Teaching Materials and Processes to First and Second Year Students

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Approaches to materials teaching

Engaging the interest of first and second year students is a challenge. In teaching students of Physics and of Materials Science it makes sense to start with the structure of the atom, building upwards through the physics of bonding, crystal structure and band theory, the thermodynamics and kinetics of alloys, finally arriving at material properties (*Figure 1* - left to right).

Students of Engineering often find this too remote from the goals that motivate them. Engineers *make* and *manage* things. What do they need to know about materials to choose and use them successfully? First, they need a *perspective* of the world of materials – the "menu" of metals, polymers, glasses, ceramics, composites, and of processes that can shape, join and finish them. Second, some *understanding* of the origin of these properties how they can be manipulated. Third, they need *methods* for selecting from these menus the materials and processes that best meet the requirements of a design. Fourth, they need access to *data* for materials attributes and – since the quantity of data is large and the methods tedious to implement by hand – computer-based tools to enable their implementation.

At the University of Cambridge, working with Granta Design and colleagues at many other universities, we have developed an approach to teaching engineering students about materials and processes that is structured to give students this understanding. It starts with an introduction to design methods and the ways in which information about materials enters the design process. Material properties are presented in property charts that provide an overview of the ranges of the properties and become a selection tool for choosing materials to meet given design constraints. Once the relevance of a property to design is established, it becomes logical to "drill down" to the underlying science, demonstrating where the property comes from and how it can be manipulated (*Figure 1*, reading right to left).

Design-driven and science-driven approaches both need tools and resources to engage and inspire students. In developing our design-driven courses we have created a number of such tools and resources that have proved to be particularly valuable for introductory courses, of whatever teaching approach.

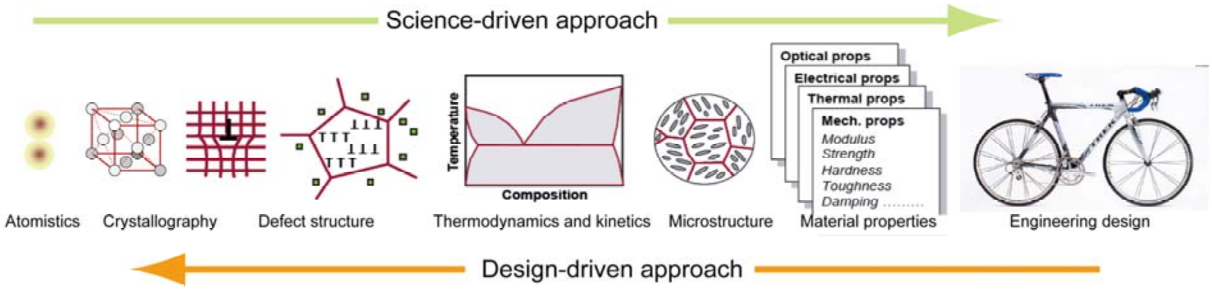


Figure 1. Two alternative approaches (much simplified) to the teaching of materials.

Property charts, selection and science

Figure 2 (overleaf) is an example of a material property chart (elastic modulus, E, plotted against density, ρ). The range of the axes is chosen to include all materials, from the lightest, softest foams to the stiffest, heaviest metals. The properties of a given family of materials (polymers, for example) cluster together; the *sub-range* associated with one family is, in all cases, much smaller than the *full range* for that property. Data for one family can be enclosed in a family-envelope, as the figure shows. Within it lie bubbles enclosing classes and sub-classes. All material properties can be presented in this way. They provide a tool-set for material selection to meet specified design constraint, the methods for which are integral to our design-driven course.

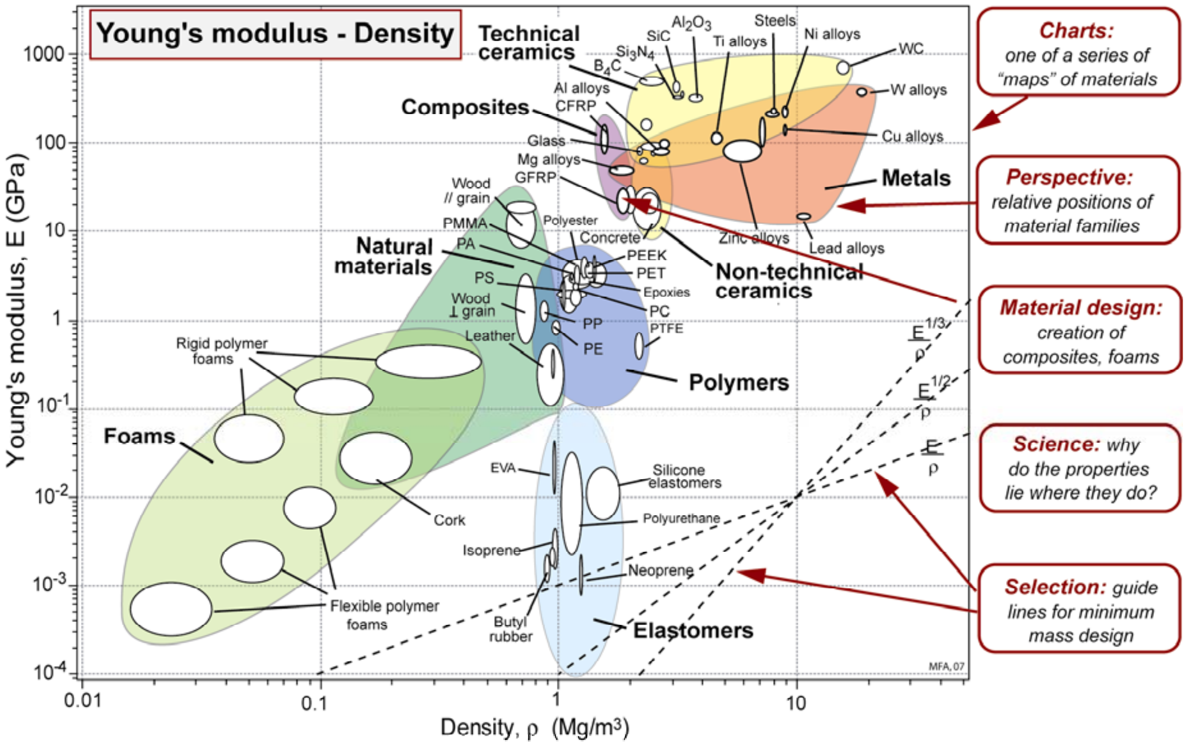


Figure 2. An example of a materials property chart and its use to give a perspective, to allow selection, to explore how properties are manipulated, and to introduce the underlying science.

Within introductory courses – whether design-driven or not – the charts can be used to explore another set of questions. Why do members of material classes cluster in the way they do? What determines where clusters lie on the charts? Why are some properties so obviously correlated? How can properties be manipulated to better meet design requirements? These questions are a natural lead-in (and one the engineering student sees as relevant) to the underlying science of the material classes – the atomic bonding and packing determining density, melting point and stiffness; the defect structure determining hardness, strength, toughness; the transport properties and the magnetic behavior.

Encouraging use of these charts to explore the materials world stimulates student interest. But, as understanding progresses, more detail is needed. The CES EduPack software, developed specifically for education, can help, allowing students to create charts with any combination of properties, to zoom in on any part to increase resolution, and to access records for the attributes of any material (*Figure 2* was created with the software).

The package includes selection tools to meet complex design requirements and backs this up by giving access to the underlying science. *Figure 3* shows part of a material record. It starts with a description of the material and an image of a familiar object made from it – a way of conveying information relevant for industrial design. That is followed by a table of material properties, a list of typical uses, and, in a higher level of the software, design guidelines, technical notes and notes concerning its impact on the environment. Each field name (e.g., "Young's Modulus") in a material record is linked to text files – known as Science Notes – giving a definition of the attribute, a description of how it is measured and explanation of its origins. Finally, each material record is linked to appropriate members of a parallel database of manufacturing processes: those that can shape, join, finish and decorate it.

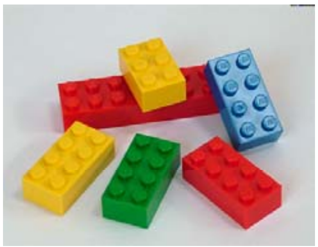
We have found that the CES EduPack software provides a simple, highly visual and engaging, framework within which students can explore rich content – "drilling down" to the fundamental science and making a direct connection between this science and design applications. Such connections help to build a materials perspective and understanding and can be particularly valuable in developing an enthusiasm for the subject amongst first and second year students.

Supporting texts and resources

The computer-based tools of CES EduPack can only provide one component of a rounded introductory materials course. We have developed a series of supporting lectures and exercises that can help lecturers to build such a course. The choice of supporting textbook(s) will also be vital.

The CES EduPack software introduces materials fundamentals in a manner that complements any introductory materials text regardless of the approach (science or design-led) or the text from which it is taught. For example, Callister's "Materials Science and Engineering: an Introduction" (2), Budinski's "Engineering Materials" (3) or Askland's "The Science

Acrylonitrile butadiene styrene (ABS)



The Material

ABS (Acrylonitrile-butadiene-styrene) is tough, resilient, and easily molded. It is usually opaque, although some grades can now be transparent, and it can be given vivid colors. ABS-PVC alloys are tougher than standard ABS and, in self-extinguishing grades, are used for the casings of power tools.

General properties

Density	1e3	-	1.2e3	kg/m^3
Price	2	-	2.7	USD/kg

Mechanical properties

Young's modulus	1.1	-	2.9	GPa
Hardness - Vickers	5.6	-	15	HV
Elastic limit	19	-	51	MPa
Tensile strength	28	-	55	MPa
Compressive strength	31	-	86	MPa
Elongation	1.5	-	1e2	%
Endurance limit	11	-	22	MPa
Fracture toughness	1.2	-	4.3	$MPa.m^{1/2}$

Thermal properties

Thermal conductivity	0.19	-	0.34	W/m.K
Thermal expansion	85	-	230	µstrain/°C
Specific heat	1400	-	1900	J/kg.K
Glass Temperature	88	-	130	°C
Max service temp.	62	-	90	°C

Electrical properties

Resistivity	2.3e21	-	3e22	µohm.cm
Dielectric constant	2.8	-	2.2	

Typical uses

Safety helmets; camper tops; automotive instrument panels and other interior components; pipe fittings; home-security devices and housings for small appliances; communications equipment; business machines; plumbing hardware; automobile grilles; wheel covers; mirror housings; refrigerator liners; luggage shells; tote trays; mower shrouds; boat hulls; large components for recreational vehicles; weather seals; glass beading; refrigerator breaker strips; conduit; pipe for drain-waste-vent (DWV) systems.

Figure 3. Part of a record for ABS from the CES EduPack materials information software

and Engineering of Materials" (4), all of which take the science-led route, can be augmented and reinforced with software-based exercises to explore the world of materials.

We have developed the design-led approach in a number of texts, of which two are appropriate for first and second year teaching. A new text "Materials: engineering, science, processing and design" (5) introduces key methods and illustrates their application to the use of materials in mechanical, thermal, electro-magnetic and optical design. It offers a high degree of integration with CES EduPack, including exercises using the software. "Materials and Design" (6) addresses issues of industrial design, providing an introduction to materials for students of product design. "Materials Selection in Mechanical Design" (7) is a more advanced text, developing the methods to a higher level, one appropriate for third, fourth year and masters level teaching. All three have numerous exercises for which solution manuals are available.

Project-based teaching

The CES EduPack provides a resource for project-based teaching. The projects that we use for first and second year students focus on analyzing material choice for familiar products, avoiding at this early stage the need for a detailed understanding of complex systems.

In the Bicycle Project, for example, students are first asked to select a component of a bicycle (frame, forks, saddle, spokes, brake-cable…) and a user group (e.g., children, shoppers, touring use, sprint, mountain biking…) for which the design is intended. They are then asked to formulate the requirements if the product is to meet the needs of that group and the objective appropriate to it (minimizing weight or cost, maximizing robustness…). These provide the inputs for the CES EduPack software, which delivers a ranked list of suitable candidates, datasheets for their properties, and suggested manufacturing routes.

Redesign to reduce the environmental impact of a product is a rich source of projects. The students must decide which phase of life (material production, product manufacture, product use, disposal at end of life) poses the greatest environmental problem, and then select appropriate materials to minimize this. The CES system provides all the resources to enable projects of this sort.

Summary

First and second year students need: a materials perspective, methods, tools and understanding to enable the rational selection and use of materials. Strong links with design, for example via a design-driven teaching approach, can provide immediate integration with the other engineering subjects. Whatever approach is adopted, the simplicity and visual impact of property charts offer valuable support, particularly within computer-based tools such as CES EduPack. Experience shows that students like such tools, which motivate them to explore materials for themselves. Such software also provides exportable skills: students gain an insight into professional-level engineering tools.

References

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