain curve.
A comparison of the relative magnitudes of the yield strength,
ultimate tensile strength and percent elongation of different material
will give a good indication of their relative toughness.
Materials with high yield strength and high ductility have high toughness.

MECHANICAL PROPERTIES

Toughness

In crystalline materials the toughness is strongly dependent on crystal structure. Face centered cubic materials are typically ductile while hexagonal close packed materials tend to be brittle. Body centered cubic materials often display dramatic variation in the mode of failure with temperature.

In many materials the toughness is temperature dependent. Generally materials are more brittle at lower temperatures and more ductile at higher temperatures. The temperature at which the transition takes place is known as the DBTT, or ductile to brittle transition temperature.

Use of alloys below their transition temperature is avoided due to the risk of catastrophic failure.

Loss Coefficient

The loss coefficient is an other important material parameter in cyclic loading. It is the fraction of mechanical energy lost in a stress strain cycle.

The loss coefficient for each material is a function of the frequency of the cycle. A high loss coefficient can be desirable for damping vibrations while a low loss coefficient transmits energy more efficiently.

The loss coefficient is also an important factor in resisting fatigue failure. If the loss coefficient is too high, cyclic loading will dissipate energy into the material leading to fatigue failure.

Macroscopic Measurement

PHYSICAL PROPERTY ~ **MECHANICAL PROPERTY**

Electrical Conductivity (Eddy Current)

Magnetic Hardness (Barkhausen)

Sound Velocity (Rayleigh Waves)

→

Strength

Hardness

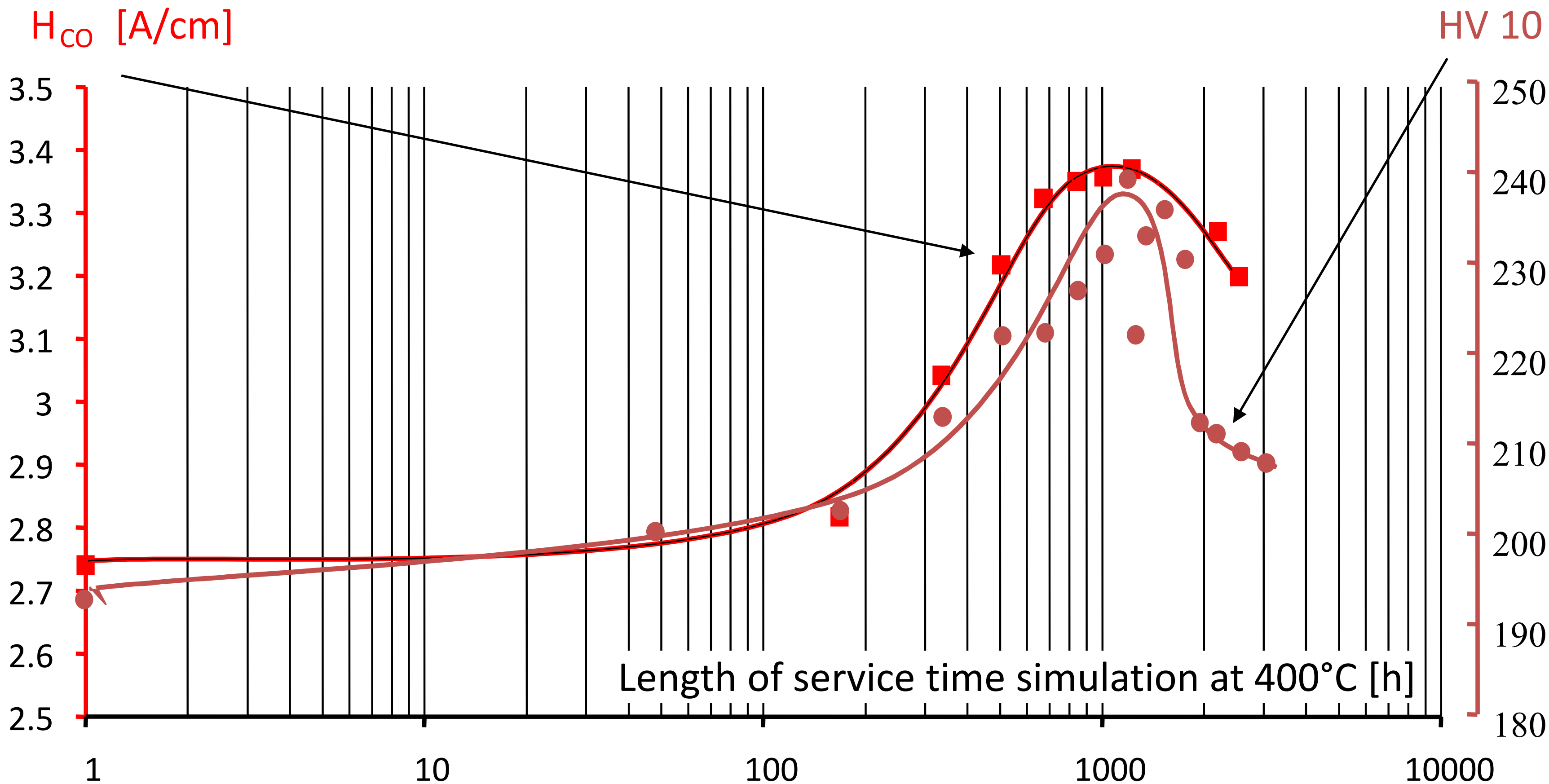
CORRELATION

Defined reference samples

Complexity of Approach
Validation

Confined material specification

NDC CONCEPTS



Analogy Between Mechanical and Magnetic Hardness

Meso - Measurement

PHYSICAL PROPERTY ~ **MECHANICAL PROPERTY**

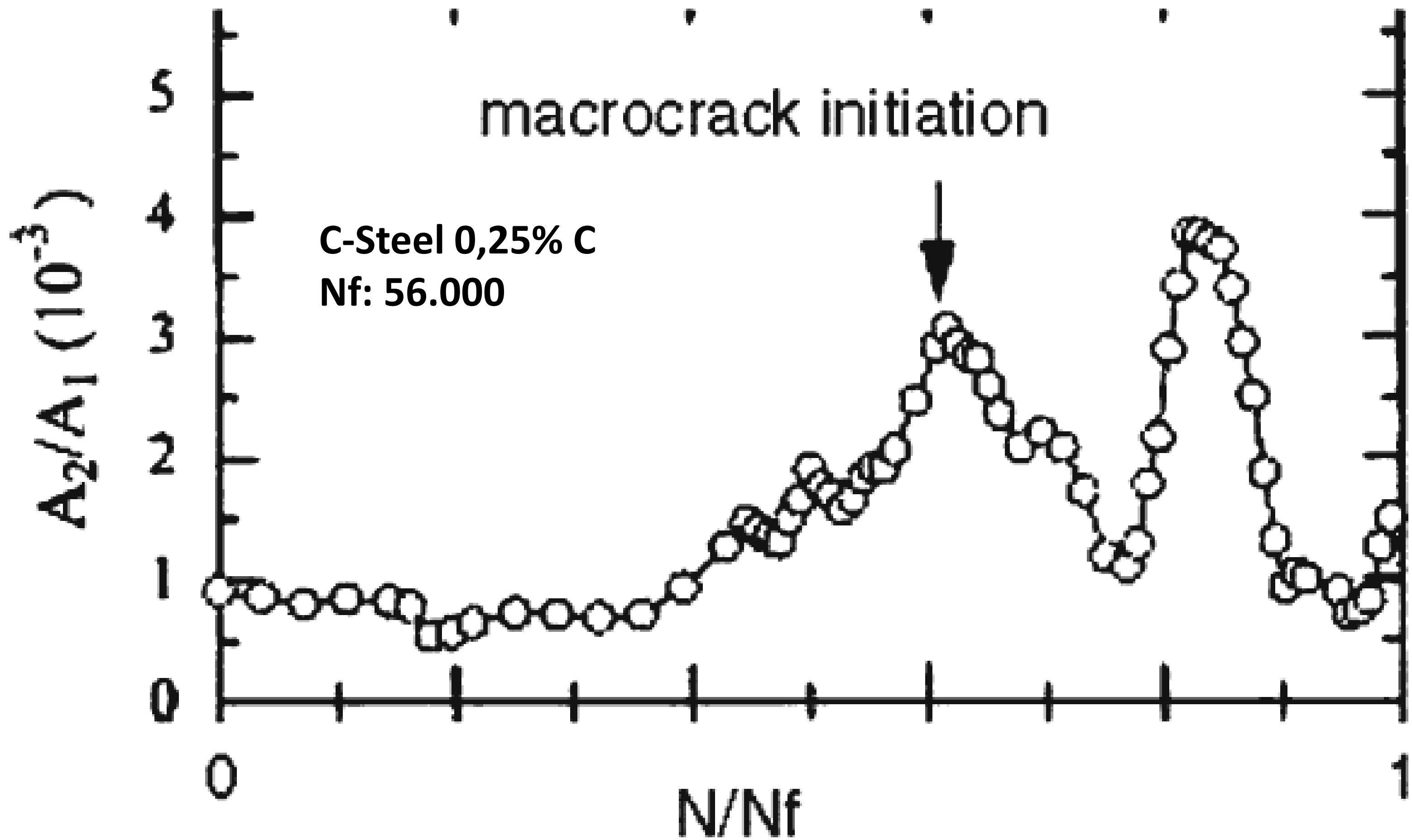
Absorption (non-linear ultrasound) → **Fatigue Evaluation**

CORRELATION

Macroscopic Measurement
of a
Specific Microstructure Effect

Confined specifics of material
Require often measurement
of Local Changes

Meso - Measurement



Y

CORRELATION: Evolution of Non-Linearity

Microscopic - Measurement

PHYSICAL PROPERTY ~ **MECHANICAL PROPERTY**

Micro-Tomography

It is NDC when mobile & applicable on components

Material Evaluation through Microstructure Evaluation

CORRELATION
(SIMULATION, MATERIAL LAWS)

Microscopic Measurement
of a
Specific Microstructure Effect

Confined specifics of material
require often measurement
of local changes

Microstructure Characterization

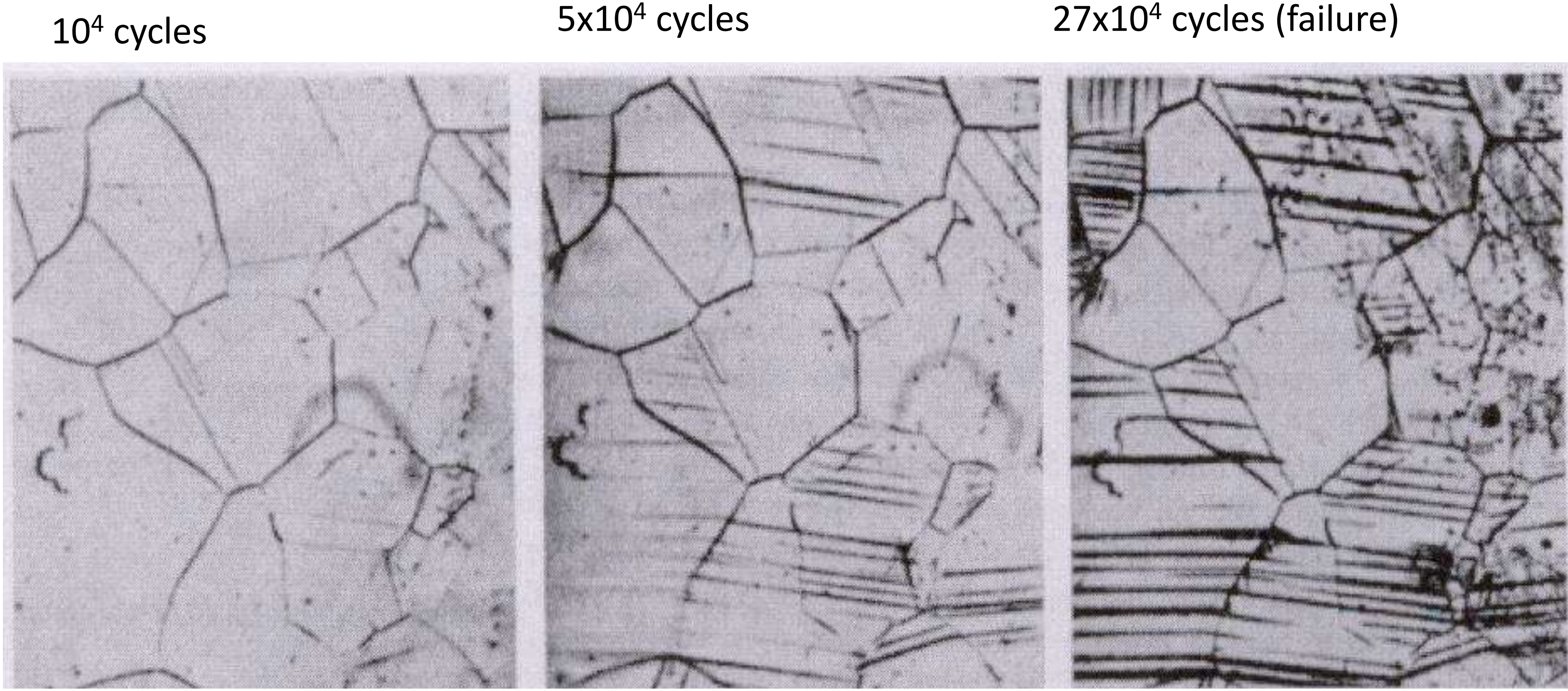
Traditional methods of microstructure analysis compare 2D micrographs to reference images. However, examining planar sections in such a way does not allow an objective assessment of the material internal structure and its properties due to the limited information accessible from this 2D data.

Advanced characterization techniques are capable of quantifying structural material features in a reasonably precise way. Depending on the size of microstructure constituents,

- **X-ray**
- **Synchrotron**
- **Positron Analysis**
- **Focused Ion Beam (FIB)**
- **Atom Probe Tomography (APT)**

can be used in order to characterize the microstructure and to understand its formation and influence on functionality of the material.

Microstructure Characterization

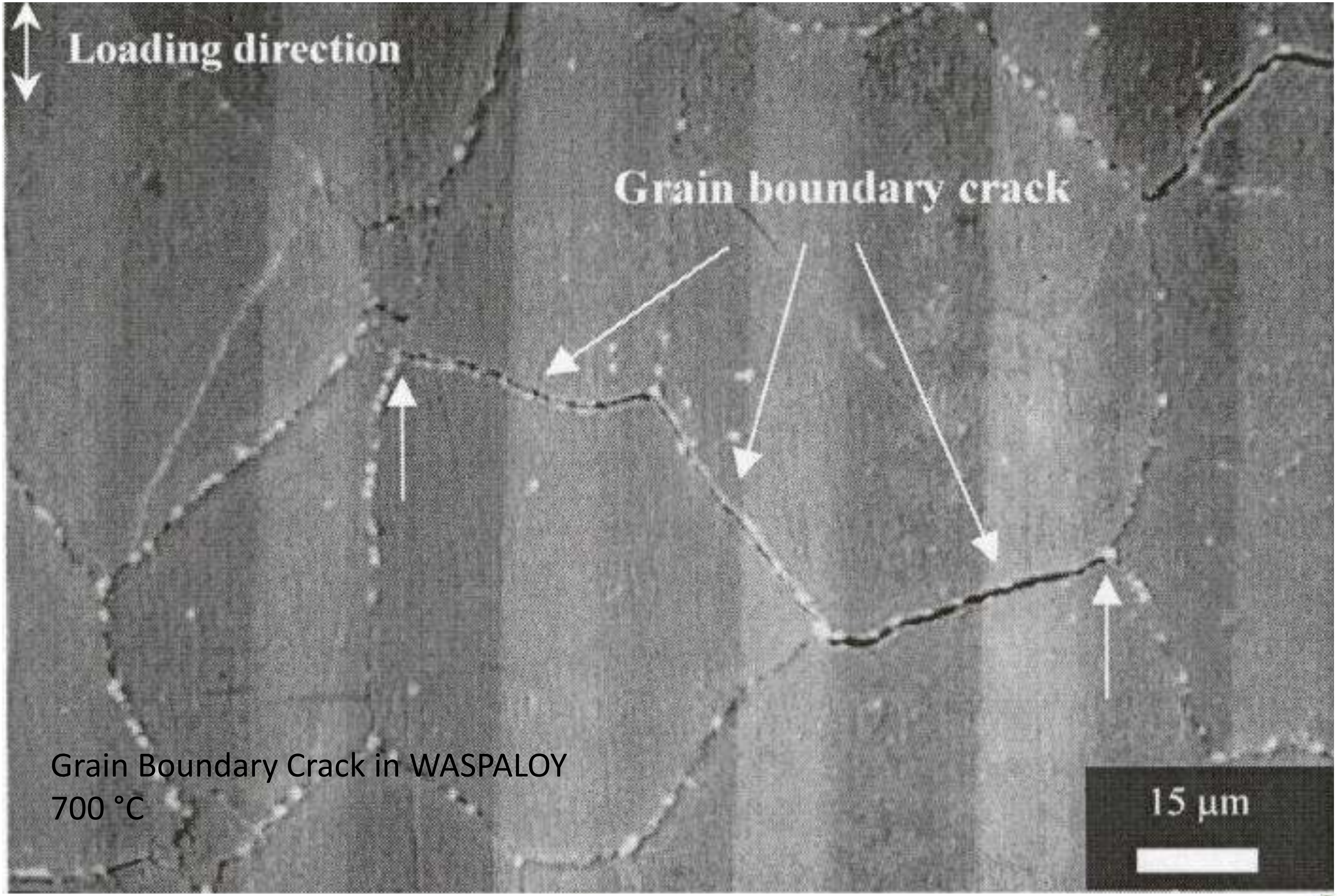


Slip progress in cyclic loading

Fatigue Evolution of Microstructure

Nickel-base super alloy Waspaloy

Microstructure Characterization



Microstructure Characterization

CONCLUSION

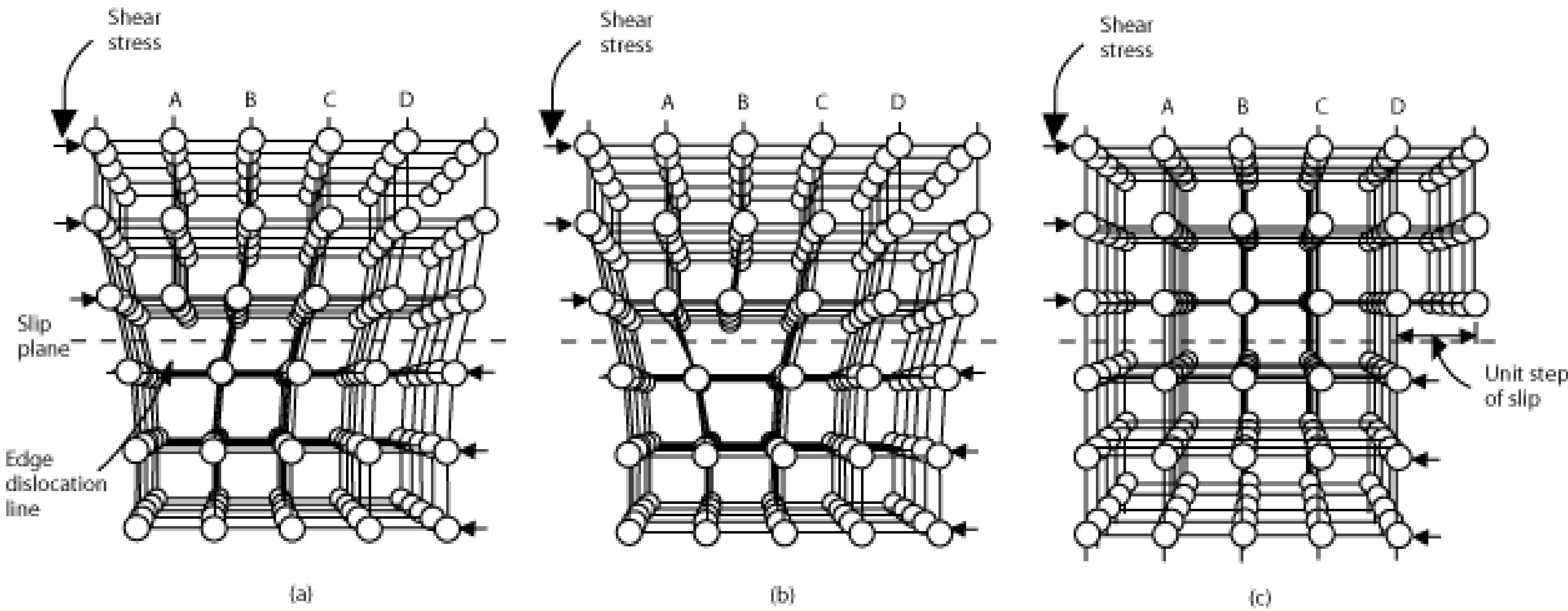
NDC cannot reveal these details until now.

However, under very well defined and confined conditions,
NDC enables the assessment of material state,
in particular when local attack is of concern.

NDC can only be applied
with deep understanding of microstructural damage evolution
and its effect on measureable physical quantities.

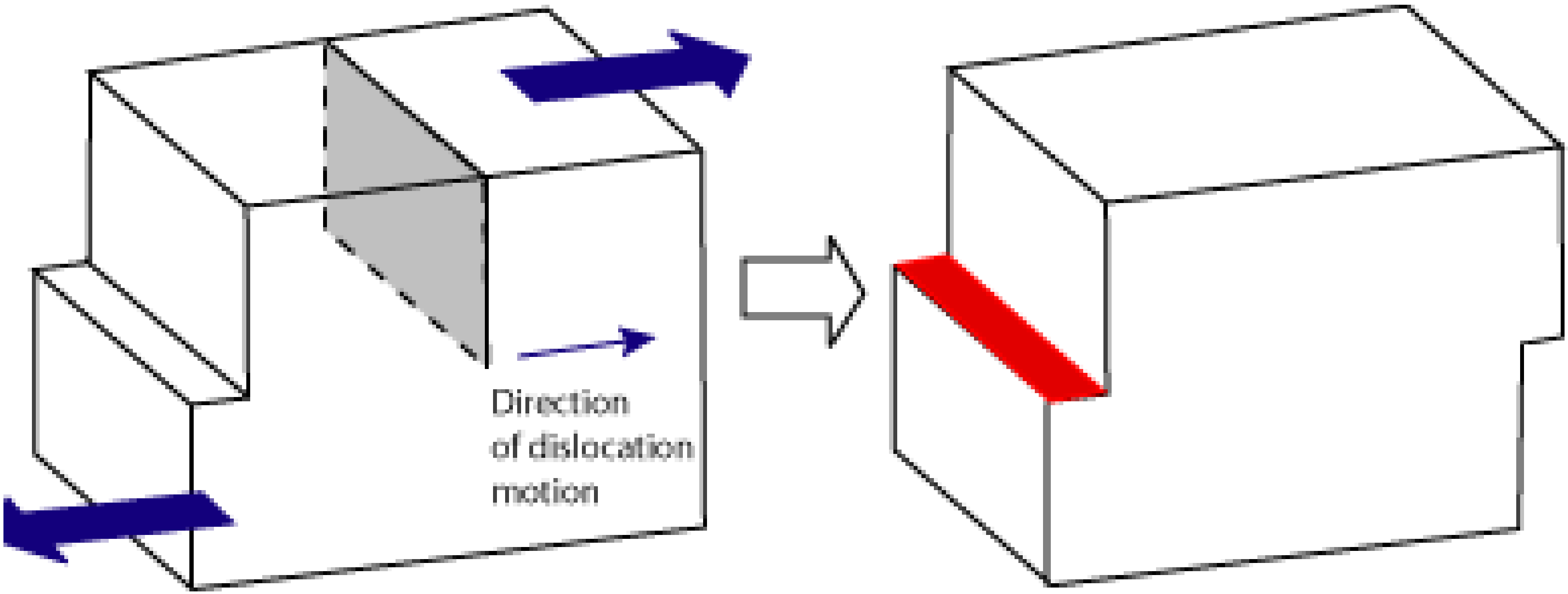
Therefore, NDC applications are unique
developed for a very specific problem.

DISLOCATION HARDENING



EDGE DISLOCATION MOVEMENT

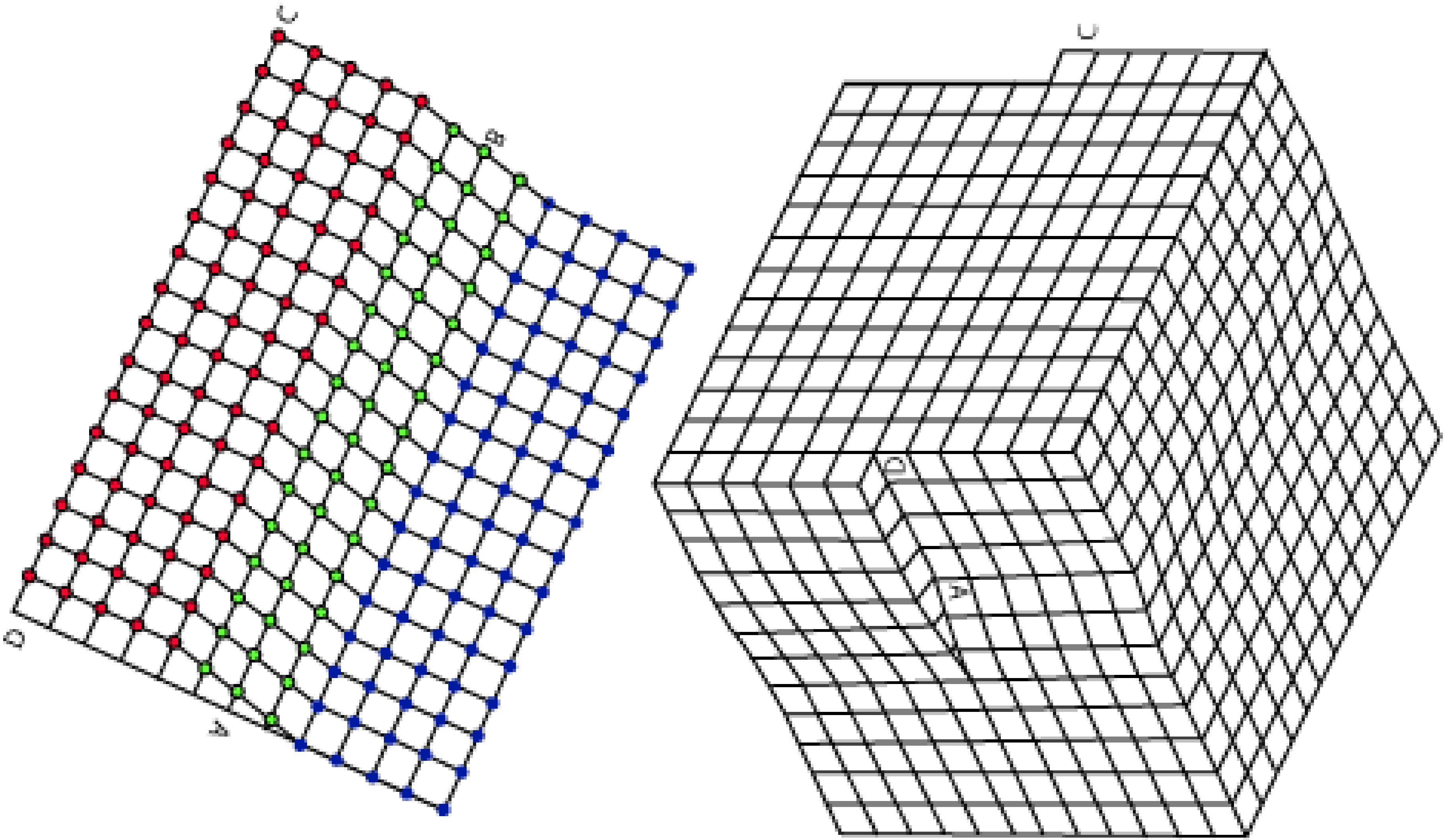
DISLOCATION HARDENING



PLASTIC DEFORMATION

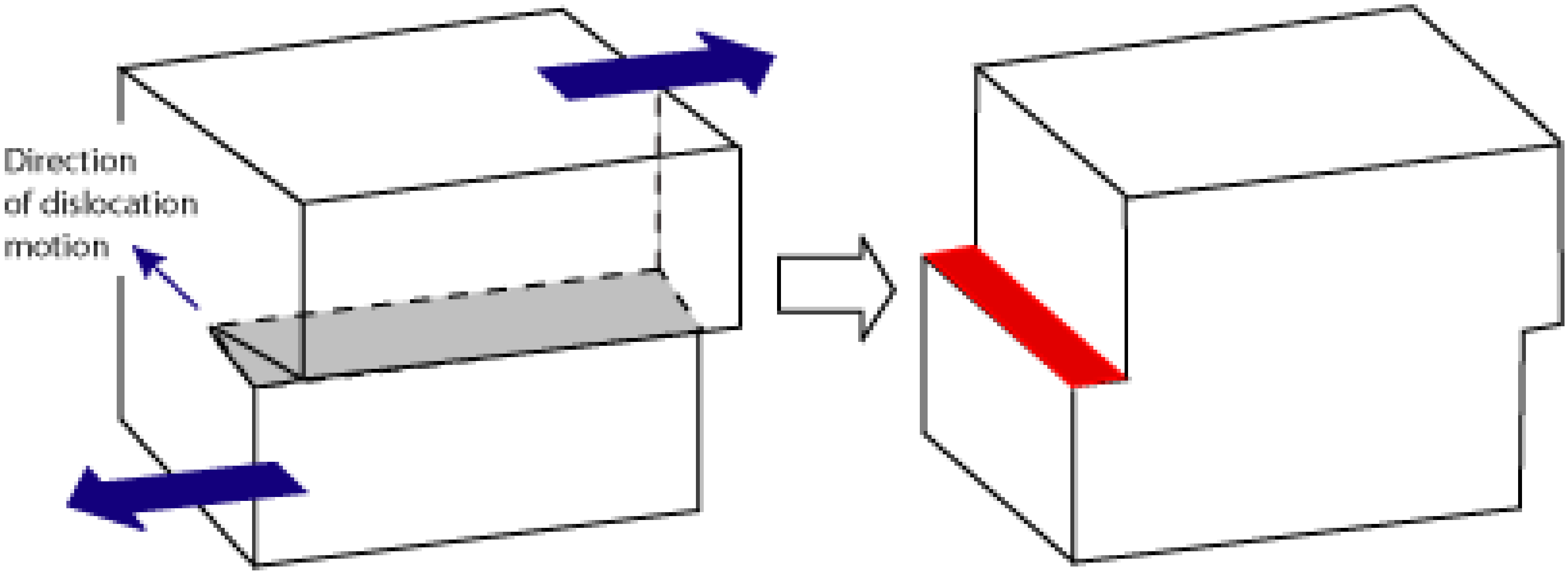
EDGE DISLOCATION MOVEMENT

DISLOCATION HARDENING



SCREW DISLOCATION MOVEMENT

DISLOCATION HARDENING



PLASTIC DEFORMATION

SCREW DISLOCATION MOVEMENT

DISLOCATION HARDENING

The dislocations move along the densest planes of atoms in a material,
because the stress needed to move the dislocation
increases with the spacing between the planes.

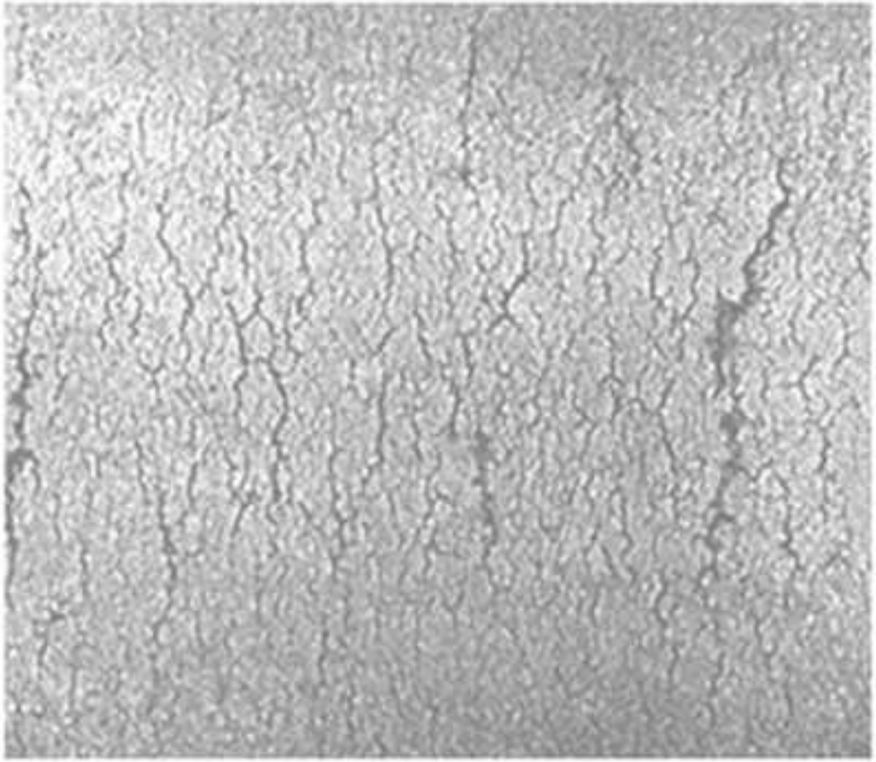
FCC and BCC metals have many dense planes,
so dislocations move relatively easy and these materials have high ductility.
Metals are strengthened by making it more difficult for dislocations to move.
This may involve the introduction of obstacles,
such as interstitial atoms or grain boundaries,
to "pin" the dislocations.

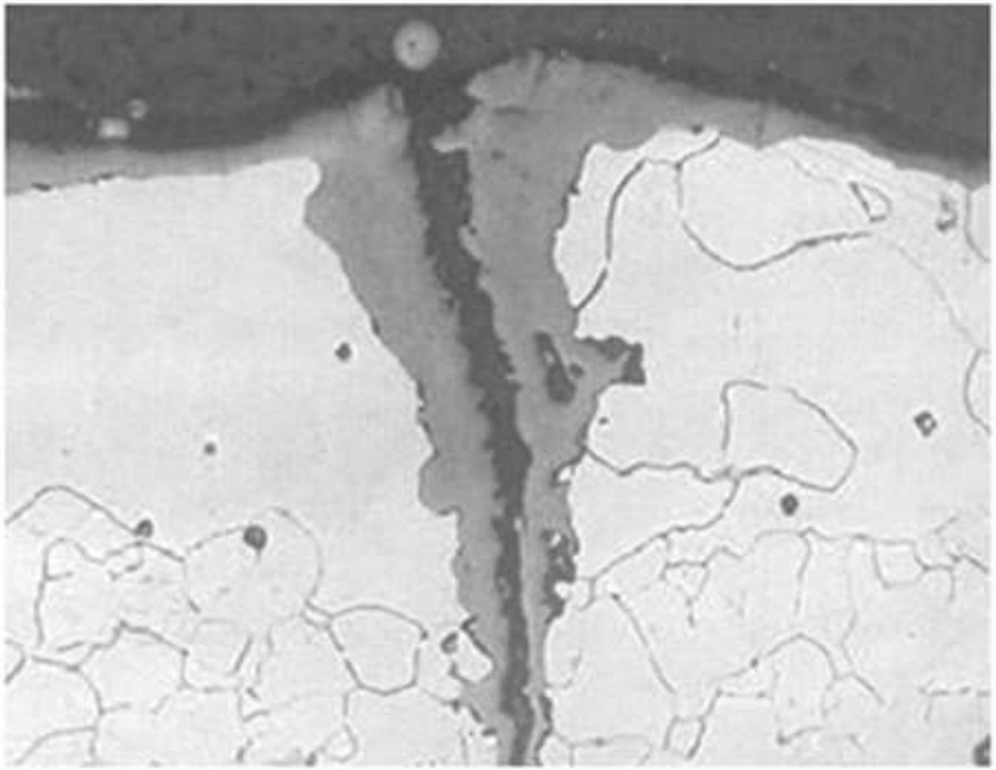
Also, as a material plastically deforms,
more dislocations are produced
and they will get into each others way and impede movement.
This is why strain or work hardening occurs.

Literature

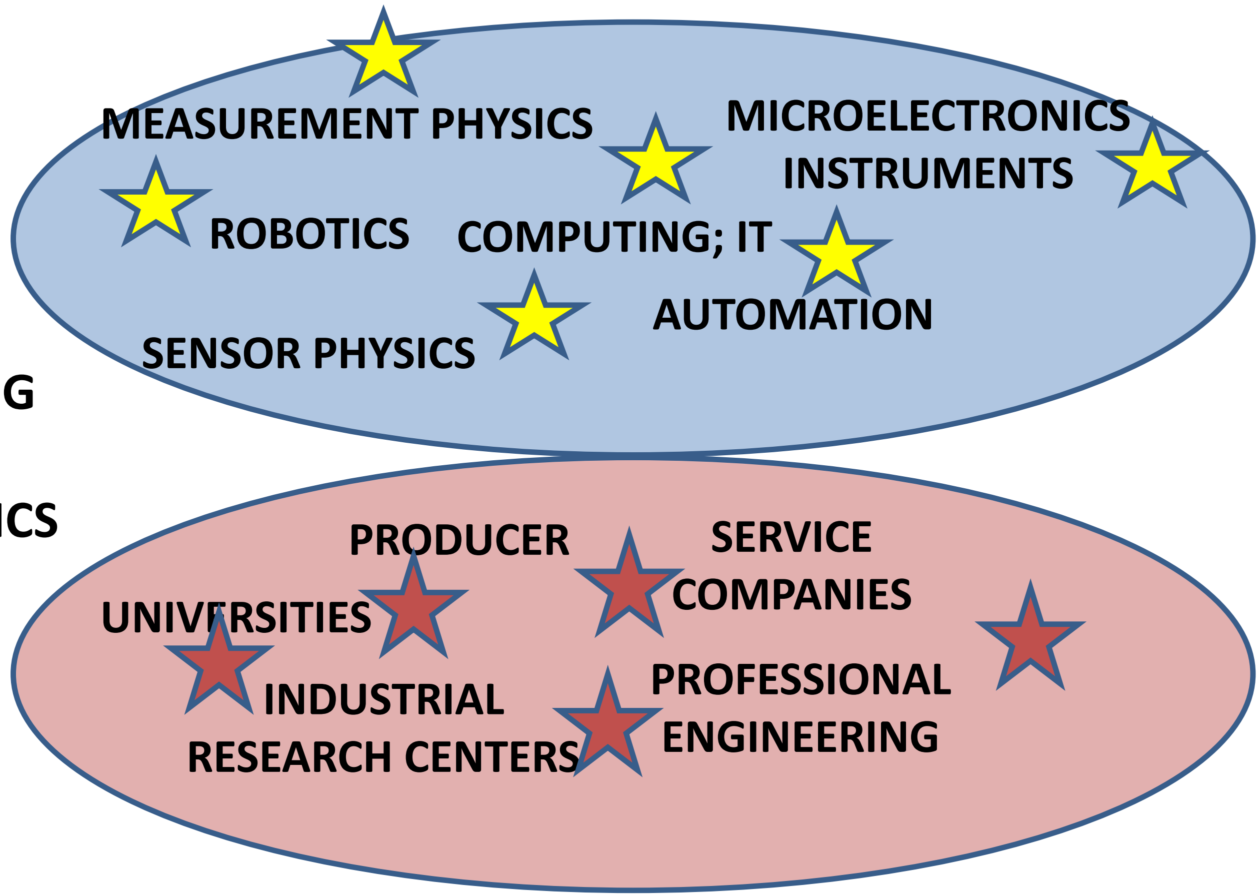
1. D. Cebon, M.F. Ashby: Materials Selection for Precision Instruments, Meas. Science and technology, vol. 5, pp 296-306 (1994)

Thermo-Mechanical Fatigue





Thermal fatigue



SYSTEM ENGINEERING
&
INNOVATION DYNAMICS

STRATEGIC NETWORKS FOR PROFESSIONAL and COMPETENT DEMAND DRIVEN DEVELOPMENT