

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

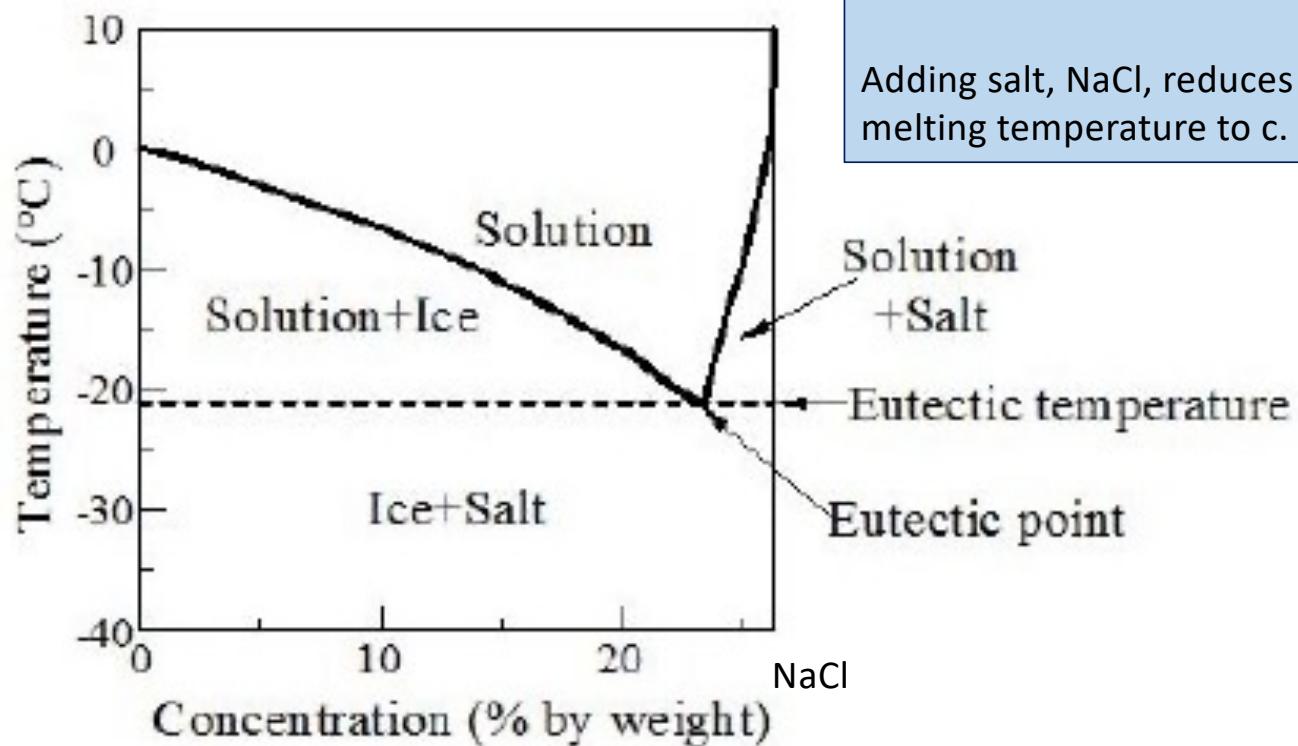
- Phase diagrams
- Exam
- Reminder of course activity workflow
- Summing up Section 2 of the course – mid point of course & transition into Materials Stories. How the **Materials toolbox** links with Properties & Microstructure (Section 2) and Materials Stories (Section 3)

Phase diagrams

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

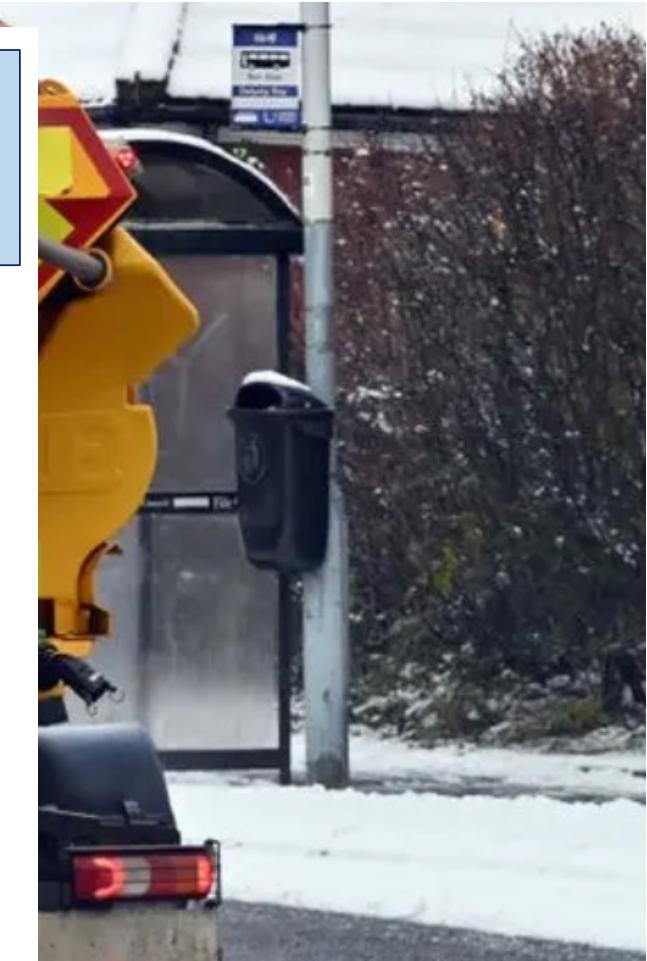


GETTY IMAGES

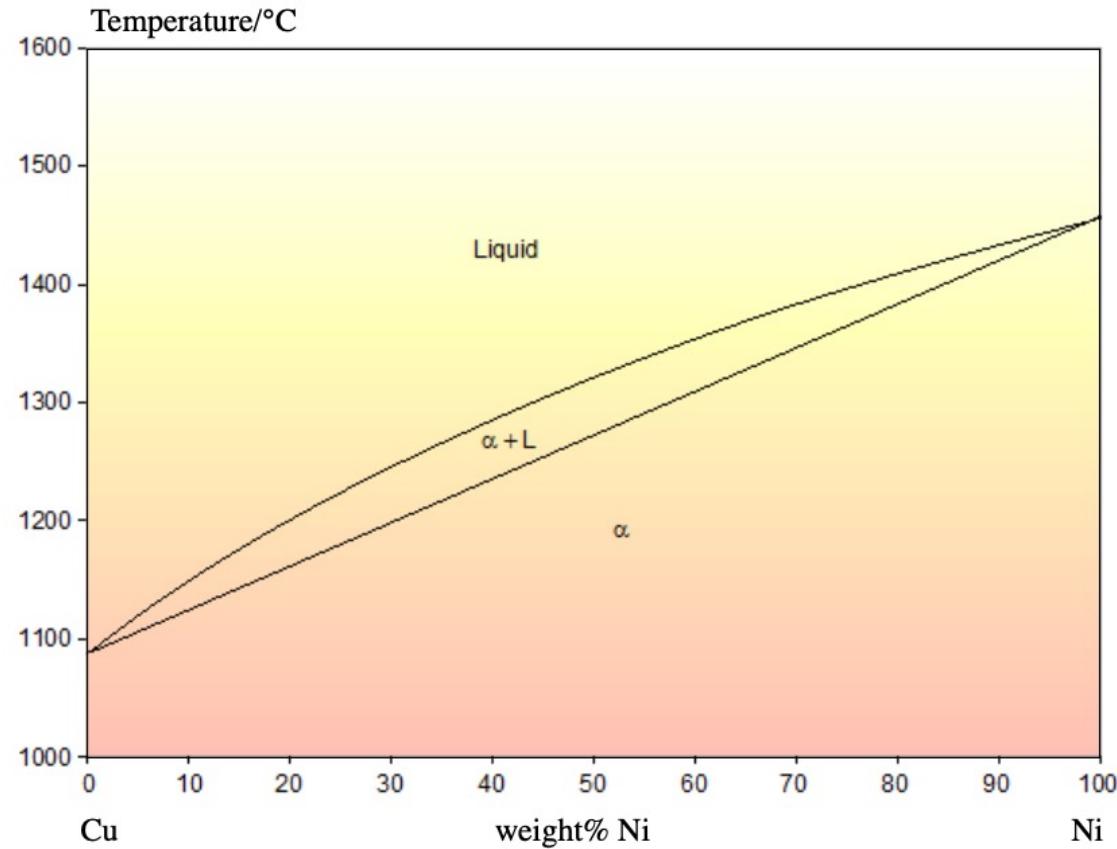


Pure water freezes at 0 °C

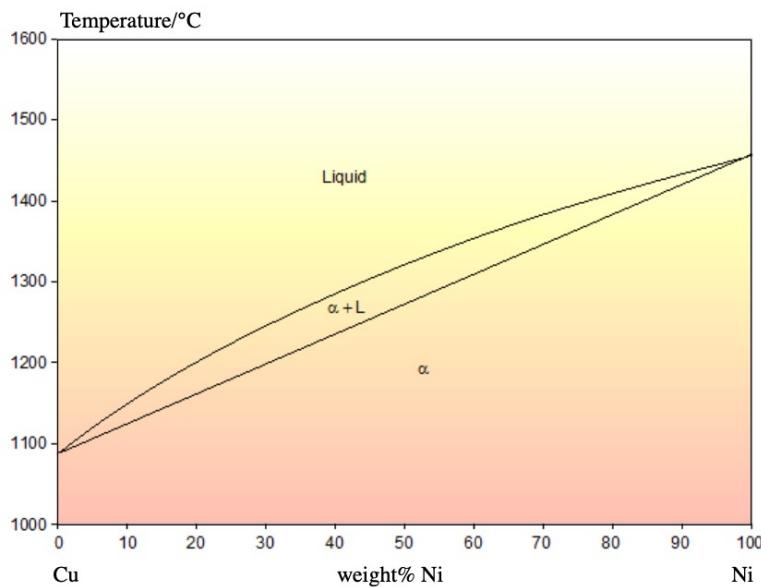
Adding salt, NaCl, reduces the melting temperature to c. -21 °C



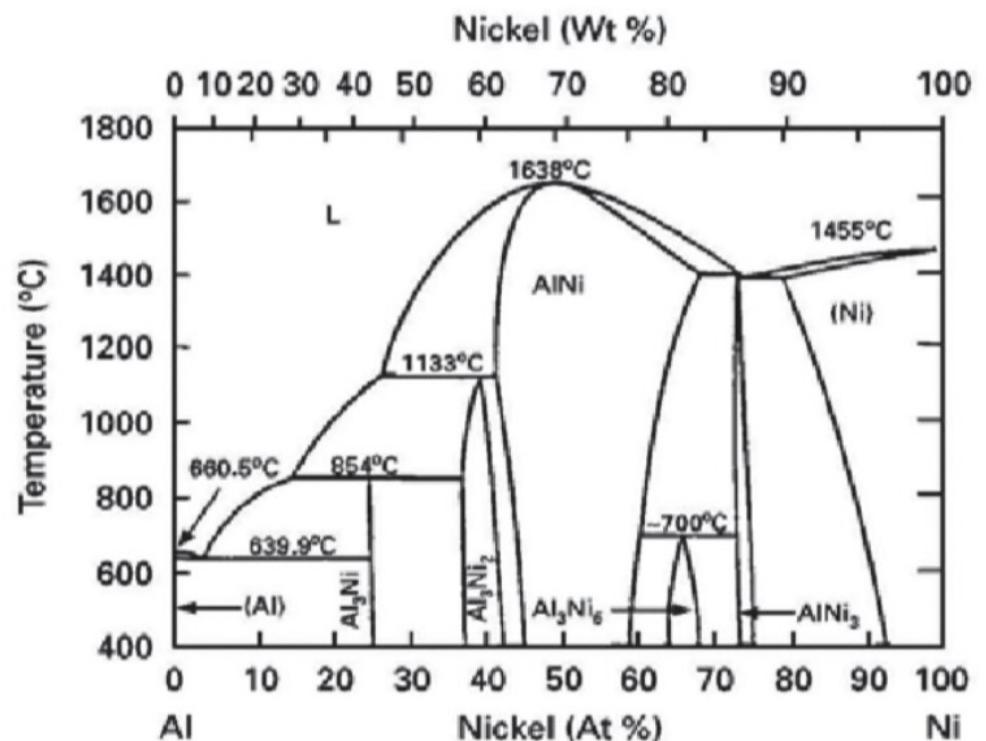
Cu-Ni phase diagram



Cu-Ni phase diagram

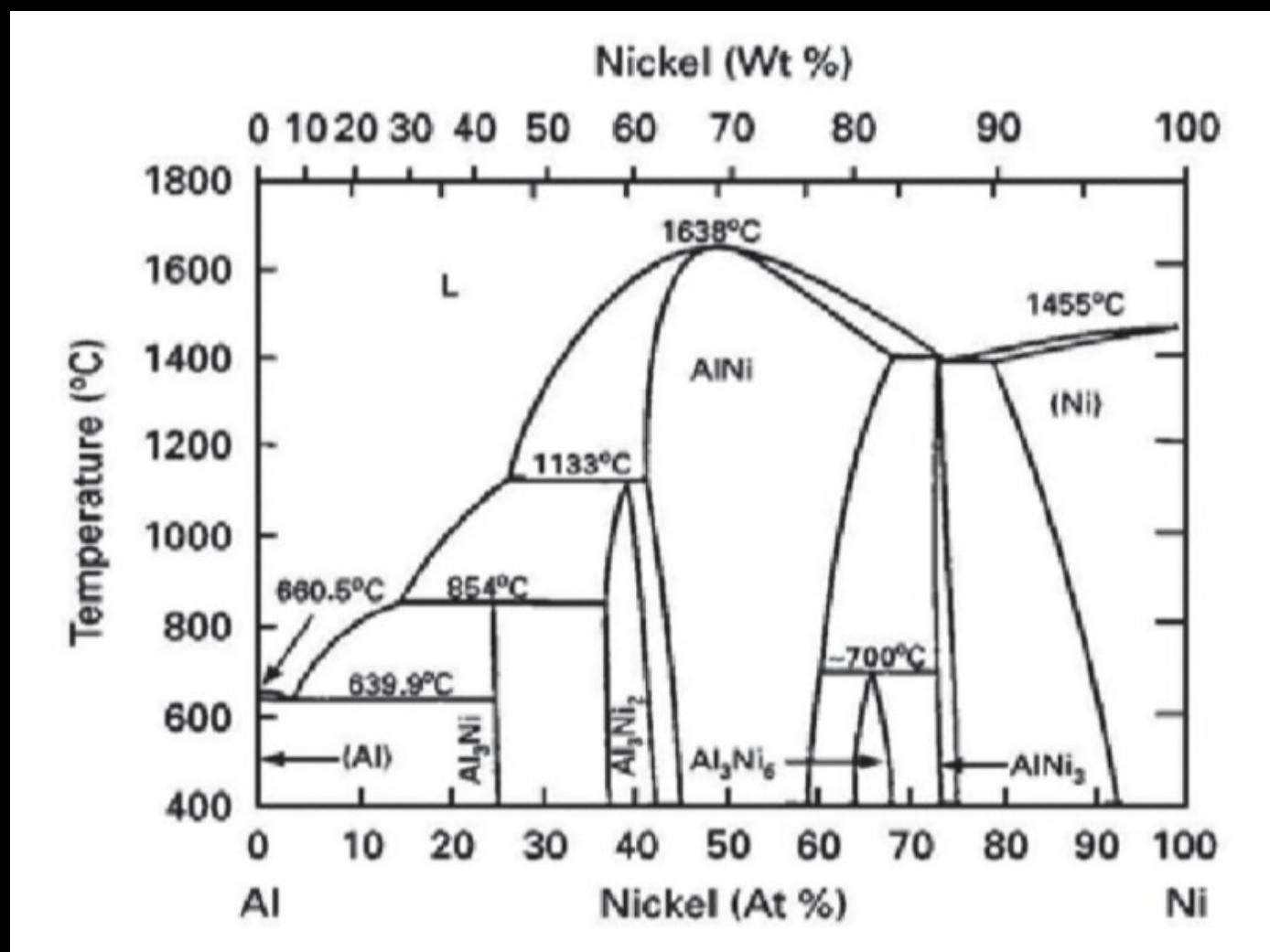


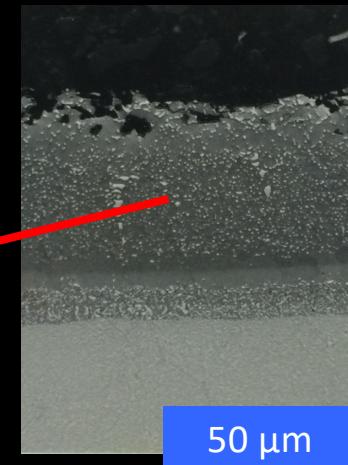
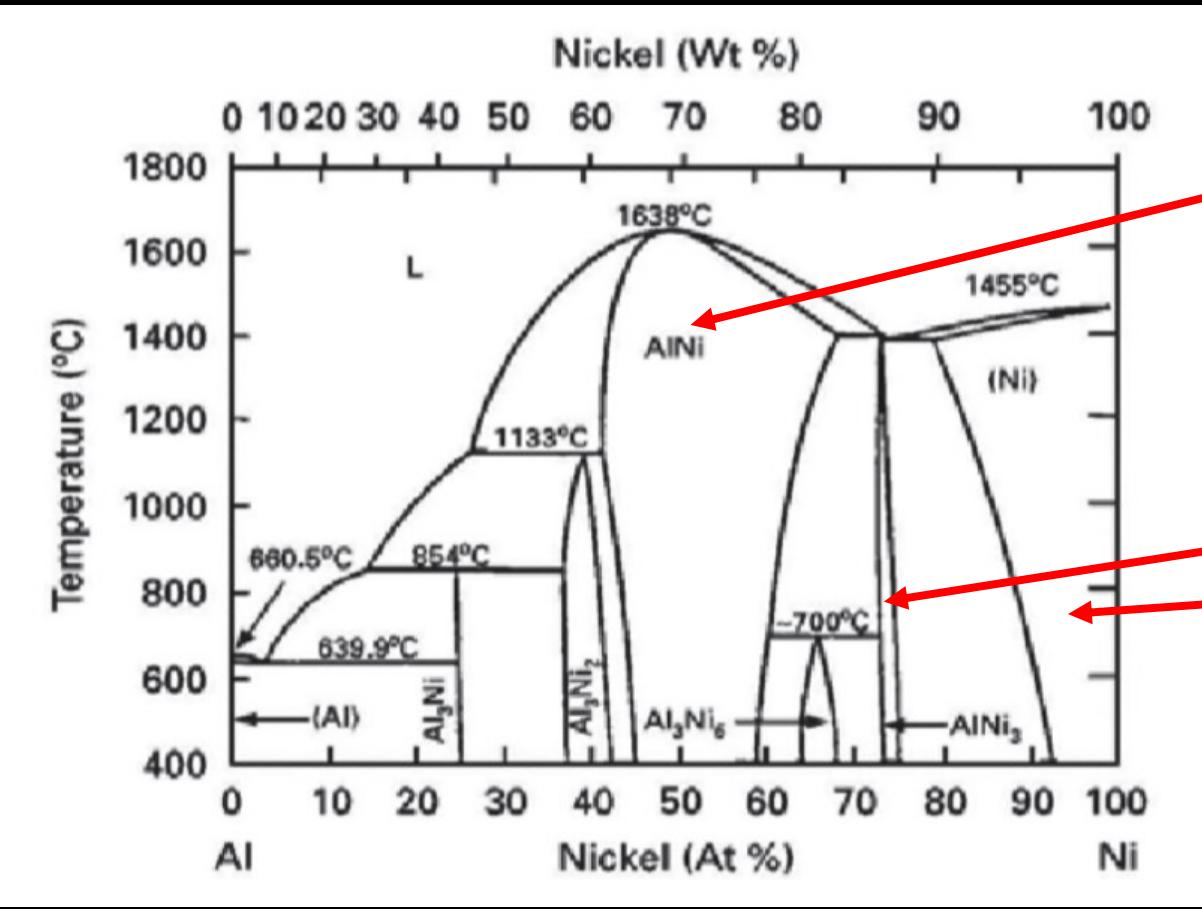
Al-Ni phase diagram



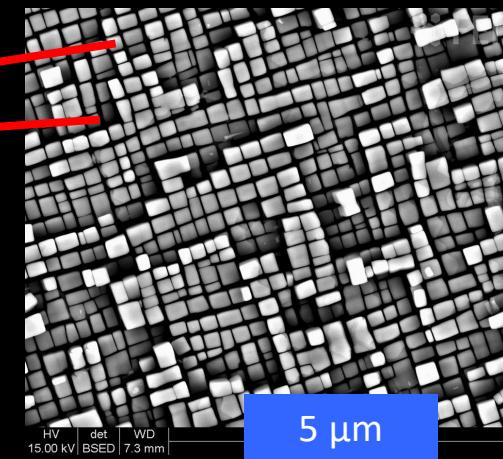
www.doitpoms.ac.uk

aluminium-nickel
phase diagram





microstructure of coating



microstructure of blade

exam

See Course guide p6

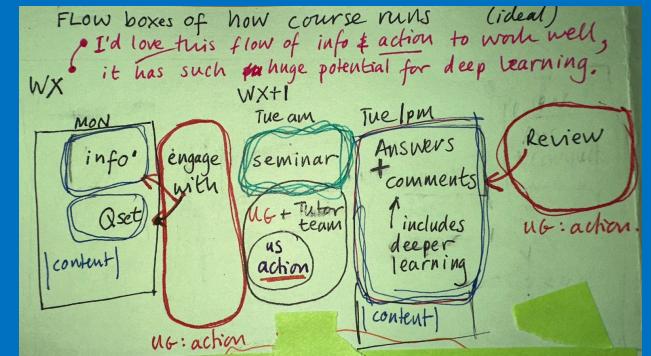
Past papers available via library website. I recommend looking at them soon so you get an idea of the style of questions and how they link to the course material.

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

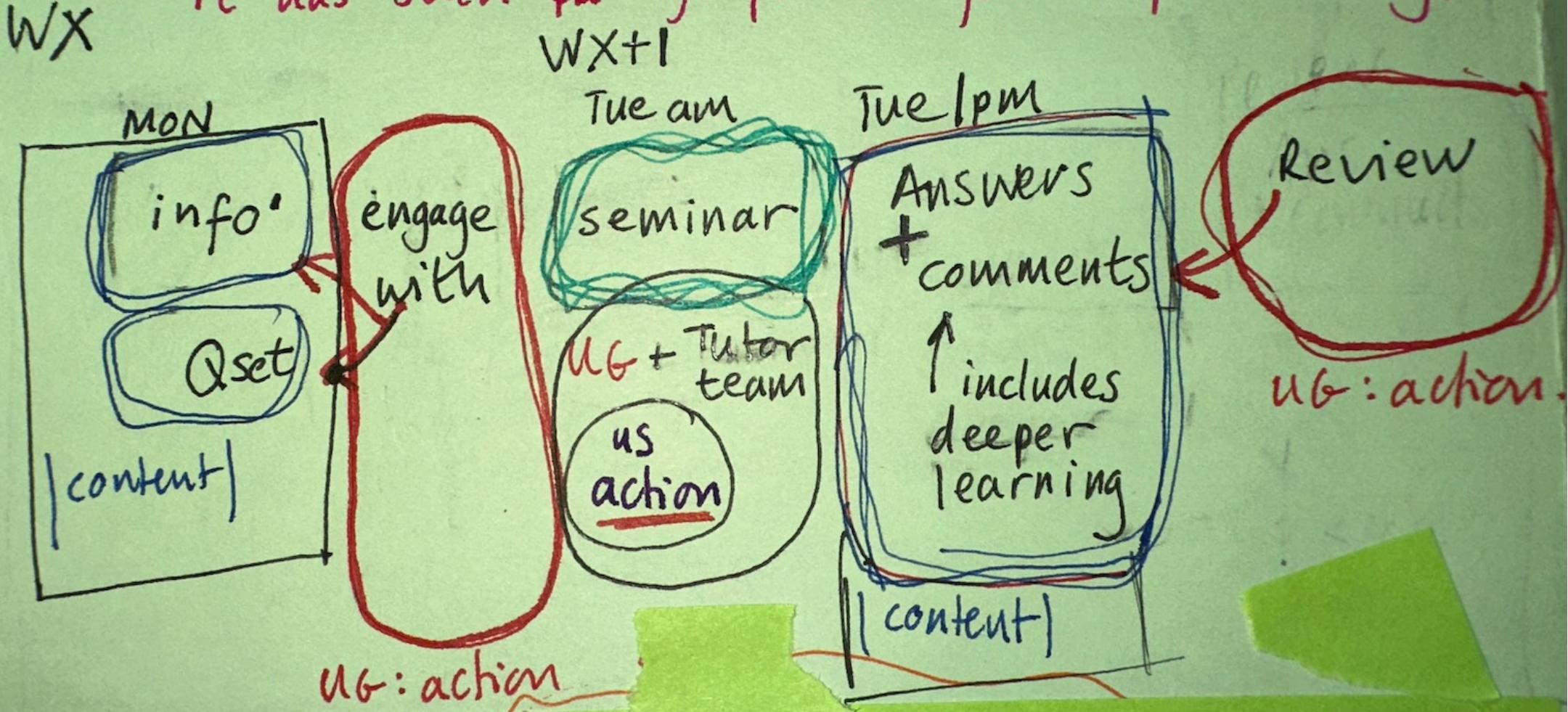
Repetition

#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 ~~so~~ 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?

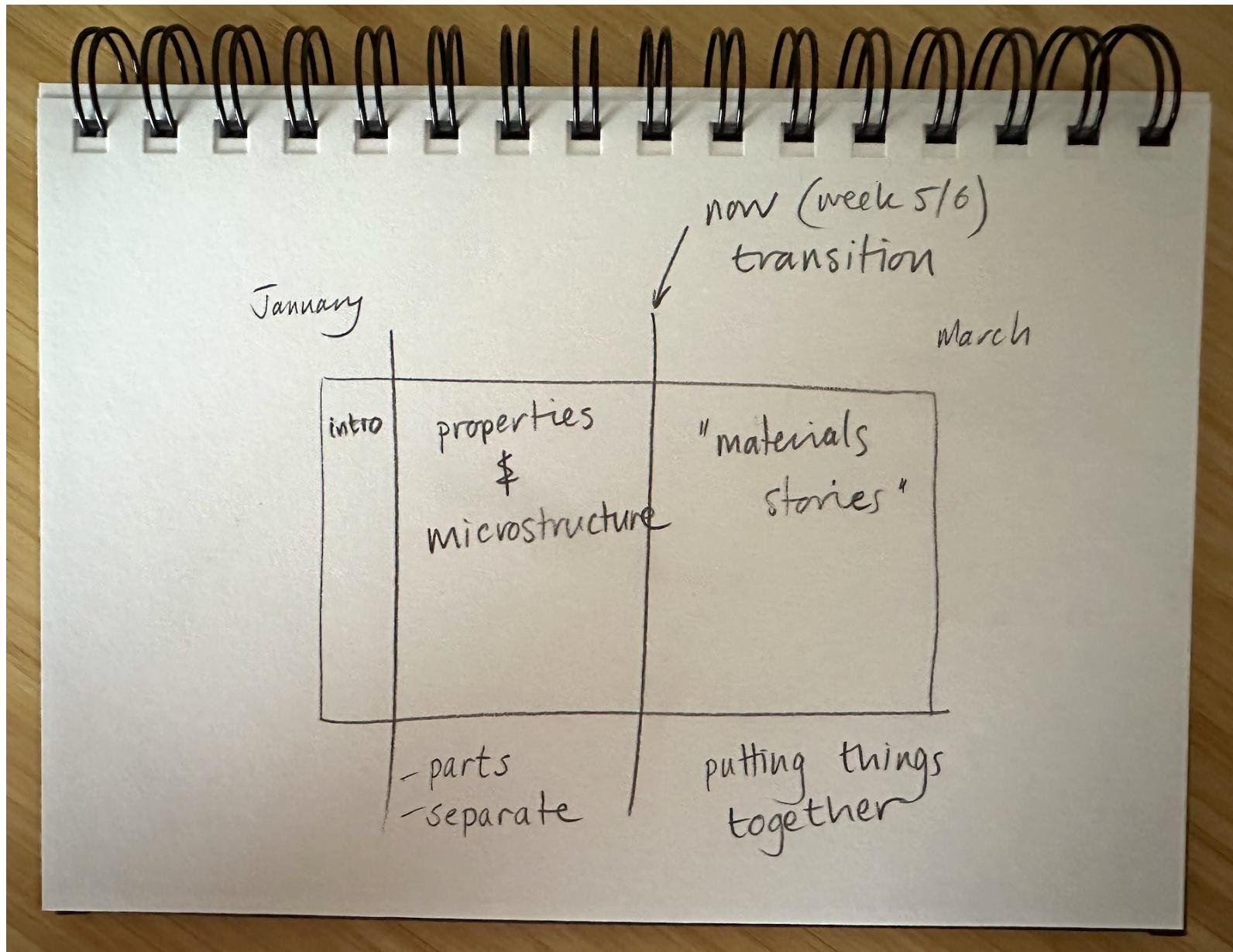
3. Course Outline

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	<ul style="list-style-type: none">• Why are materials important for engineers?• Classification of materials.• What are you going to study in this course?• Introduction to your building own materials toolbox.• How to learn and engage with the course	
Section 2: Properties and Microstructure How do things behave and why? The building blocks for using and understanding materials		
2	<p>Properties:</p> <ul style="list-style-type: none">• What are material properties?• How do we find material property data (tests, resources, Ashby materials section chart)?• Testing for mechanical properties; what happens inside the material as it is deformed?	
3	<p>Small scale structure (microstructure):</p> <ul style="list-style-type: none">• Structures on different length scales• Links between everyday observations, properties, material classes, and small scale structures.• As an engineer, which structures are essentially fixed, and which can you change?	Lab *
4 – 5	<p>Small scale structures of metals, ceramics and polymers</p> <ul style="list-style-type: none">• Classifications of metals, ceramics and polymers.• The small scale structure of metals, ceramics and polymers and links to their behaviour.• What makes alloys stronger than pure metals?	Granta *
5 – 6	<p>Phase Diagrams</p> <ul style="list-style-type: none">• What are phases in materials?• Use phase diagrams to understand metallic alloy microstructure and properties.	
Section 3: Materials Stories, and Materials Selection		
7-10	<p>Examples of applications of materials. Deepening your understanding of materials and making connections through case studies.</p> <ul style="list-style-type: none">• Concrete and timber.• Composite materials.• The Challenger disaster and Liberty ships.• 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.



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 commonality 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*, ρ (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, ν , 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	ρ (kg/m^3)
Mechanical	Elastic moduli (Young's, shear, bulk)	E , G , K (GPa)
	Strength (yield, ultimate, fracture)	σ_f (MPa)
	Toughness	G_c (kJ/m ²)
	Fracture toughness	K_{Ic} (MPa m ^{1/2})
	Damping capacity	η (—)
	Fatigue endurance limit	σ_e (MPa)
Thermal	Thermal conductivity	λ (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	α (°K ⁻¹)
	Thermal shock resistance	ΔT (°K)
	Creep resistance	— (—)
Wear	Ardachy 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.

"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

Resources

MFA 1989, CH chapters 2009

Library including e-books on Resource List

Ansys Granta

ICE Manual Vol. 27, No. 5, pp. 1273-1281, 1989
Printed in Great Britain. All rights reserved
0014-1180/89 \$1.00 + 0.00
Copyright © 1989 Pergamon Press plc

OVERVIEW NO. 80
ON THE ENGINEERING PROPERTIES OF MATERIALS

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Cambridge University Engineering Department, Trumpington Street, Cambridge CB3 1FZ, England

(Received 8 October 1988)

Abstract — The basic mechanical and thermal properties of engineering materials are surveyed and interpreted. The chart reveals the range of each property, the sub-range associated with each material class, and the range of applications. These applications are illustrated by diagrams, some of which 10 are presented here. The diagrams have numerous applications which range from the identification of fundamental relationships between material properties to the selection of materials for engineering design.

Résumé — Nous passons en revue et nous discutons entre elles les propriétés mécaniques et thermiques fondamentales des matériaux d'ingénierie. Le tableau indique la portée de chaque propriété, la sous-portée associée à chaque classe de matériau, et la portée d'applications. Ces applications sont illustrées par des diagrammes, dont 10 sont présentés ici. Ces diagrammes ont de nombreuses applications qui vont de l'identification fondamentale entre les propriétés du matériau à la sélection du matériau à une utilisation technique.

Zusammenfassung — Die grundlegenden mechanischen und thermischen Eigenschaften von Konstruktionsstoffen werden zusammengefasst und interpretiert. Diese Zusammenfassung beschreibt die Breite eines jeden Eigenschaften, die Unterbreitung, die mit jeder Materialklasse verbunden ist, und die Breite der Anwendungen. Diese Anwendungen sind durch Diagramme illustriert, von denen 10 hier dargestellt werden. Diese Diagramme haben zahlreiche Anwendungen, die von der Identifizierung fundamentaler Beziehungen zwischen Materialeigenschaften bis zur Auswahl von Werkstoffen für Konstruktionen reichen.

SYMBOLS, DEFINITIONS AND UNITS

a	stress (MPa)
A	yield-stressing strength (MPa)
A_c	crack tip crack length (m)
c	velocity (m/s)
C_p	specific heat at constant pressure (J/kg K)
E	Young's modulus (GPa)
f	allowable stress (MPa)
f_t	nonthermal modulus (GPa)
F	failure energy (J/m ²)
G	shear modulus (GPa)
g	gravitational acceleration (9.81 m/s ²)
h	heat transfer coefficient (W/m ² K)
J	bulk modulus (GPa)
J_0	fracture toughness (J/m ²)
J_{∞}	mean free path (nm)
R	radius of gyration (m)
S	heat capacity (J/kg K)
T	thickness of section (m)
T_m	melting point (K)
α	coefficient of thermal expansion (m/m)
κ	linear expansion coefficient (K ⁻¹)
σ	surface energy (J/m ²)
τ	Graebner's constant (J/m ²)
ρ	density (kg/m ³)
v	Poisson's ratio (—)

I. INTRODUCTION. MATERIAL PROPERTY CHARTS

Each property of an engineering material has a characteristic range of values. The range is enormous: for the ten properties considered here, properties such as the ion properties cover ranges of values over all three orders of magnitude. Within this range, however, there are smaller ranges, called sub-ranges, which determine the value of the property. It is conventional to classify the solids themselves into the following groups: metals, ceramics, glasses, polymers, elastomers, ceramics, glasses and composites. Within a class, a range of properties is narrowest, and within a material, the range is widest. The classifications of this sort have their dangers, notably those of narrowing vision and of obscuring relationships. Within a class, it is often useful for comparing materials, examining the relationships between the properties of six or seven.

One way of doing this is by constructing *Material Property Charts*. The idea is illustrated by Fig. 2. One property (the modulus, E , in this case) is plotted

1273

doi:10.1080/096033309320013001
ICE Manual of Construction Materials © 2009 Institution of Civil Engineers
www.icemanuals.com 1

Chapter 1
Fundamentals of materials

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

The long and still visible history of civil engineering shows how materials influence construction practice and design. Modern materials are diverse in composition and internal microstructure. Broadly, we recognise three major families: metals, ceramics and polymers. Each family has its own characteristic features of composition and microstructural organisation, including pore structure. There is increasing emphasis on sustainability in the selection and performance of materials, not least because of the prodigious quantities consumed in civil engineering and building throughout the world.

Introduction

Materials are at the heart of all branches of engineering. It can be argued – and with not much exaggeration – that engineering is the creative and rational use of materials for practical purposes. *Homo faber*, man the maker, works with the materials of the world to make what is possible. Engineers are better engineers if they have a good understanding of the properties of the materials which they use. In the past this came from tradition and familiarity rooted in tradition and craft practice. Now the range and variety of materials is so great that this is hardly feasible. The challenge to the engineer is also made greater by the fact that new materials are constantly being developed. But, at the same time, scientific knowledge of materials – of their composition, behaviour and properties – is also growing. Scientific progress is the key to understanding materials, both new and old. Within this framework we can include all types of materials, thus to some extent modifying the treatment of the metals, ceramics, glasses and composites sections of the *Materials science*.

Masonry has not only a great cost, but also requires joining materials such as gypsum, reins, bitumens, and, later, times have been of value since Egyptian times. The vault and the dome. Nonetheless, wood, another as-found material, was used widely in construction. Being less dense than stone, structures survive less frequently. Timber beams resistant to bending carried tensile loads from earliest times.

Masonry may be built using shaped stones, and joining materials such as gypsum, reins, bitumens, and, later, times have been of value since Egyptian times. The vault and the dome. Nonetheless, wood, another as-found material, was used widely in construction. Being less dense than stone, structures survive less frequently. Timber beams resistant to bending carried tensile loads from earliest times.

The metallic tradition (a phrase of J. E. Gordon) has been dominant throughout engineering for the last two centuries. It is from physical metallurgy that have emerged the combustion engine, the jet engine, the oil tanker, the automobile, the skyscraper, the space shuttle, the mobile telephone, the petrochemical plant and the machines of war. We can add to this list countless innovations in electrical power engineering and in electrical machines, including the engineering of building services. Metals, of

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Health and safety in materials	2
Type of material: composition	3
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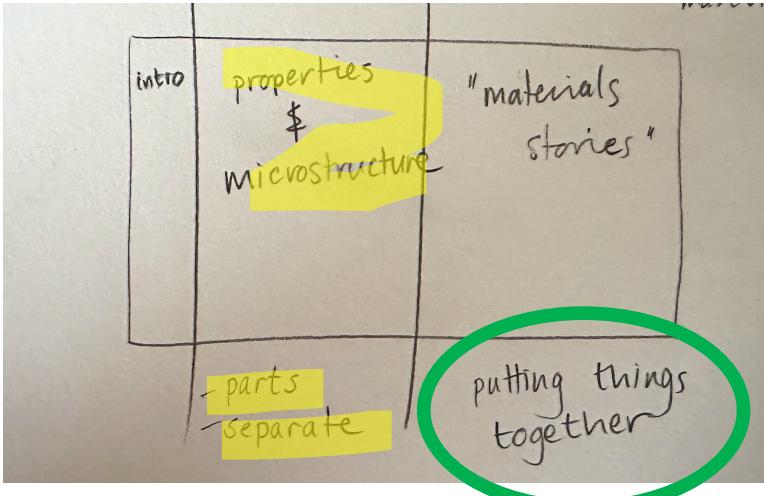
Resources

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 ^{and AI} 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.



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

How do things behave and why?

The **WHAT** Framework

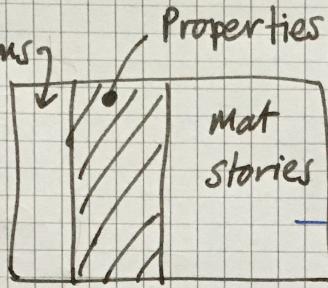
Materials

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

putting things together
- combinations of materials
- Applications – ‘big picture’

Materials 2

- Foundations



Properties + small scale structure
(microstructure)

WHAT

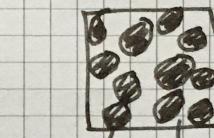
framework

- Materials
 - metals
 - ceramics
 - polymers
- Properties
- Microstructure
- processing
- Applications

individual
materials

Learn basics

• Concrete • timber • snow



cement
matrix

"space"
cellular
materials.

fibres
e.g. ceramic



Project:
Title:
Date:

Made by:
Title:
Date:
Checked by:

Combinations
of materials
interactions / interfaces

Application
'big picture'



MEASURE
THAT!



thinkinwile.org

Materials toolbox: in practice

moving between parts & ‘big picture’

complex messy ambiguous real can be more interesting than ‘parts’

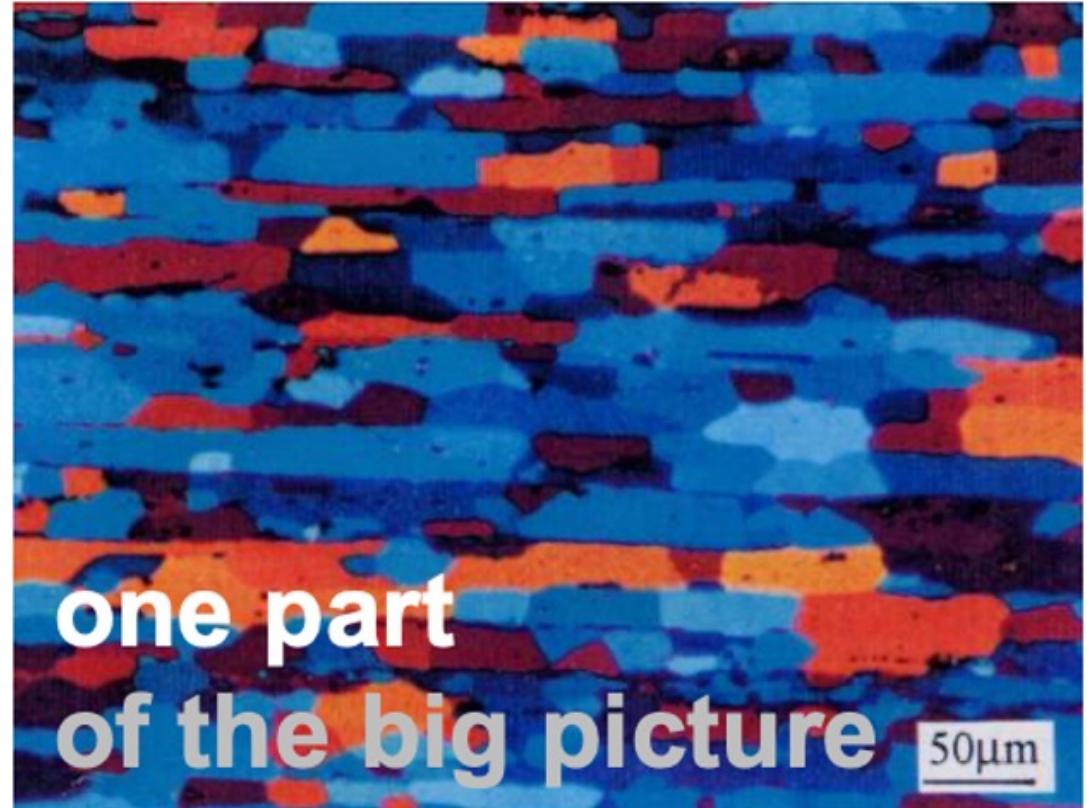
making assumptions – can’t consider everything decision making

Materials toolbox: in practice

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



big picture



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**

www.

'devices'

social media

artificial
intelligence *

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.

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.

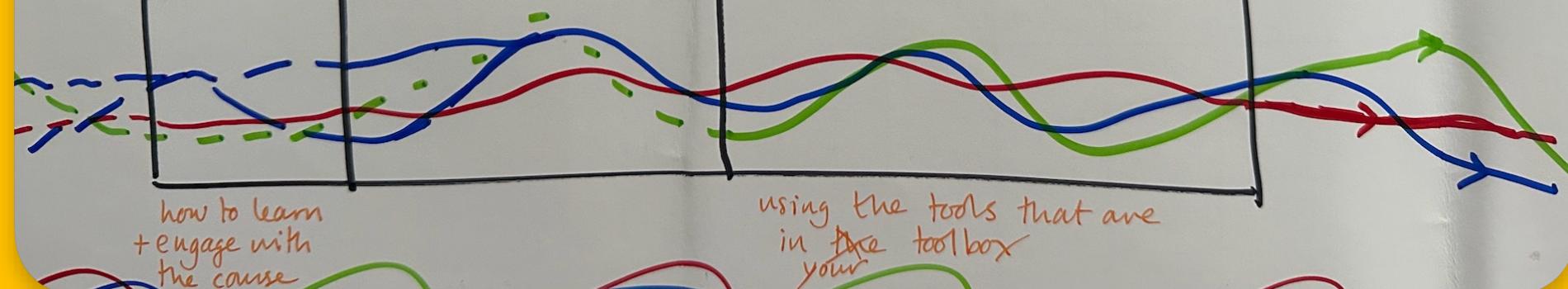
why are materials
important?
And what
interests
you?

- 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.



#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



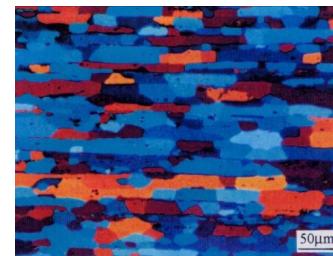
Wood = natural polymer
And we can see the small scale structure

WHAT Framework

Materials

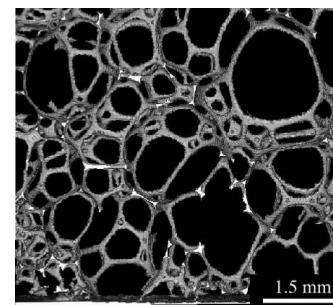
- Classifications
- Properties
- Small scale structure (microstructure)
- Processing / manufacturing
- Applications

Microstructure



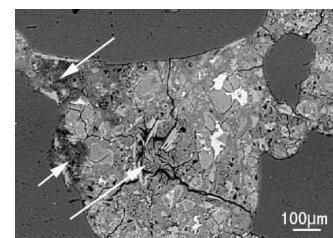
Al alloy
bike frame

metal



open cell
polymer
foam
(saddle)

polymer



concrete
(that's
degrading)

ceramic

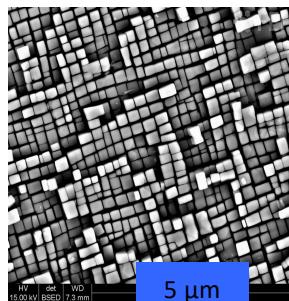
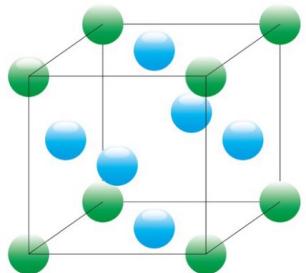
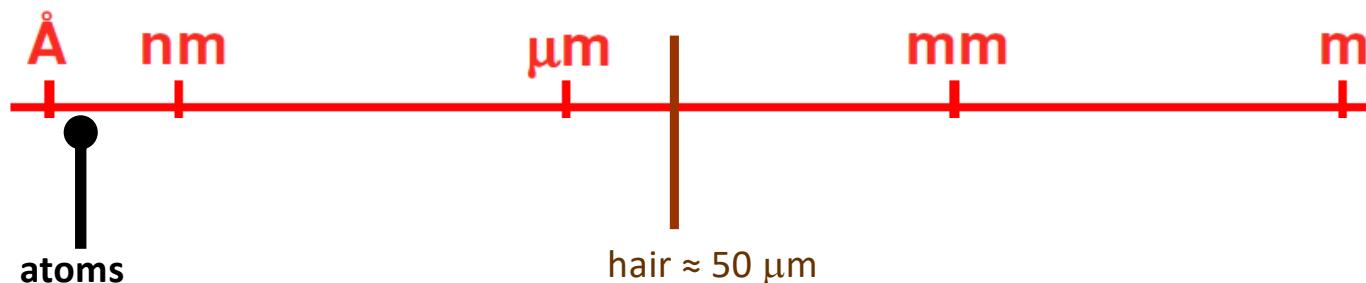
Note image scale bars – they indicate how big the features are

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 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 also used in industrial power generation turbines



WHAT Framework

Materials

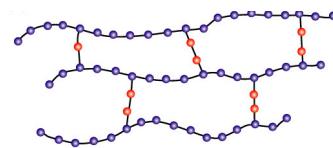
- **Classifications**
- **Properties**
- **Small scale structure**
(microstructure)
- Processing / manufacturing
- **Applications**

extra

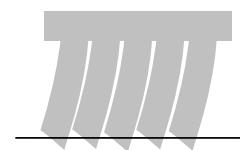
Rubber & tyre development - hierarchy

pure
rubber

tyre rubber



tread block



whole tyre



car



science
simple systems

engineering
driving performance
complex systems

Experimental techniques & length scales

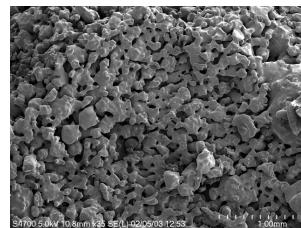
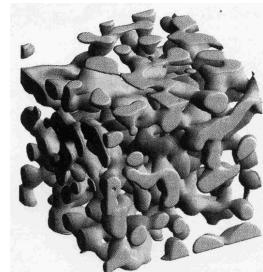
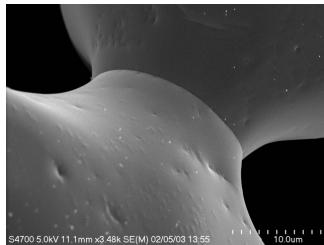
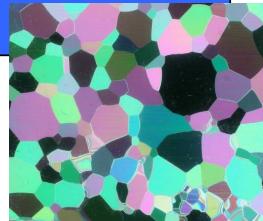
extra

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

