Summing up Section 2 of the course

# Properties and Microstructure

– the building blocks for using and understanding materials
How do things behave and why?

Materials 2, Thursday week 5

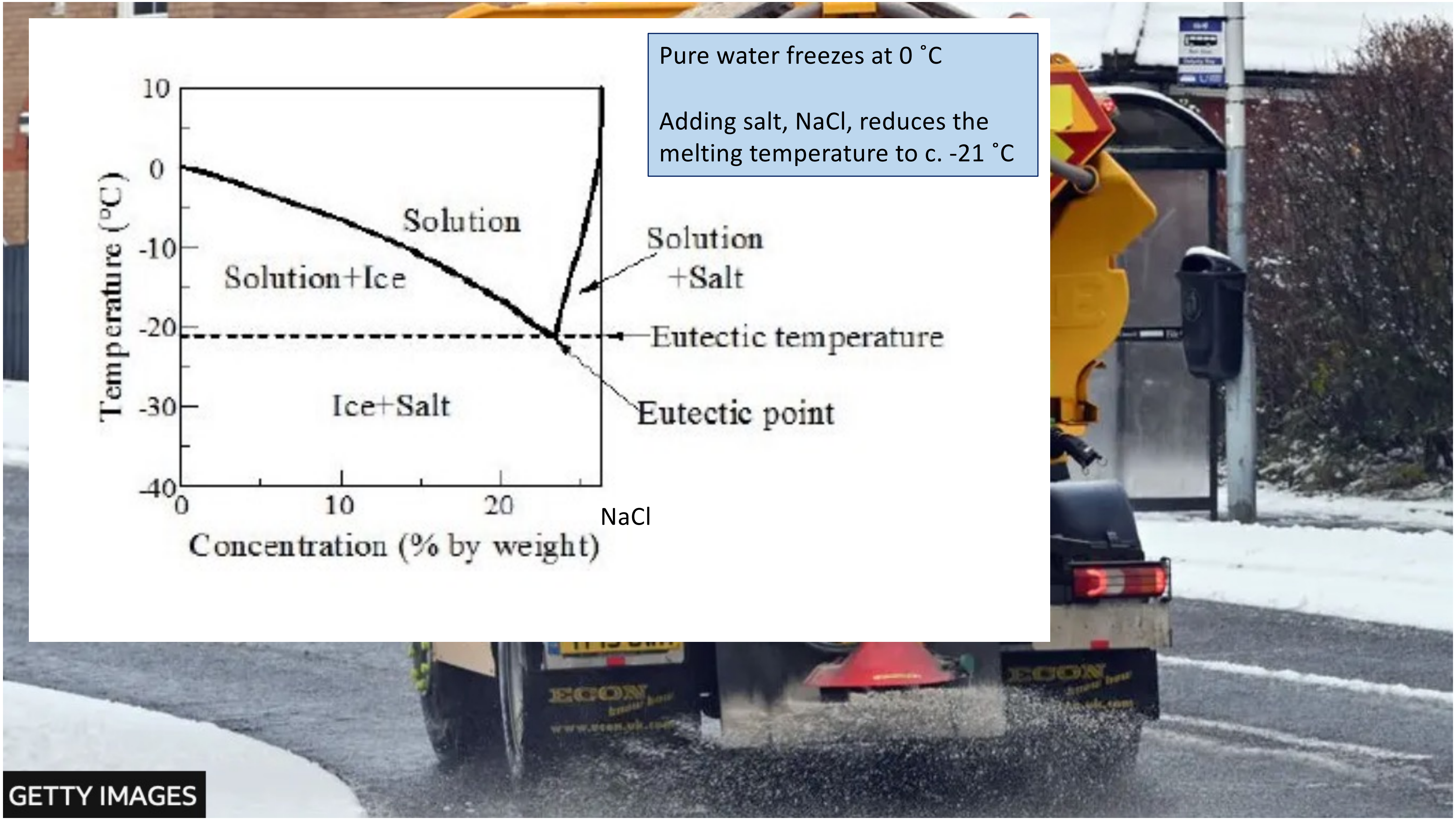
# Today’s session

- Phase diagrams
- Exam
- Reminder of course activity workflow
- Summing up Section 2 of the course – mid point of course & transition into Materials Stories. How the **Materials toolbox** links with Properties & Microstructure (Section 2) and Materials Stories (Section 3)

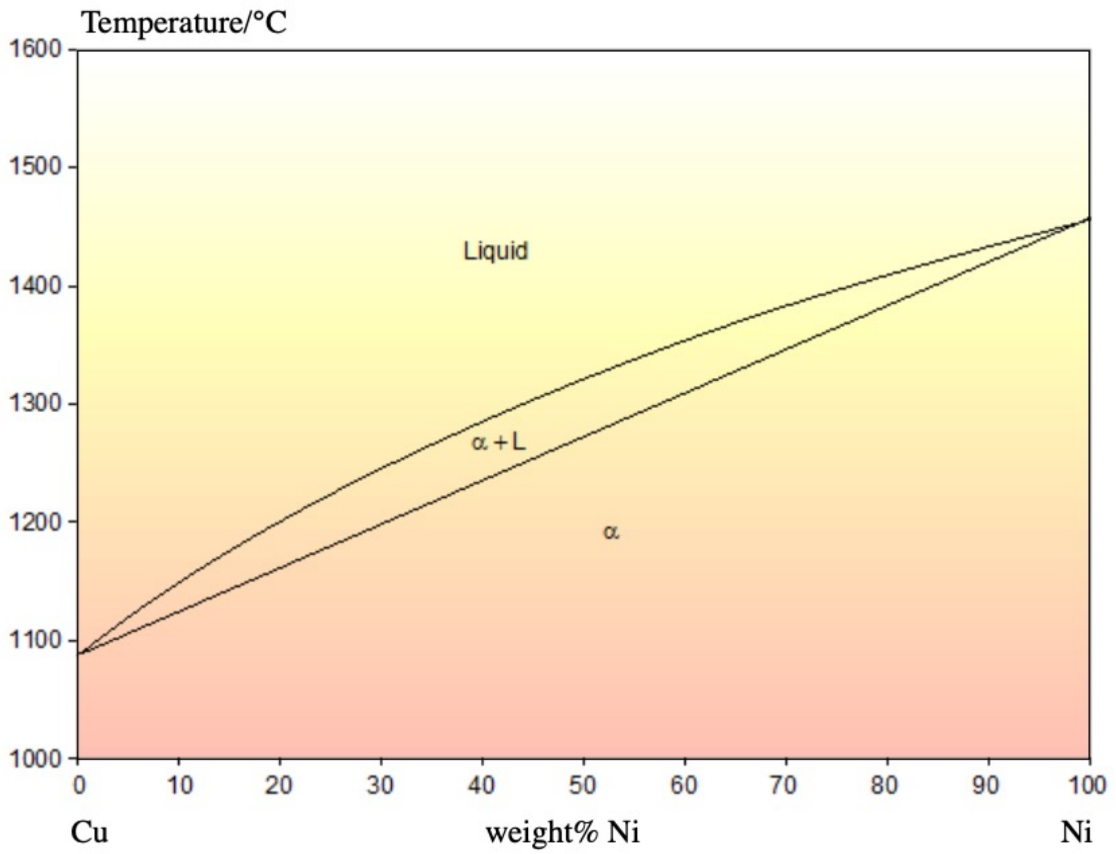
# Phase diagrams

Definition of phase: regions of a material having a specific chemical composition and atomic arrangement.

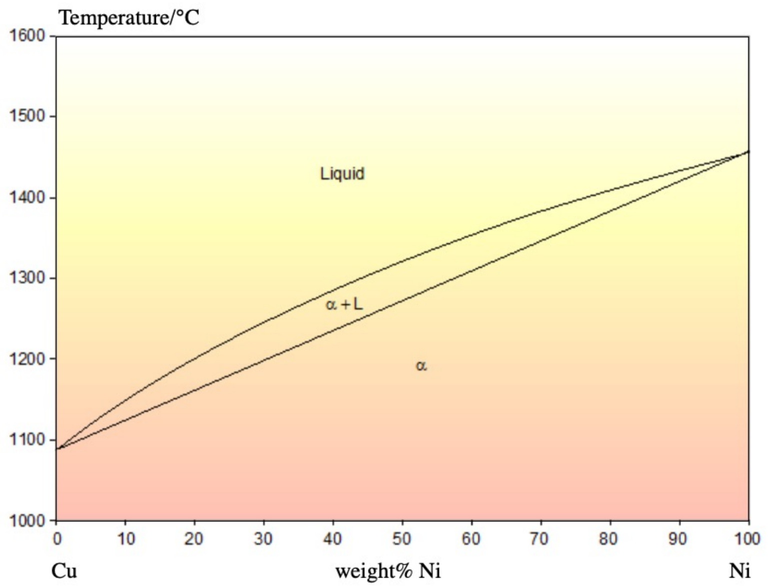

CCTV
YF19 UWM
ECON
GETTY IMAGES


Pure water freezes at 0 ˚C
Adding salt, NaCl, reduces the melting temperature to c. -21 ˚C
10
0
-10
-20
-30
-40
Temperature (°C)
Solution
Solution+Ice
Solution
+Salt
Eutectic temperature
Ice+Salt
Eutectic point
0
10
20
NaCl
Concentration (% by weight)
GETTY IMAGES

Cu-Ni phase diagram

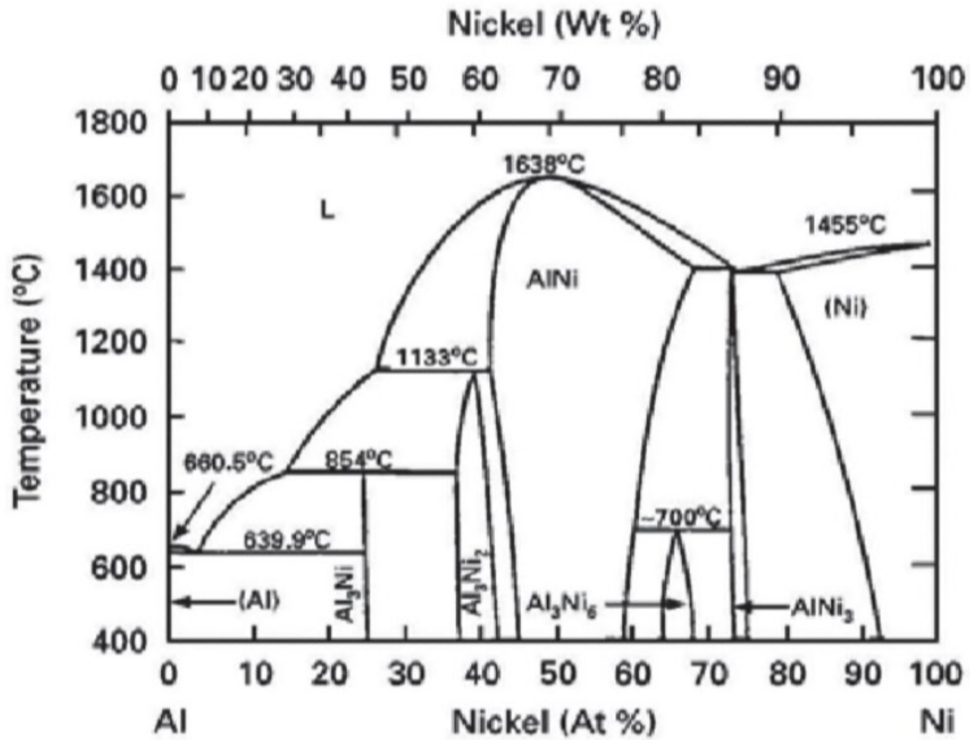


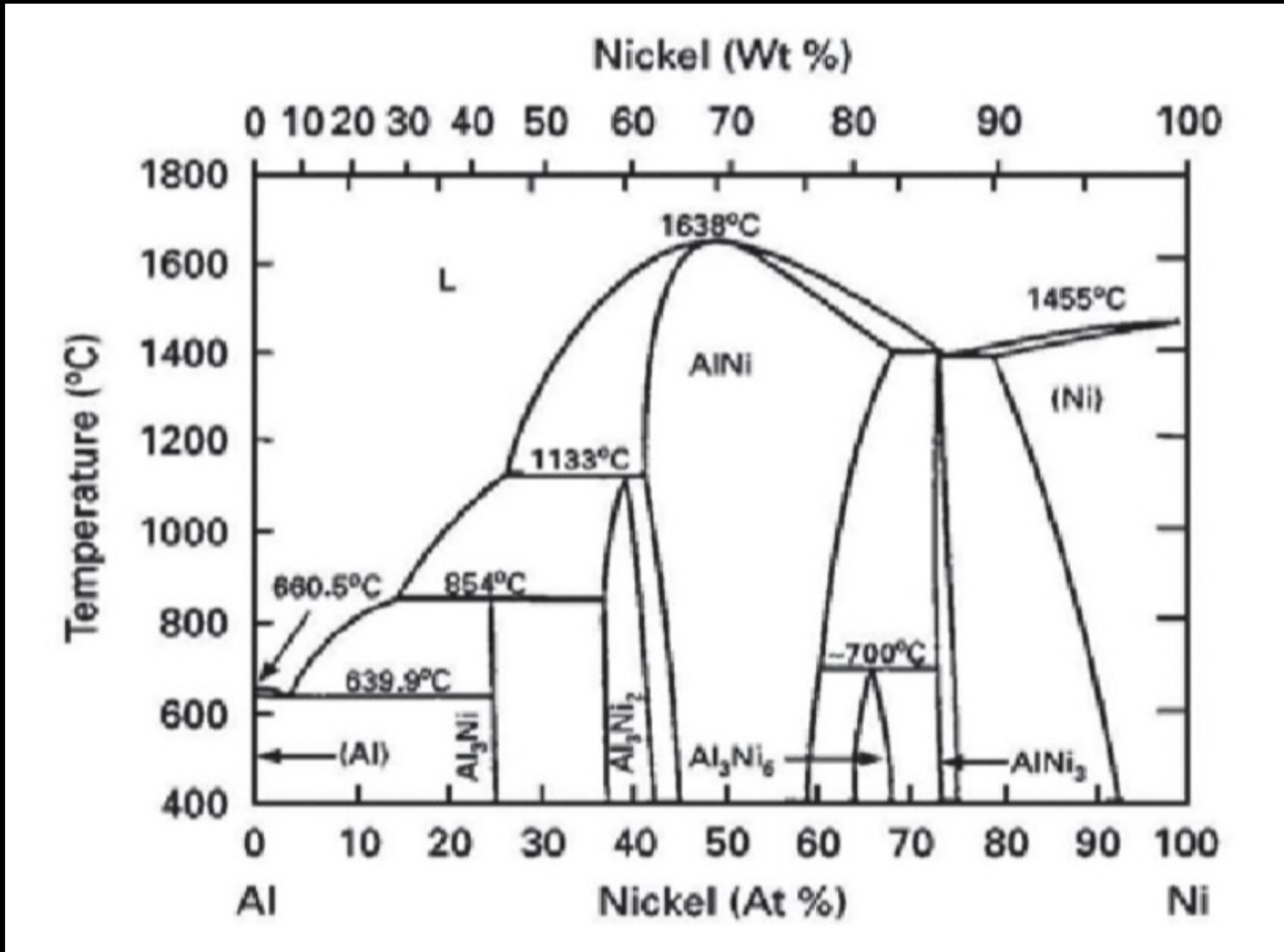
Cu-Ni phase diagram



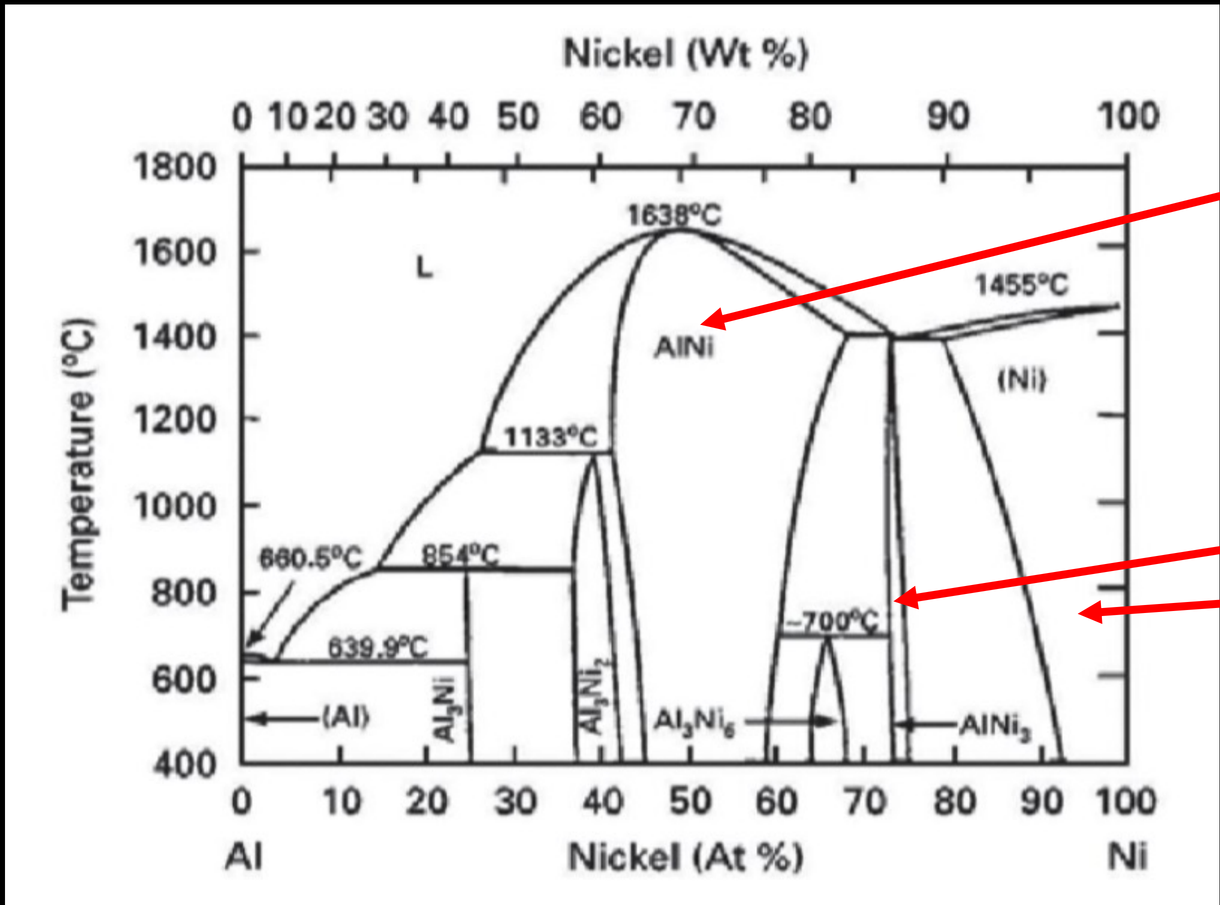


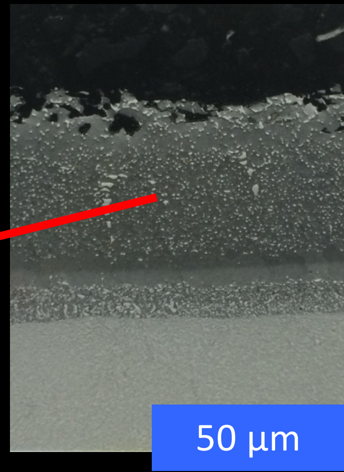

Al-Ni phase diagram



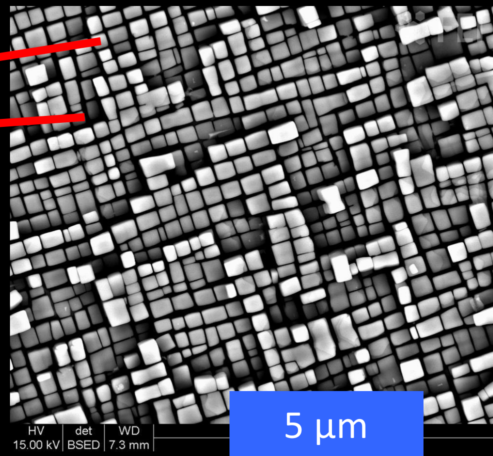



aluminium-nickel
phase diagram




microstructure of coating



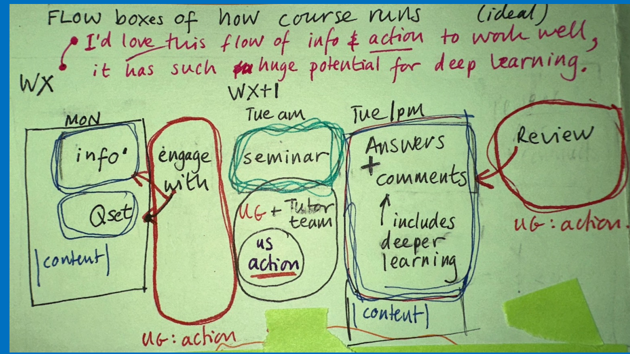

microstructure of blade

# exam

See Course guide p6

Past papers available via library website. I recommend looking at them soon so you get an idea of the style of questions and how they link to the course material.

You can take one A4 sheet of paper to the exam. I recommend doing a first version of this now, so you consolidate what we have done in the course so far *#diagrams & equations ©©GWG*



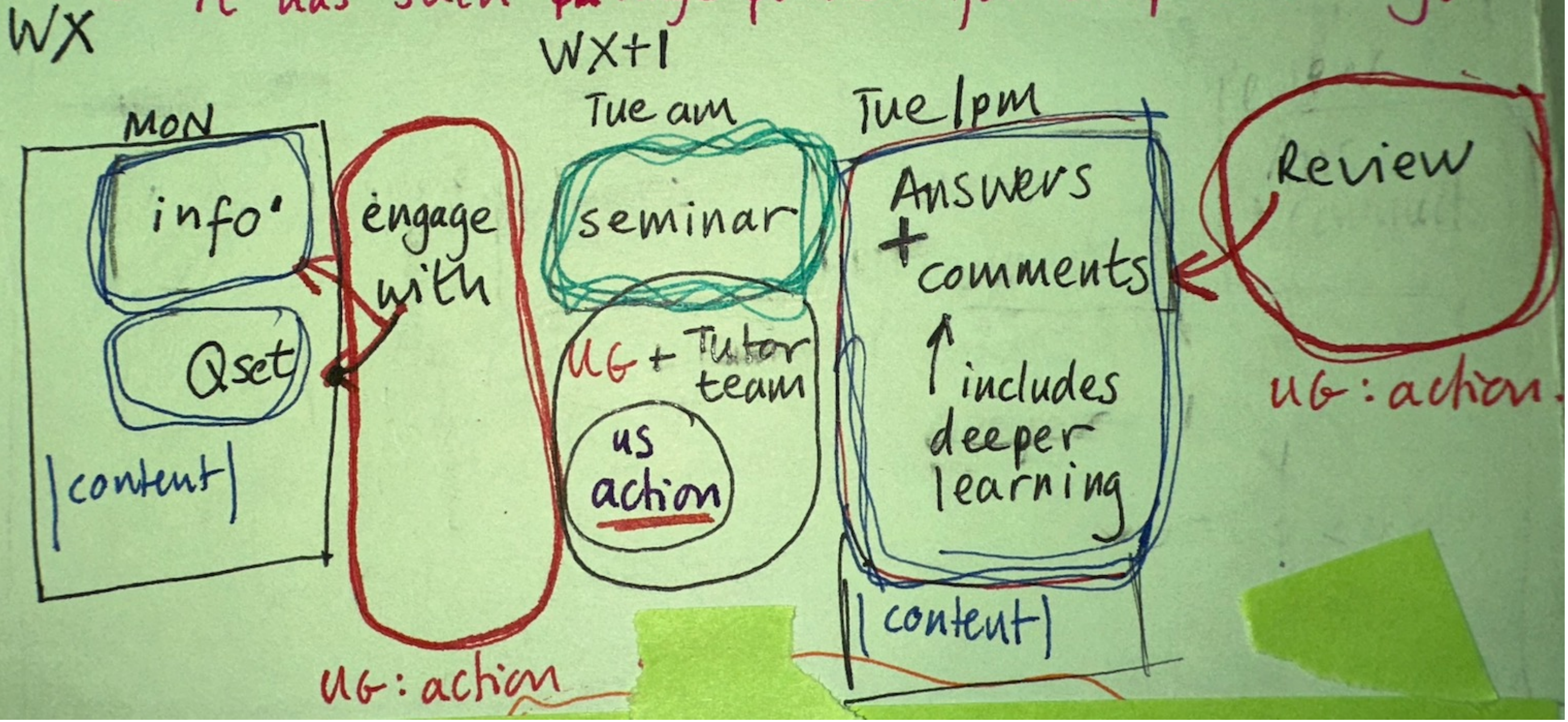

# course design
# activity workflow reminder

Repetition

#into the record / e.g. 'jb reading Colbeck in 2000 then months and years later' /

FLOW boxes of how course runs (ideal)

I'd love this flow of info & action to work well, it has such ~~a~~ huge potential for deep learning.



Summing up Section 2 of the course

# Properties and Microstructure

– the building blocks for using and understanding materials

How do things behave and why?

## 3. Course Outline

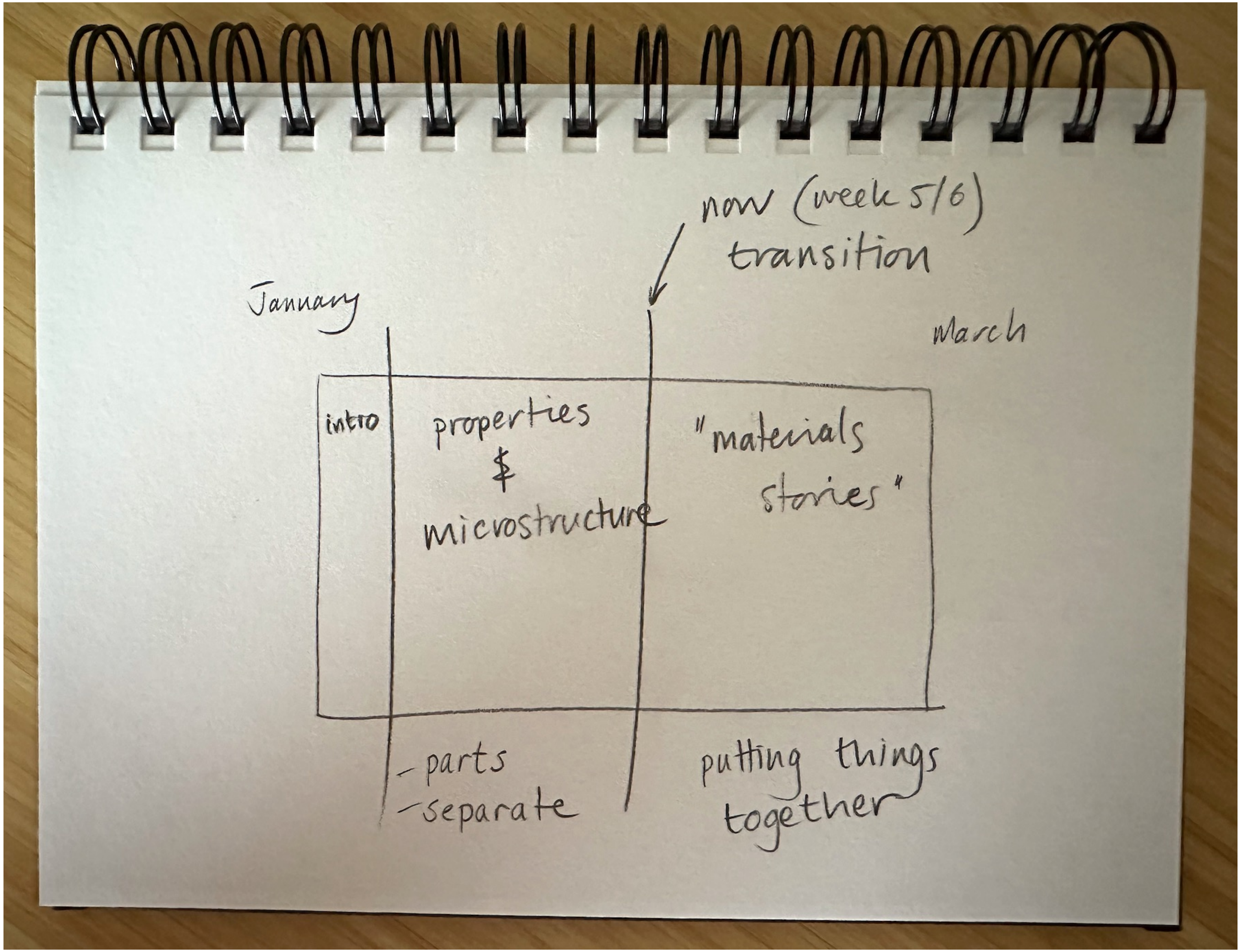
Materials 2 is divided into three sections, as shown below. The course outline is intended to help you pace your studies.

| Week | Topics | Other activities | |
|---|---|---|---|
| **Section 1: Introduction and Materials Foundations** | | | |
| 1 | • Why are materials important for engineers?<br>• Classification of materials.<br>• What are you going to study in this course?<br>• Introduction to your building own **materials toolbox.**<br>• How to learn and engage with the course | | |
| **Section 2: Properties and Microstructure**<br>How do things behave and why? The building blocks for using and understanding materials | | | |
| 2 | Properties:<br>• What are material properties?<br>• How do we find material property data (tests, resources, Ashby materials section chart)?<br>• Testing for mechanical properties; what happens inside the material as it is deformed? | | |
| 3 | Small scale structure (microstructure):<br>• Structures on different length scales<br>• Links between everyday observations, properties, material classes, and small scale structures.<br>• As an engineer, which structures are essentially fixed, and which can you change? | Lab * | |
| 4 – 5 | Small scale structures of metals, ceramics and polymers<br>• Classifications of metals, ceramics and polymers.<br>• The small scale structure of metals, ceramics and polymers and links to their behaviour.<br>• What makes alloys stronger than pure metals? | | Granta * |
| 5 – 6 | Phase Diagrams<br>• What are phases in materials?<br>• Use phase diagrams to understand metallic alloy microstructure and properties. | | |
| **Section 3: Materials Stories, and Materials Selection** | | | |
| 7-10 | Examples of applications of materials. Deepening your understanding of materials and making connections through case studies.<br>• Concrete and timber.<br>• Composite materials.<br>• The Challenger disaster and Liberty ships.<br>• Materials selection. | | |
| 11 | Revision | | |

* Other activities during the course:

- You will have a **Materials 2 lab** scheduled at some point during Weeks 2 to 5. This will appear in your personal timetable.
- You will be introduced to **Ansys Granta materials software** during Materials 2.

5


now (week 5/6)
transition
January
March
intro
properties
&
microstructure
"materials
stories"
- parts
- separate
putting things
together

# Materials toolbox

**materials toolbox = WHAT + HOW + Resources**

# WHAT

The **WHAT** Framework

**Materials**

- **Classifications**
- **Properties**
- **Small scale structure** (microstructure)
- Processing / manufacturing
- **Applications**

22 Materials Selection in Mechanical Design

The classification of Figure 3.1 has the merit of grouping together materials which have some commonalty in properties, processing and use. But it has its dangers, notably those of specialization (the metallurgist who knows nothing of polymers) and of conservative thinking ('we shall use steel because we have always used steel'). In later chapters we examine the engineering properties of materials from a different perspective, comparing properties across all classes of material. It is the first step in developing the freedom of thinking that the designer needs.

## 3.3 The definitions of material properties

Each material can be thought of as having a set of attributes: its properties. It is not a material, *per se*, that the designer seeks; it is a specific combination of these attributes: a *property-profile*. The material name is the identifier for a particular property-profile.

The properties themselves are standard: density, modulus, strength, toughness, thermal conductivity, and so on (Table 3.1). For completeness and precision, they are defined, with their limits, in this section. It makes tedious reading. If you think you know how properties are defined, you might jump to Section 3.4, returning to this section only if the need arises.

The *density*, $\rho$ (units: kg/m$^3$), is the weight per unit volume. We measure it today as Archimedes did: by weighing in air and in a fluid of known density.

The *elastic modulus* (units: GPa or GN/m$^2$) is defined as 'the slope of the linear-elastic part of the stress–strain curve' (Figure 3.2). Young's modulus, $E$, describes tension or compression, the shear modulus $G$ describes shear loading and the bulk modulus $K$ describes the effect of hydrostatic pressure. Poisson's ratio, $\nu$, is dimensionless: it is the negative of the ratio of the lateral strain to the

**Table 3.1** Design-limiting material properties and their usual SI units*

| *Class* | *Property* | *Symbol and units* | |
|---|---|---|---|
| General | Cost | $C_m$ | (\$/kg) |
| | Density | $\rho$ | (kg/m$^3$) |
| Mechanical | Elastic moduli (Young's, shear, bulk) | $E, G, K$ | (GPa) |
| | Strength (yield, ultimate, fracture) | $\sigma_f$ | (MPa) |
| | Toughness | $G_c$ | (kJ/m$^2$) |
| | Fracture toughness | $K_{Ic}$ | (MPa m$^{1/2}$) |
| | Damping capacity | $\eta$ | (—) |
| | Fatigue endurance limit | $\sigma_e$ | (MPa) |
| Thermal | Thermal conductivity | $\lambda$ | (W/mK) |
| | Thermal diffusivity | $a$ | (m$^2$/s) |
| | Specific heat | $C_p$ | (J/kg K) |
| | Melting point | $T_m$ | (K) |
| | Glass temperature | $T_g$ | (K) |
| | Thermal expansion coefficient | $\alpha$ | (°K$^{-1}$) |
| | Thermal shock resistance | $\Delta T$ | (°K) |
| | Creep resistance | - | (—) |
| Wear | Archard wear constant | $k_A$ | (MPa$^{-1}$) |
| Corrosion/ Oxidation | Corrosion rate | $K$ | (mm/year) |
| | Parabolic rate constant | $k_P$ | (m$^2$/s) |

*Conversion factors to imperial and cgs units appear inside the back and front covers of this book.

Materials Selection in Mechanical Design, MF Ashby textbook, and e-book, available from library

The **WHAT** Framework
**Materials**
- **Classifications**
- **Properties**
- **Small scale structure** (microstructure)
- Processing / manufacturing
- **Applications**

"The properties themselves are standard: density, modulus, strength, toughness, thermal conductivity, and so on… For completeness and precision, they are defined, with their limits in this section. It makes tedious reading. If you think you know how properties are defined, you might jump [ahead], returning to this section only if the need arises."

JB comments
'tedious'. Yes it can be. And we can say the same for other parts of the **WHAT** framework. But it is important to know, understand, and use properties etc. with appropriate precision.

and 'jumping ahead' can be great – if what's ahead is more interesting to you

OVERVIEW NO. 80

ON THE ENGINEERING PROPERTIES OF MATERIALS

M. F. ASHBY

Chapter 1

Fundamentals of materials

Christopher Hall School of Engineering, The University of Edinburgh, UK

# Resources

MFA 1989, CH chapters 2009

Library including e-books on Resource List

Ansys Granta

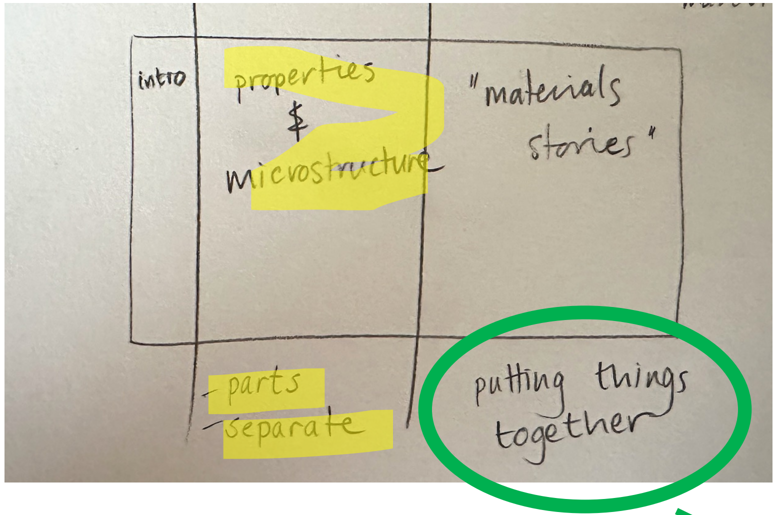
# Resources

In the context of the materials toolbox, we define “Resources” broadly, it is not only the resources section on the Materials 2 Learn site.

Resources cover: textbooks, handbooks, manufacturers’ data sheets, databases, Ansys GRANTA – materials and processes database and software tools, academic papers – original research publications and review articles. In short, any materials-related resources available in the library and on the internet. You do not need to engage with/learn all of these in this course; you will gradually build your abilities for using resources over time.

*and AI*

The internet and mobile devices have changed how most of us access data significantly – we can now get near-instant access to huge amounts of data. Being able to decide what information we need, where to find it, and what quality it is are key skills that you will develop with practice and over time.




The **WHAT** Framework

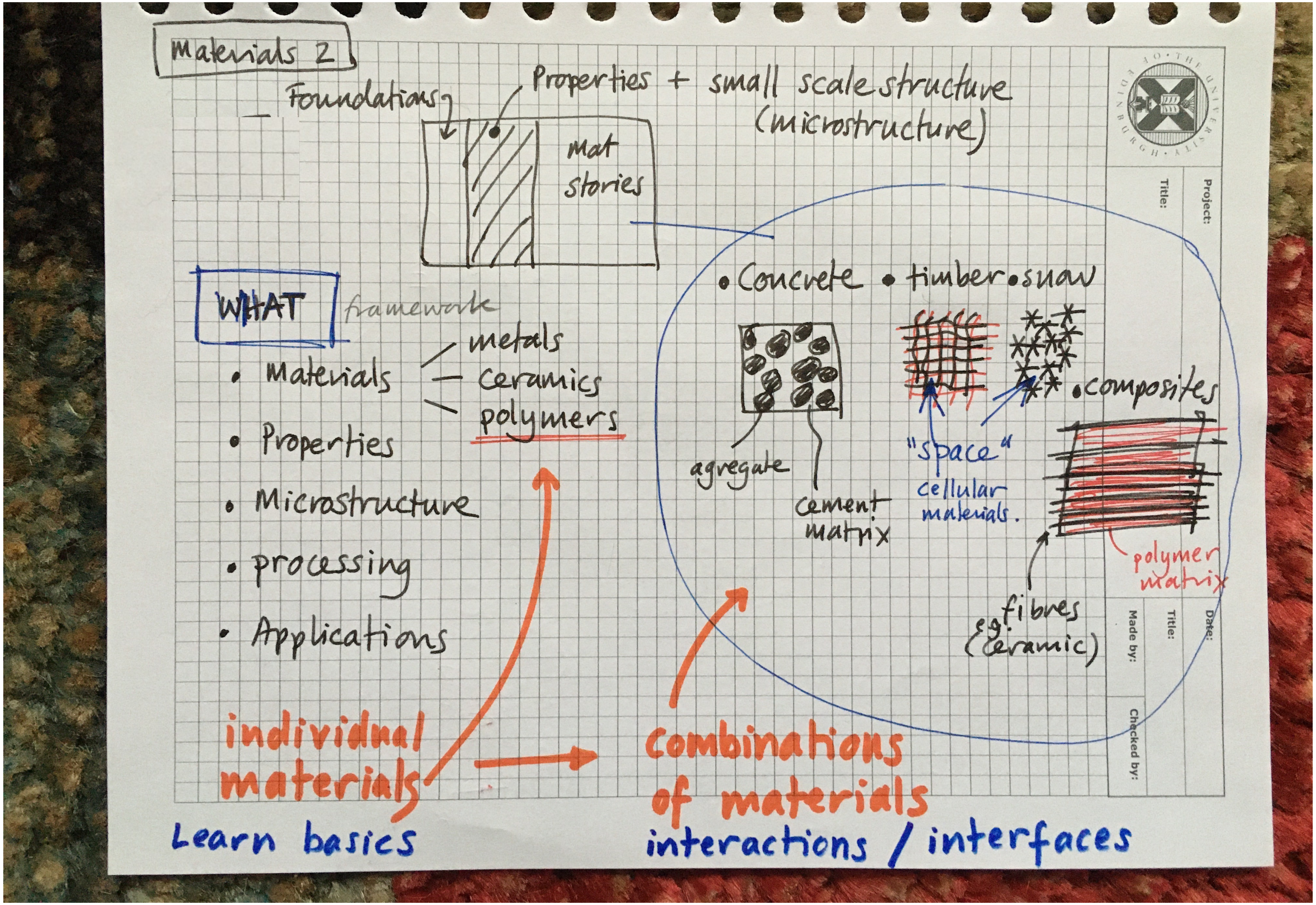
**Materials**

- **Classifications**
- **Properties**
- **Small scale structure** (microstructure)
- Processing / manufacturing
- **Applications**

putting things together
- combinations of materials
- Applications – 'big picture'

**Properties and Microstructure**
– the building blocks for using and understanding materials

How do things behave and why?


Materials 2
Foundations
Properties + small scale structure
(microstructure)
mat stories
WHAT
framework
• Materials
metals
ceramics
polymers
• Properties
• Microstructure
• processing
• Applications
• Concrete
• timber
• straw
• composites
agregate
cement matrix
"space"
cellular materials.
polymer matrix
eg. fibres (ceramic)
individual materials
combinations of materials
Learn basics
interactions / interfaces
Project:
Title:
Made by:
Title:
Date:
Checked by:

Application
‘big picture’


www.flightglobal.com


MEASURE THAT!
thinsilence.org

# Materials toolbox: in practice

moving between parts & 'big picture'

complex messy ambiguous real can be more interesting than 'parts'

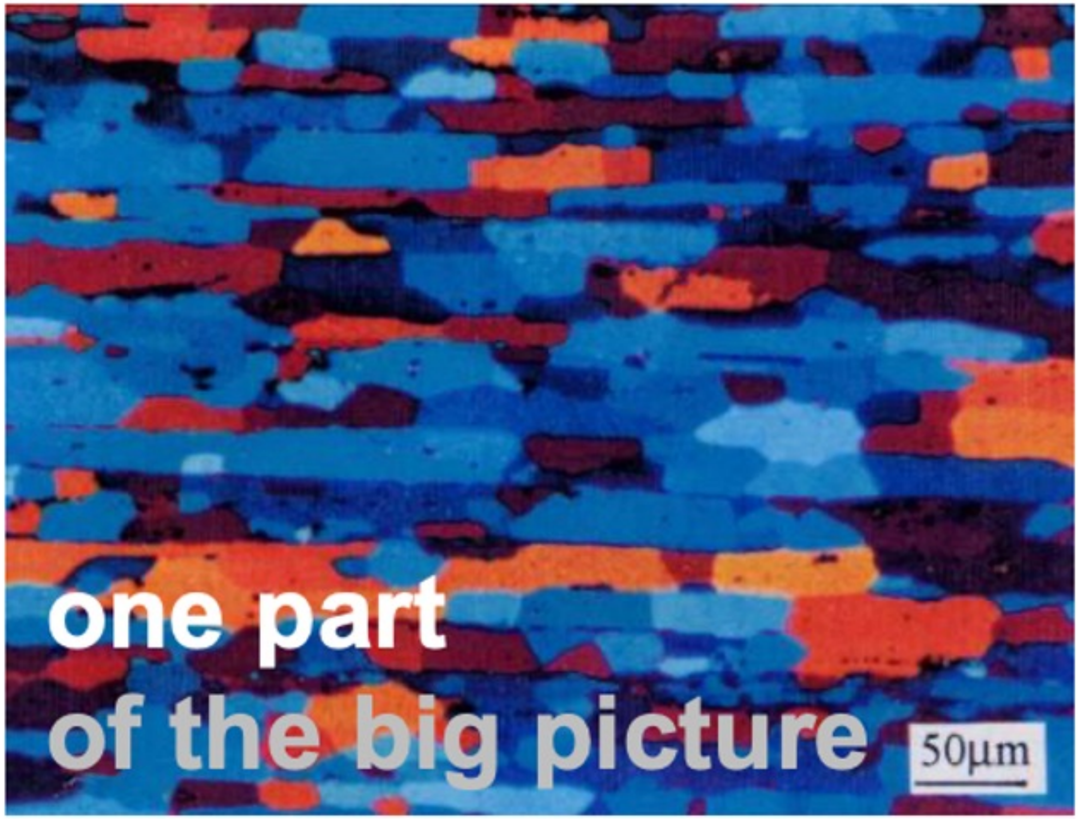
making assumptions – can't consider everything decision making

Materials toolbox: in practice

The WHAT Framework

**Materials**

- **Classifications**
- **Properties**
- **Small scale structure** (microstructure)
- Processing / manufacturing
- **Applications**


making connections

materials toolbox = **WHAT** + **HOW** + **Resources**

# HOW

'HOW' is about people you, me, us, collaboration, learning

**WHAT** and **Resources** aren't about people

Open question about artificial intelligence (AI)

**materials toolbox = WHAT + HOW + Resources**

# Which aspects of the materials toolbox can AI do?

… a good, open question
Not sure I've a 'good' answer, and things are changing rapidly*
Probably all aspects.
But I sense there is stuff we can do that AI can't … what is that?
using human consciousness and creativity

**HOW** is about us as people.
I feel this matters.

www.

'devices'

social media

artificial intelligence *

## HOW

How we learn and use the **WHAT** framework is covered in **HOW**, which gives core concepts for learning, e.g. asking **questions** (asking questions, learning to ask better questions), **interest** (what interests you? what doesn't? how can exploring this help you engage with your learning?). Being curious and asking questions is a key part of learning well. Further information about **HOW** (core concepts for learning and learning to learn) is in the final section of this guide.

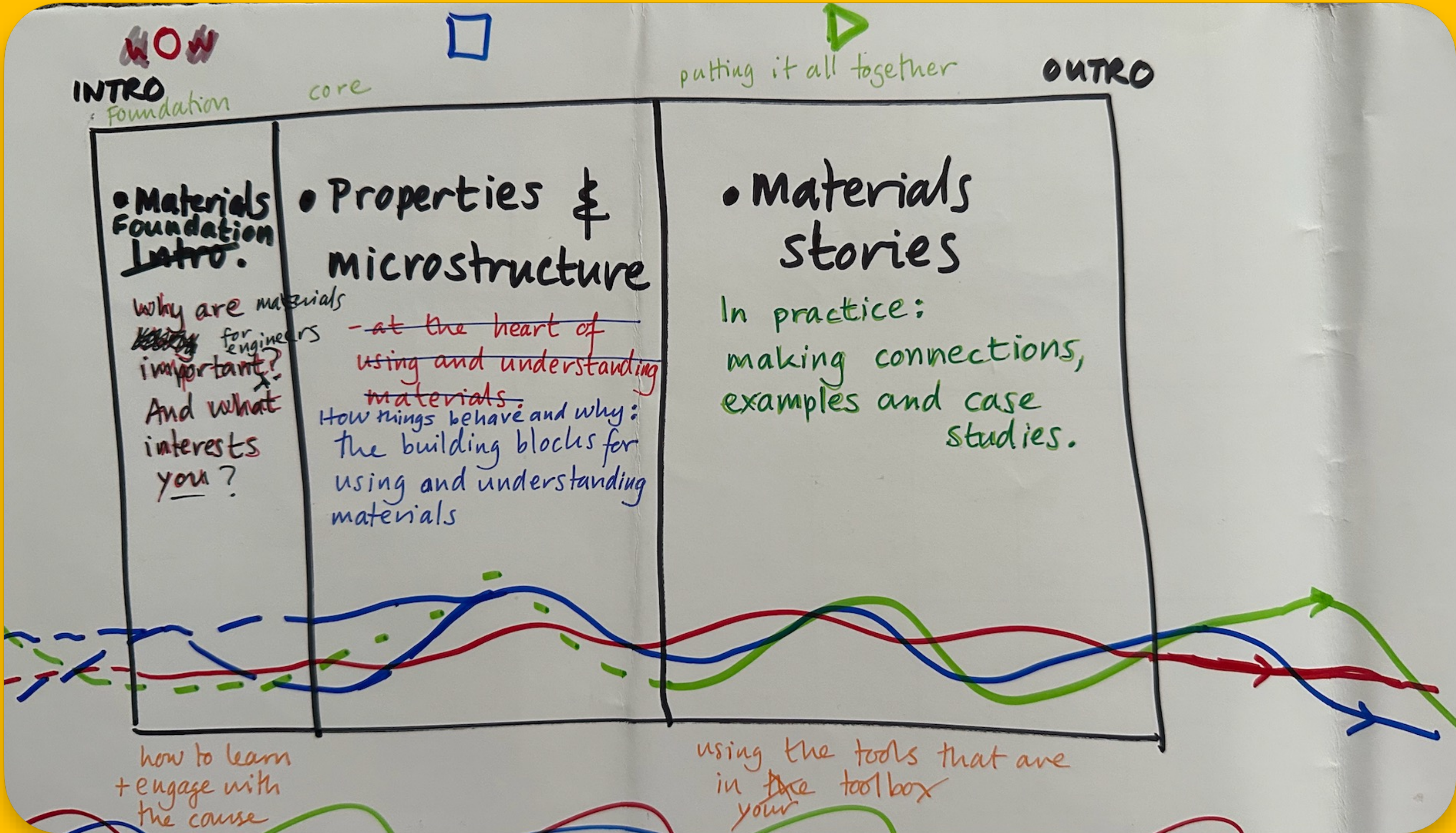
p9 Course Guide
and next slide

**HOW Core concepts for learning**
Based on **experience, neuroscience, psychology, and common sense**

**#interest**
#real stuff
#awareness
**#questions**
#thinking&linking
#rigour
#clear communication
#resources
#balance
#messy stuff
#into-the-record
#time-to-process
#getting-stuck #making-mistakes
#feedback
**#connection**
#safe environment
#everyone is different
#curiosity

# #interest

my interests: materials science & learning (engineering less so) – but deep interest in teaching others – in materials and complex engineering+ decision making – so others learn to think, to question. to question the status quo.


WOW
INTRO
Foundation
core
putting it all together
OUTRO
• Materials Foundation ~~Intro~~.
why are materials ~~[illegible]~~ for engineers important?
And what interests you?
• Properties & microstructure
~~- at the heart of using and understanding materials.~~
How things behave and why: the building blocks for using and understanding materials
• Materials stories
In practice: making connections, examples and case studies.
how to learn + engage with the course
using the tools that are in ~~the~~ your toolbox

#questions

# what’s going on in the material?


# Materials toolbox

**materials toolbox = WHAT + HOW + Resources**

This is based on **principles**

# Examples of aspects of the materials toolbox

mostly that you’ve seen

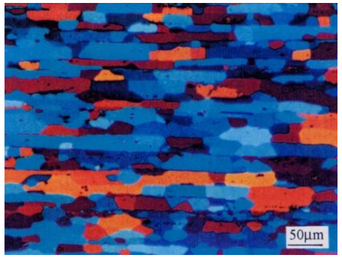

Wood = natural polymer
And we can see the small scale structure

**WHAT** Framework

**Materials**

- **Classifications**
- **Properties**
- **Small scale structure** (microstructure)
- Processing / manufacturing
- **Applications**

# Microstructure

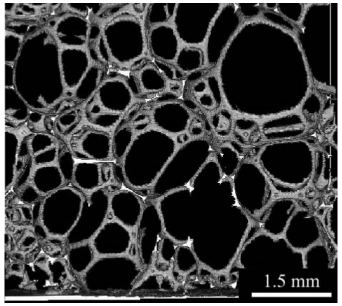



Al alloy
bike frame

— 50 µm

**metal**

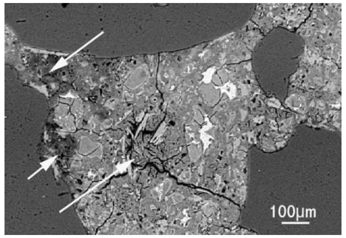
**core**




open cell
polymer
foam
(saddle)

— 1.5 mm
(1500 µm)

**polymer**




concrete
(that's
degrading)

— 100 µm

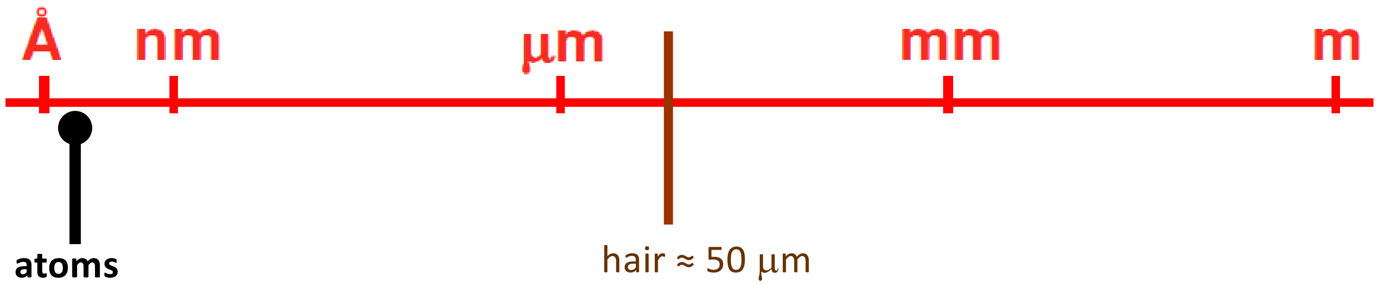
**ceramic**

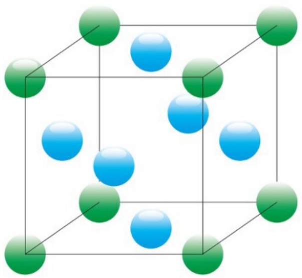
*Note image scale bars – they indicate how big the features are*

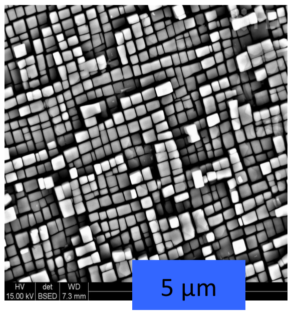
Based on Slide in Part-1-learning by awareness-the WHAT framework-interactive activity

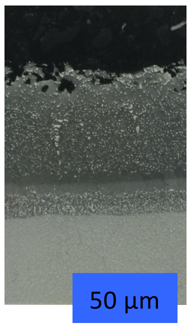
# Structure on different scales

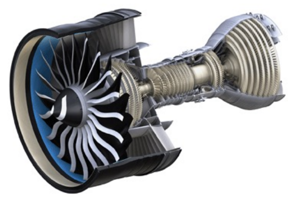
**WHAT** Framework
**Materials**
- Classifications
- Properties
- **Small scale structure (microstructure)**
- Processing / manufacturing
- Applications





www.asminternational.org

www.rolls-royce.com

| **WHAT** Framework, for high temperature turbine blade **Materials** | |
|---|---|
| **Classification** | Nickel superalloy, based on Ni+Cr+Al, e.g. IN713 |
| **Properties** | Mechanical, thermal & chemical<br>high temperature strength, fracture toughness, creep, fatigue, thermomechanical fatigue, oxidation, hot corrosion, erosion |
| Processing | Casting, heat treatment, coating processes |
| **Small scale structure** (microstructure) | Grain structure, coating structure (based on NiAl), $Ni_3Al$ cuboid shape strengthening precipitates in blade, packing of Ni & Al atoms at atomic scale |
| **Applications** | Jet engines<br>also used in industrial power generation turbines |

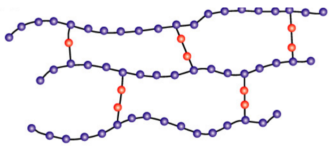
**WHAT** Framework
**Materials**
- **Classifications**
- **Properties**
- **Small scale structure** (microstructure)
- Processing / manufacturing
- **Applications**

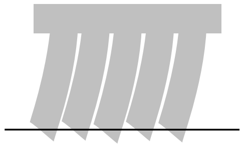
extra

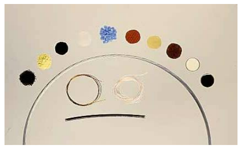
# Rubber & tyre development - hierarchy

**pure rubber**

**tyre rubber** | **tread block** | **whole tyre** | **car**







**science**
**simple systems**

**engineering**
**driving performance**
**complex systems**

# Experimental techniques & length scales

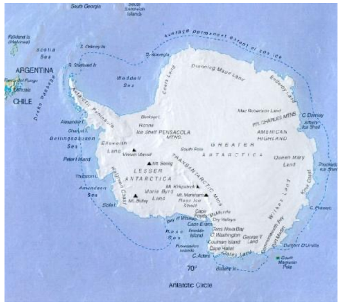
extra

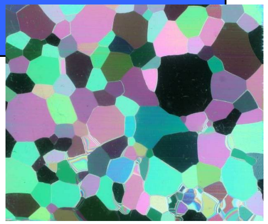
Remote sensing

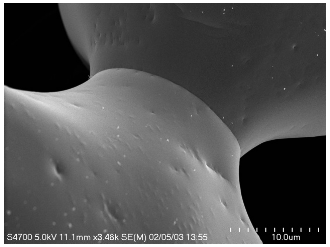
Visual observation & optical microscopy

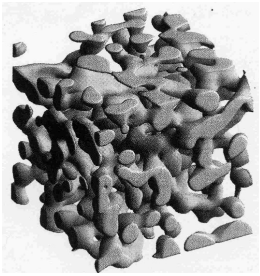
X-ray MT

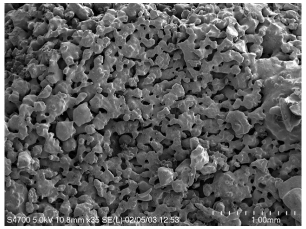
SEM









$10^{-9}$ m    $10^{-6}$ m    $10^{-3}$ m    1 m    $10^{3}$ m    $10^{6}$ m