Granta EduPack White Paper

Teaching Engineering Materials: Granta EduPack

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Abstract

A design-led procedure for the teaching of materials and processes is described. It is based around Granta EduPack: a set of resources for teaching materials and manufacturing processes. The texts and tools explain material and process properties, develop the underlying science and allow design-led selection. A central element is a materials selection method that is systematic, building on the identification of constraints that the material or process must meet, and on the objectives that govern the design. The method is documented and demonstrated in the texts and is supported by extensive computer-based methods, tools and data. The underlying science is presented through links to explanatory text and developed further via an additional database documenting the properties of the elements of the Periodic Table. The structure, the various levels, the specific tools and the advanced databases of Granta EduPack support teaching from introductory to more advanced levels and into research areas across multiple disciplines.

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1. Introduction

Engineers *make* things. They make them out of materials. What do they need to know to choose and use materials successfully? First, a *perspective* of the world of materials – the "menu" of metals, polymers, glasses, ceramics, composites and so forth – and of processes that can shape, join and finish them. Second, some *understanding* of the origin of these properties and of the ways that 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 material attributes and – since the quantity of data is large and the methods tedious to implement by hand – computer-based tools to enable their implementation. And, of course, they need *common sense*: the ability to use experience and knowledge of the world at large to recognize inspired choices and to reject those that are impractical.

The interaction between the choice of material, the function of the part and the manufacturing process for that part cannot be neglected: a systematic selection of a material will have to take that into account (Figure 1). Data on cost of raw materials, cost of manufacturing and environmental impact should also be present.

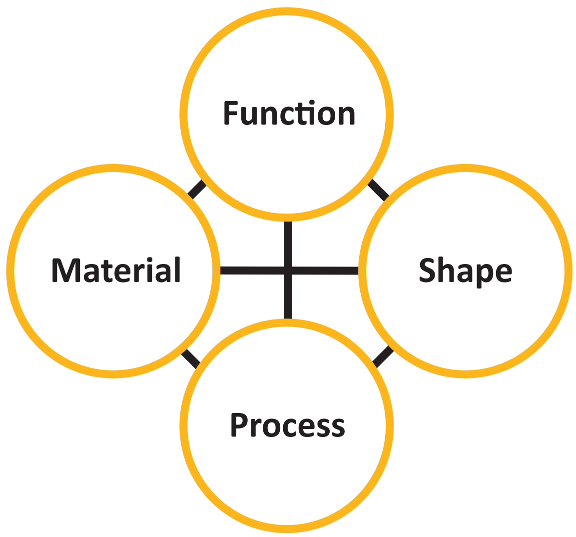


Figure 1. The choice of a material for a given application is not independent of shape, function and manufacturing process.

2. Material and process attributes

A material has *attributes*: its density, strength, cost, resistance to corrosion, and the like [1 - 4]. A design demands a certain profile of these: a low density, a high strength, a modest cost and resistance to sea water, or low environmental impact, perhaps. The task of selection is that of matching the choice of material to the requirements of the design [5 - 11].

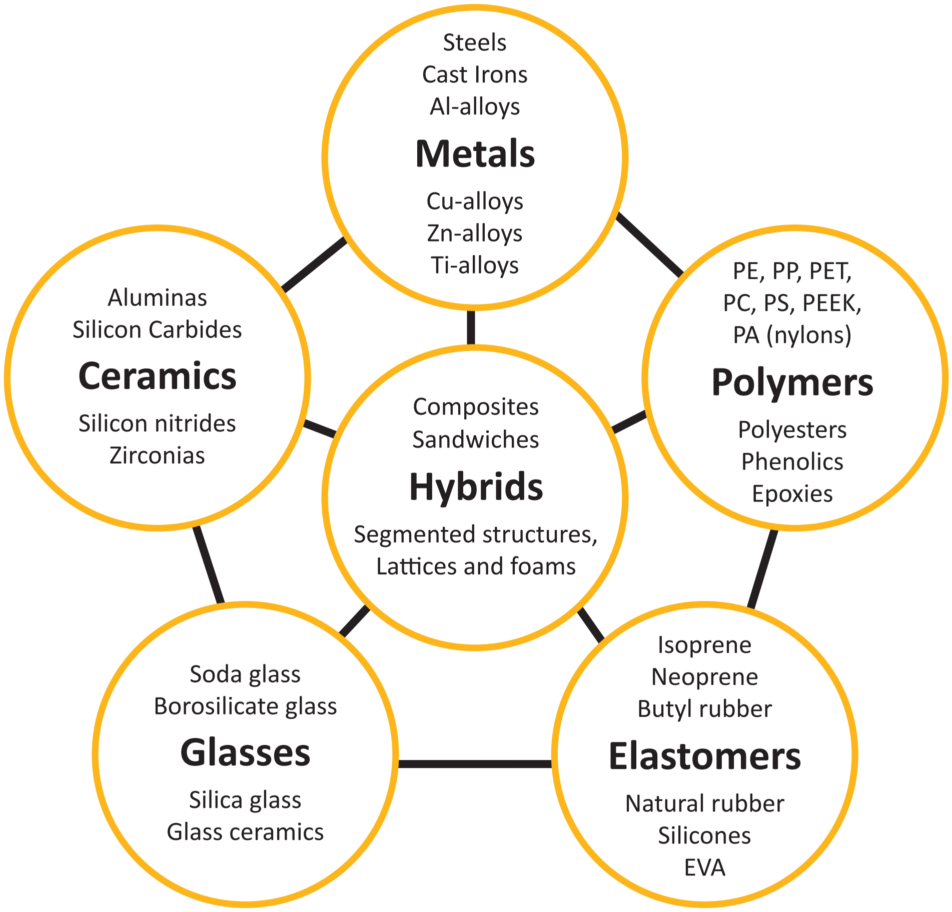


Figure 2. The menu of engineering materials. The basic families of metals, ceramics, glasses, polymers and elastomers can be combined in various geometries to create hybrids.

Material attributes

The starting point is the "*universe*" of materials. Figure 2 shows the material families: p*olymers, metals, ceramics, glasses, natural materials*, and the *hybrids* that can be synthesized by combining these. Figure 3 expands this structure, suggesting a hierarchical organization of the population. Each family embraces classes, sub-classes and members; in this figure the family of metals is expanded to show the class of aluminum alloys and the sub-class of 6000-series aluminum alloys, containing many members (e.g. Al-6061). It, and every other member of the universe, is characterized by a set of attributes that include its mechanical, thermal, electrical, optical and chemical properties, its processing characteristics, its cost and availability, and the environmental consequences of its use. We call this its *property profile*.

Process attributes

Information about manufacturing processes can be organized in a similar way. Figure 4 shows part of the hierarchy. The Process universe has three families: shaping, joining and surface treatment. In this figure, the shaping family is expanded to show classes: casting, deformation, molding etc. One of these – molding – is again expanded to show its members: rotation molding, blow molding, injection molding and so forth. Each process is characterized by a set of attributes: the materials it can handle, the shapes it can make, their size, precision, economic attributes like batch size (the number of units that it can make most economically) and labor intensity and a set of parameters that enable a simple cost model to predict a relative cost index.

3. The selection strategy

Selection involves seeking the best match between the property profiles of the materials in the universe and that required by the design. The strategy for achieving this match is sketched in Figure 5. It connects with the literature on design [12-16].

Translating

The first task is that of *translation*: converting the design requirements into a prescription for selecting a material and a process to shape it. Any engineering component has one or more *functions*: to support a load, to contain a pressure, to transmit heat, and so forth. This must be achieved subject to *constraints*: that certain dimensions are fixed, that the component must carry the design loads without failure–that it insulates or conducts, that it can function in a certain range of temperature and in a given environment, and many more. In designing the component, the designer has one or more *objectives*: to make it as cheap as possible, perhaps, or as light, or as safe, or with the least environmental impact, or perhaps some combination of these.

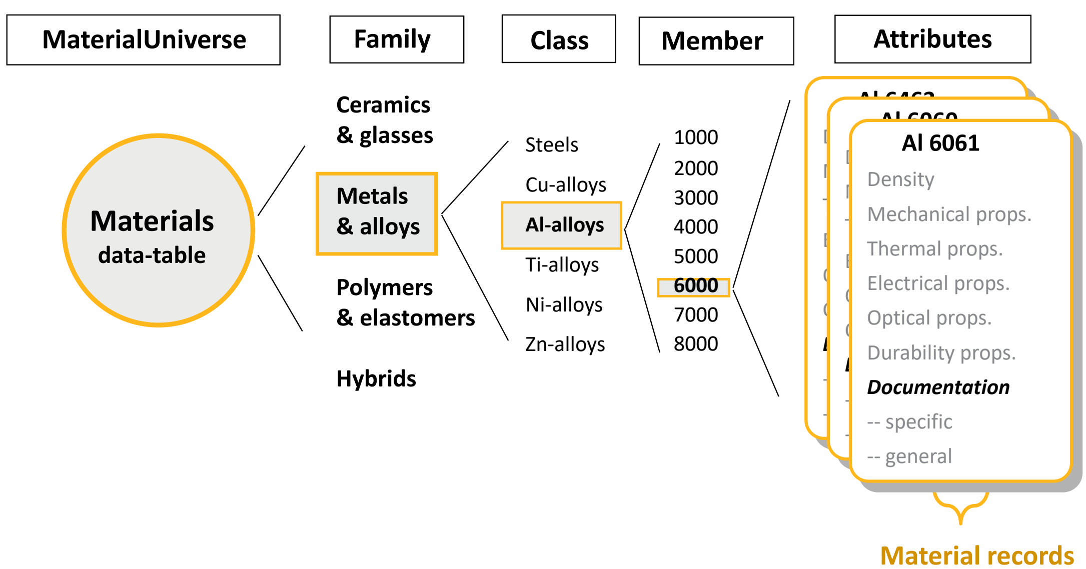


Figure 3. A hierarchical structure for material classification, ending with a schematic of a record.

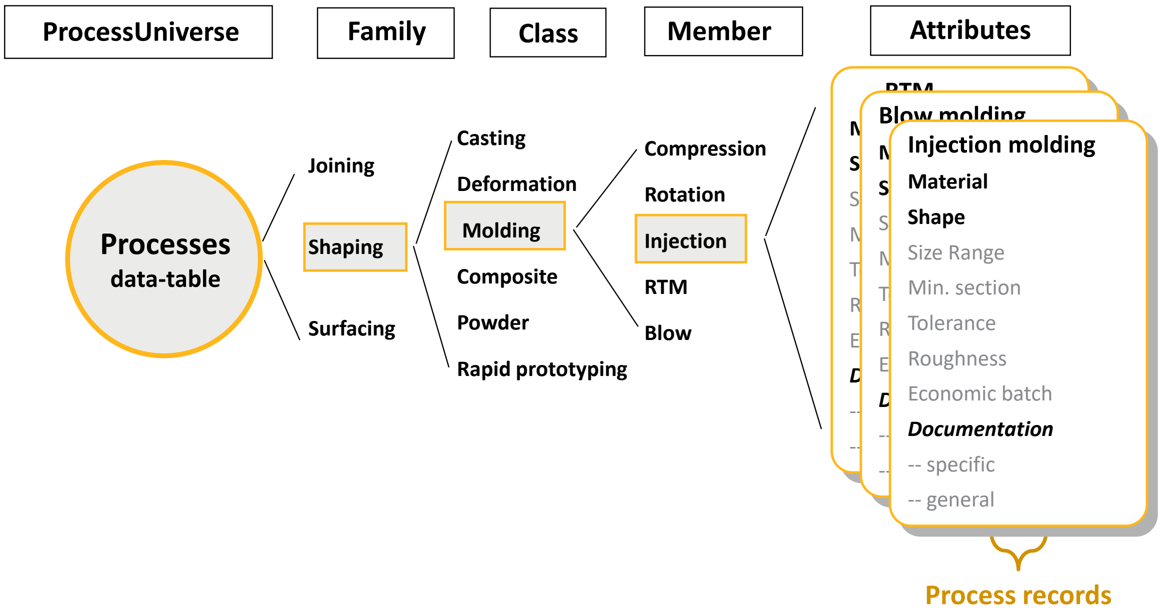


Figure 4. A hierarchical structure for process classification, ending with a schematic of a record.

Certain parameters can be adjusted in order to optimize the objective – the designer is free to vary dimensions that are not constrained by design requirements and, most importantly, free to choose the material for the component. We refer to these as free variables. Function, constraints, objectives and free variables (Table 1) define the boundary conditions for selecting a material and – in the case of load-bearing components – a shape for its cross-section. The first step in relating design requirements to material properties is a clear statement of function, constraints, objectives and free variables. Manufacturing processes can also play a role in constraining the selection. The designer may be interested in a material that can be processed in a specific way (the one in use in his/her current manufacturing plant) therefore limiting the choice of materials.

Function	What does component do?
Constraints	What non-negotiable conditions must be met? What negotiable but desirable conditions…?
Objective	What is to be maximized or minimized?
Free variables	What parameters of the problem is the designer free to change?

Table 1. Function, constraints, objectives and free variables in a materials selection project

Screening: constraints as attribute limits

Unbiased selection requires that all materials are considered to be candidates until shown to be otherwise, using the steps in the boxes below "Translate" in Figure 5. The first of these, *screening*, eliminates candidates that cannot do the job at all because one or more of their attributes lies outside the limits set by the constraints. As examples, the requirement that "the component must function in boiling water", or that "the component must be transparent" imposes obvious limits on the attributes of *maximum service temperature* and *optical transparency* that successful candidates must meet. We refer to these as *attribute limits*.

Ranking: objectives expressed as material indices

To rank the materials that survive the screening step we need optimization criteria. They are found in material indices. A material index measures how well a candidate that has passed the screening steps can perform, that is, meet the objective.

Performance is sometimes limited by a single property, sometimes by a combination of them. Thus the best materials for buoyancy are those with the lowest density, ρ; those best for thermal insulation the ones with the smallest values of the thermal conductivity, λ, provided, of course, that they also meet all other constraints imposed by the design. Here maximizing or minimizing a single property maximizes performance. Often it is not one, but a group of properties that are relevant. Thus the best materials for a light stiff tie-rod are those with the greatest value of the specific stiffness, E / ρ , where E is Young's modulus. The best materials for a spring are those with the greatest value of σ_f^2 / E where σ_f is the failure stress. The property or property-group that maximizes performance for a given design is called its *material index*. There are many such indices, each associated with maximizing some aspect of performance [9, 10]. They provide criteria of excellence that allow ranking of materials by their ability to perform well in the given application.

To summarize: screening isolates candidates that are capable of doing the job; ranking identifies those among them that can do the job best.

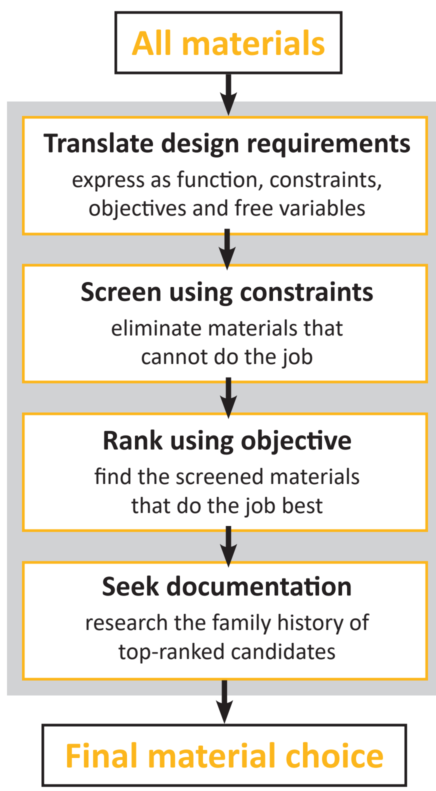


Figure 5. The strategy. There are four steps: translation, screening, ranking and documentation. All can be implemented in software, allowing large populations of materials to be investigated.

Documenting

The outcome of the steps so far is a ranked short-list of candidates that meet the constraints and that maximize or minimize the criterion of excellence, whichever is required. You could just choose the top-ranked candidate, but what hidden weaknesses might it have? What is its reputation? Has it a good track record? To proceed further we seek a detailed profile of each: its documentation (Figure 5, bottom). Typically, it is descriptive, graphical or pictorial: case studies of previous uses of the material, details of its corrosion behavior in particular environments, of its availability and pricing, warnings of its environmental impact. Such information is found in handbooks, suppliers' data sheets, CD-based data sources and high quality Web sites. Documentation helps narrow the short-list to a final choice, allowing a definitive match to be made between design requirements and material attributes.

Why are all these steps necessary? Without screening and ranking, the candidate-pool is enormous and the volume of documentation overwhelming. Dipping into it, hoping to stumble on a good material, gets nowhere. But once the screening-ranking steps have identified a small number of potential candidates, detailed documentation can be sought for these few alone, making the task viable.

4. Visual and data-rich implementation

We now have a strategy. How best to implement it? Figure 6 through 7 illustrate some aspects of a method that we have found to work well. More details can be found in [9, 10]. The first, Figure 6, shows one material property (here the elastic modulus, E) plotted against another (the density, ρ) on logarithmic scales. The range of the axes is chosen to include all materials, from the lightest, flimsiest foams to the stiffest, heaviest metals. It is then found that data for a given family of materials (polymers for example) cluster together on the chart; the *sub-range* associated with one material family is, in all cases, much smaller than the *full* range of 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.

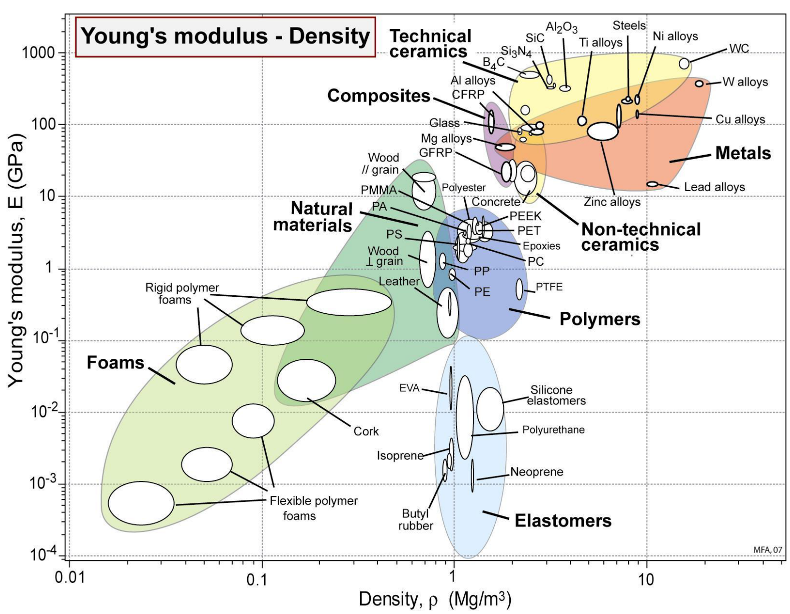


Figure 6. A chart of Young's modulus and density for materials created using Granta EduPack with the Level 2 database.

Figure 7 shows a second example, here two thermal properties – thermal expansion, α, and thermal conductivity, λ. As in Figure 6, members of a given family cluster in a small area of the chart: ceramics and metals to the right, with low expansion and high conductivity; polymers and elastomers in the upper left, with ten times the expansion and only 1% of the conductivity of the first two. Electrical properties can be mapped in a similar way: Figure 8 shows the electrical resistivity and the thermal conductivity. The chart makes it clear that, for metals at least, the two are closely correlated.

Charts like these, available for all the usual material properties [9, 10], give a perspective of the world of materials. The charts locate the families in material-property space, revealing the areas that are occupied and (importantly) those that are not. By building the materials attributes into a database and addressing this with appropriate search and graphical software, charts can be plotted at will, choosing any pair of properties.

Already the student has something useful for engineering design. A design requires a material that is light and stiff – Figure 6 guides the choice. A material with low thermal expansion or expansion that matches another material? Figure 7 suggests answers. A material that conducts heat well but is an electrical insulator? Figure 8 provides candidates. The charts put material properties in perspective: metals are 20 to 100 times stiffer than polymers and conduct heat 100 times faster. Elastomers have enormous expansion coefficients but are excellent electrical insulators. This "order of magnitude" familiarity is useful; much engineering design, even today, is intuitive, but the intuition is informed by just this sort of familiarity.

And the charts lead naturally to another set of questions. Why do the members of each material class cluster in the way they do? What determines where the clusters lie on the charts? Why are some material properties so obviously correlated? 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. The materials texts cited as references [1 - 11] provide this information.

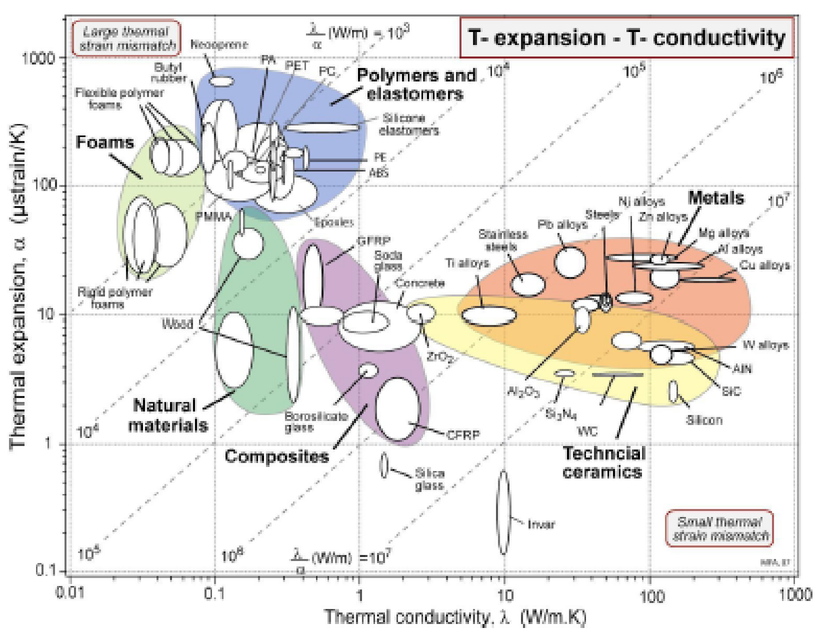


Figure 7. A chart of thermal conductivity and thermal expansion for materials created using Granta EduPack with the Level 2 database.

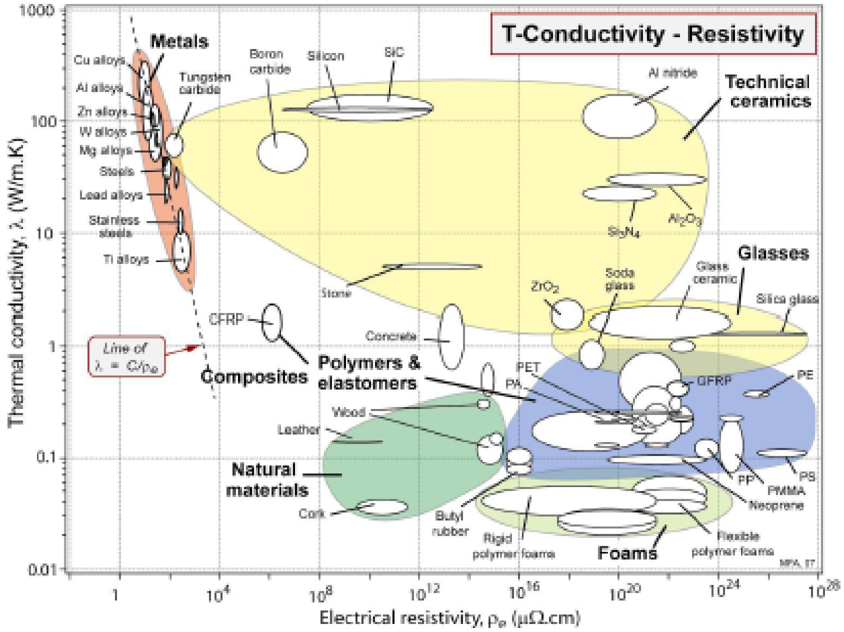


Figure 8. A chart of thermal conductivity and electrical resistivity for materials created using Granta EduPack with the Level 2 database.

Figure 9 through 11 show some aspects of manufacturing that can have a significant impact on materials selection. Figure 9 shows the relative cost of a part manufactured by low pressure die casting, using a set of parameters: load factor, capital write-off time, part mass and material cost. Changing one of these parameters will change the expected relative cost of the part. There is a range of variation for the part cost because different manufacturers of equipment provide a range of machinery and options that makes it difficult to provide one value. For a preliminary estimation of batch size or part cost, this may still be enough. The reason why the cost of each part decreases as the batch size increases has to do with dividing the cost of tooling and dies over the entire production run, meaning that the cost of the part will, in the limit, approach the cost of the raw material to produce the part.

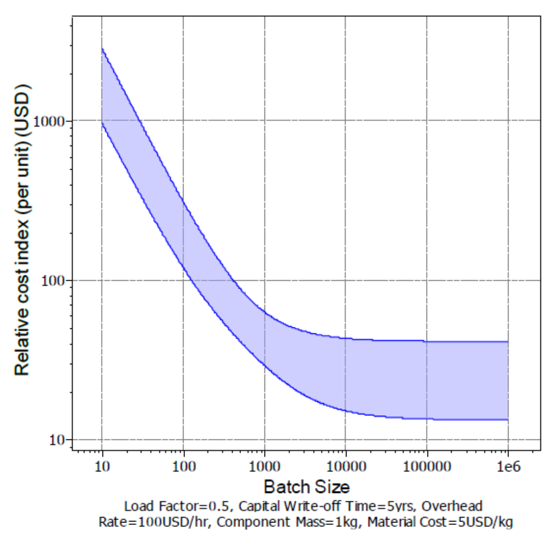


Figure 9. Relative cost index for low pressure die casting, varying with batch size. See the assumptions for this prediction below the x-axis.

When the cost of the part stabilizes (the right part of the graph in Figure 9) the economic batch size is reached. This is the minimum number of parts that have to be manufactured with a specific manufacturing process for that part to be economically viable. The value of the economic batch size is directly influenced by the tooling costs. Figure 10 shows this general dependence, with economic batch size increasing for increasing tooling costs. The economic batch size varies from process to process. Figure 11 shows the values for a number of manufacturing processes.

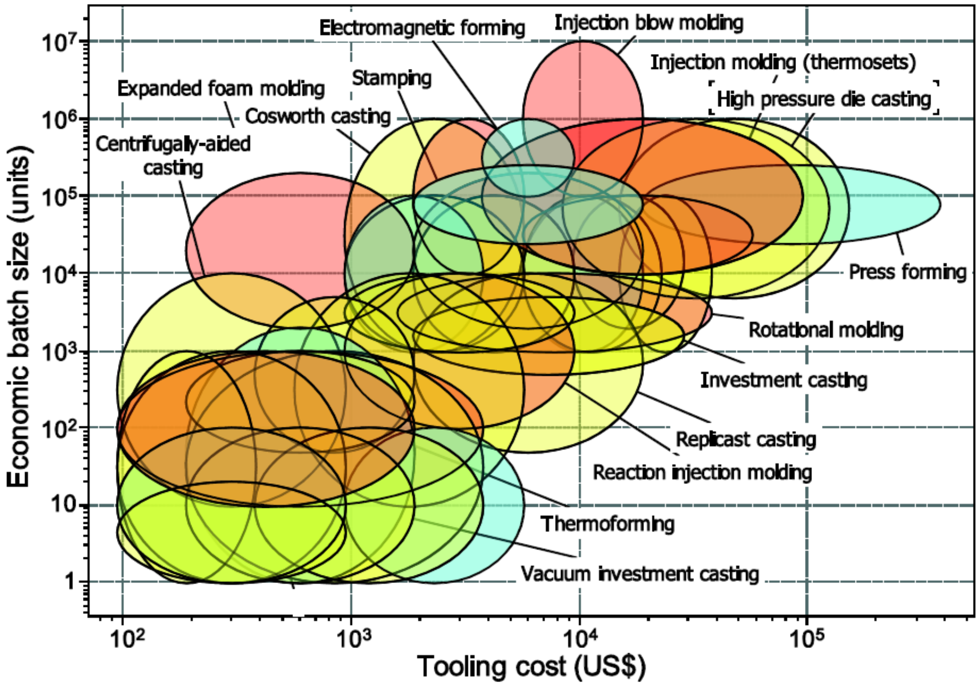


Figure 10. A chart of economical batch size versus tooling cost. As expected, a growing cost of tooling will inevitably force the economic batch size to grow.

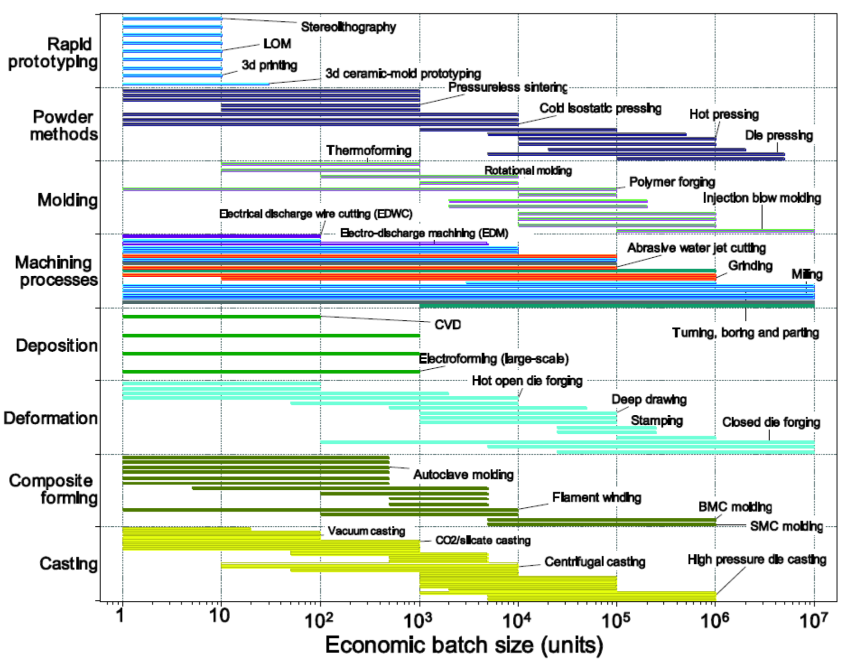


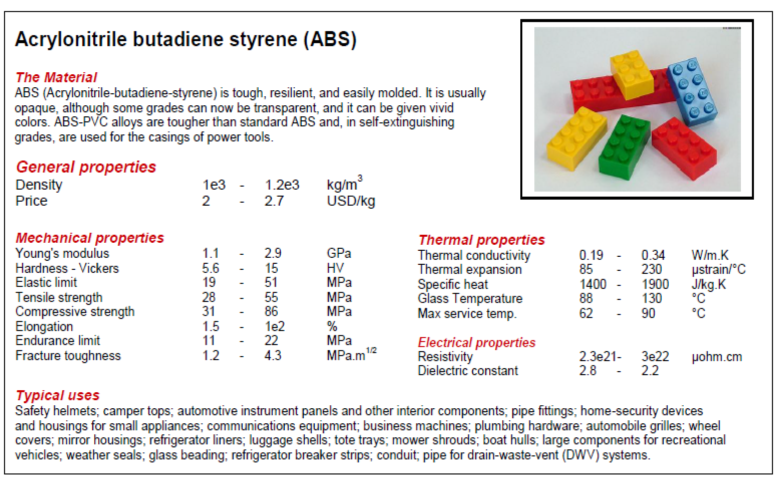
Figure 11. Economic batch sizes for a number of shaping processes.

Student interest is stimulated by encouragement to use these charts to explore the materials and processes world. But as understanding progresses, more detail is needed. It is here that software can help, allowing the student to create charts with any desired combination of properties, to zoom in on any chosen part to increase resolution, and to access records for the attributes of individual materials and processes. Figures 5 through 11 were created using one such software package [17] specifically designed for education. It is described next.

5. Introducing Granta EduPack

Granta EduPack provides an extensive database of material and process information. It offers tools to apply this information in selecting materials and processes to meet complex design requirements. And it helps students to explore and learn the underlying science. Figure 12 shows part of a material record – that for ABS – contained in Granta EduPack. 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. 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. Figure 13 is part of one of the shaping records linked to ABS – it lists information for injection molding. It, in turn, is linked to all materials that can be injection molded. Each field name is linked to text files, known as science notes, that give a definition, a description of how it is measured and explanation of its origins (Figure 14).

The software has three levels of data so that it evolves with the needs of the student. Level 1 contains limited data for 69 of the most widely used materials, drawn from the six families of Figure 2. A material record, of which Figure 12 is a part, starts with a brief description of the material and its history, illustrated with an image of a familiar product in which it is used. Numeric data follow for the most basic mechanical, thermal, electrical and optical properties. A material record ends with a list of its common applications. Manufacturing processes for shaping, joining and finishing, 77 of them in all, are treated in a similar, simple way: a description, a schematic illustrating how the process works, a brief list of attributes and applications (see Figure 13). The Level 1 system allows the student to explore materials and processes without being overwhelmed by detail.



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 12. Part of a record for a material, ABS.
It contains numeric data, text and image-based information.

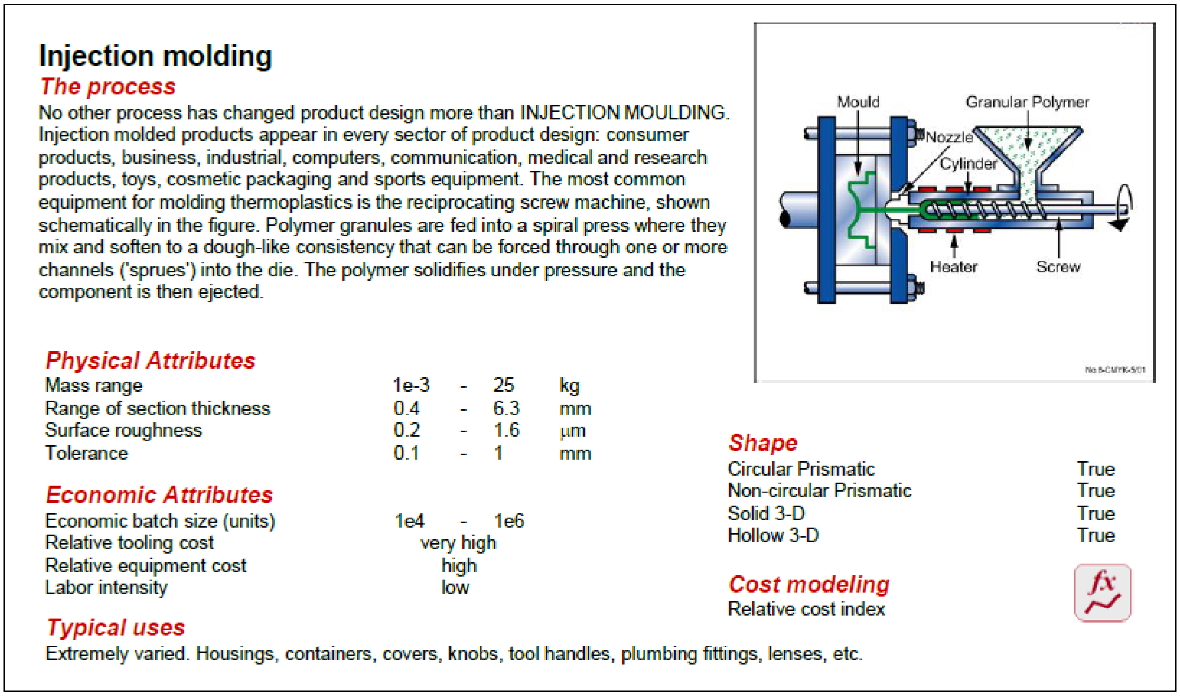


Figure 13. Part of a record for a process, injection molding. The image shows how it works, and the numeric and Boolean data and text document its attributes.

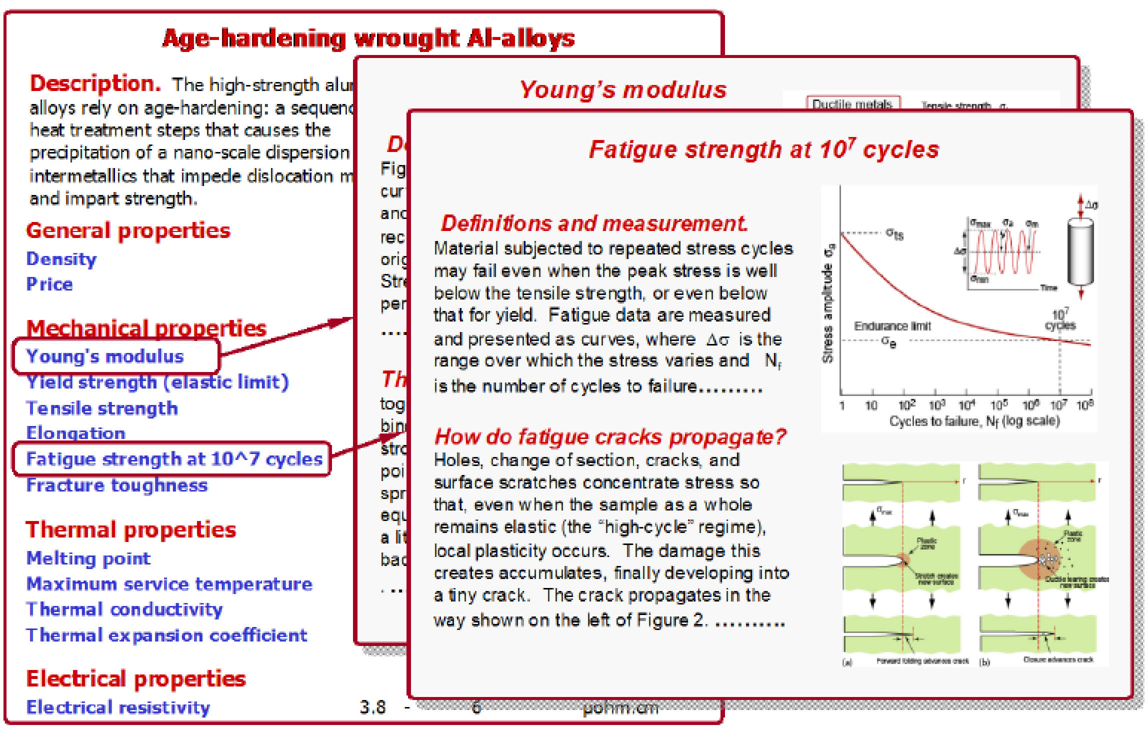


Figure 14. A schematic illustrating the way in which science notes providing definitions, measurement and the underlying scientific origin of each material and process attribute can be accessed from within a record.

Level 2 retains this format, expanding the number of records (to 100 materials and 109 processes) and the detail of the data to include information on design, on technical details and on possible environmental concerns. It allows more ambitious exercises and projects, still without smothering the student with information. The final, third, level develops this yet further with a much larger number of data records, providing a tool with which the student is already familiar, but now capable of professional-level selection exercises and projects (currently 3798 materials, 230 processes).

All three levels are managed by the same search and selection engine, so although the complexity and power increase, the interface remains familiar. Records can be retrieved by browsing and by a number of simple search methods. The science notes that are linked to every attribute in the database, describing how the property is defined, how it is measured and the science that underlies its values, create a built-in textbook, further supporting the educational role of EduPack. They also provide links to chapters in widely used textbooks. More challenging (and stimulating) is the range of tools for selection to meet a set of engineering design requirements. They are based on systematic methods, documented in [9, 10 and 11] that engender understanding and encourage creative thinking. A selection exercise starts with an analysis of the design requirements: What is the function of the component? What constraints must it meet? What objectives influence the choice (maximizing performance, perhaps, or minimizing cost)? What freedom of choice exists – choice of material, of dimensions, of shape? The selection tools allow the user to eliminate materials that fail to meet the constraints and to rank the candidates that remain by their ability to meet the objective. Trade-off methods allow compromises to be reached between conflicting objectives (performance versus cost, for instance). The way the selection system works is described next.

6. The selection tools

Granta EduPack does much more than just provide data and create charts. It allows the entire strategy of Figure 5 to be implemented, allowing sequential steps that apply the constraints, rank the survivors and initiates a search for documentation via a Web portal to materials information, using the top-ranked materials designations as search strings. We now look briefly at selection, more specifically at screening and ranking.

Screening. Any design imposes certain non-negotiable demands ("constraints") on the material of which it is made. The Granta EduPack system provides a number of screening tools that impose the constraints. Attribute limits can be imposed by setting upper or lower limits on material or process attributes as in Figure 15. Alternatively, limits can be plotted as horizontal or vertical lines on material property charts, as illustrated in Figure 16. It shows a schematic the E – Relative cost chart. We suppose that the design imposes limits on these of $E > 10$ GPa and Relative cost < 3, shown on the figure. All materials in the window defined by the limits, labeled "Search region", meet both constraints. Stages like those of Figures 11 and 12 can be stacked, allowing multiple constraints to be applied. Granta EduPack also lets you select from a subset of materials or manufacturing processes, eliminating others from the outset. It can let you narrow down the selection to Polymers than can be injection molded, or to ferrous metals. It also lets you select a group of favorite materials to select from.

Ranking: mass or cost per unit of function. The next step is to seek, from the subset of materials that meet the constraints, those that maximize the performance of the component. We will use the design of light, stiff components as an example. Figure 17 shows a schematic of the $E – \rho$ chart.

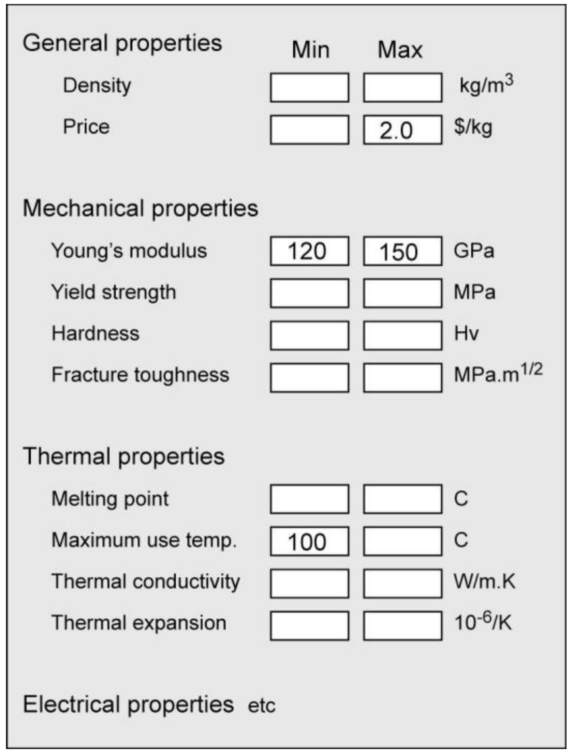


Figure 15. The query interface, imposing the constraints that the material price is less than 2 $/kg, the modulus is between 120 and 150 Gpa and the maximum use temperature is greater than 200°C.

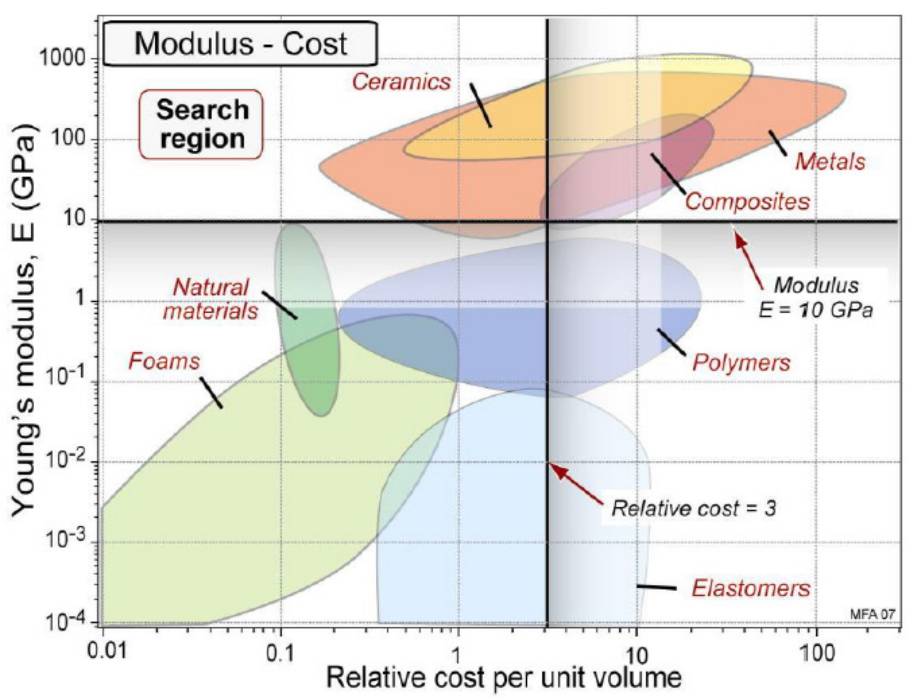


Figure 16. Constraints of modulus greater than 10 GPa and relative cost less than 3 plotted on a graph.

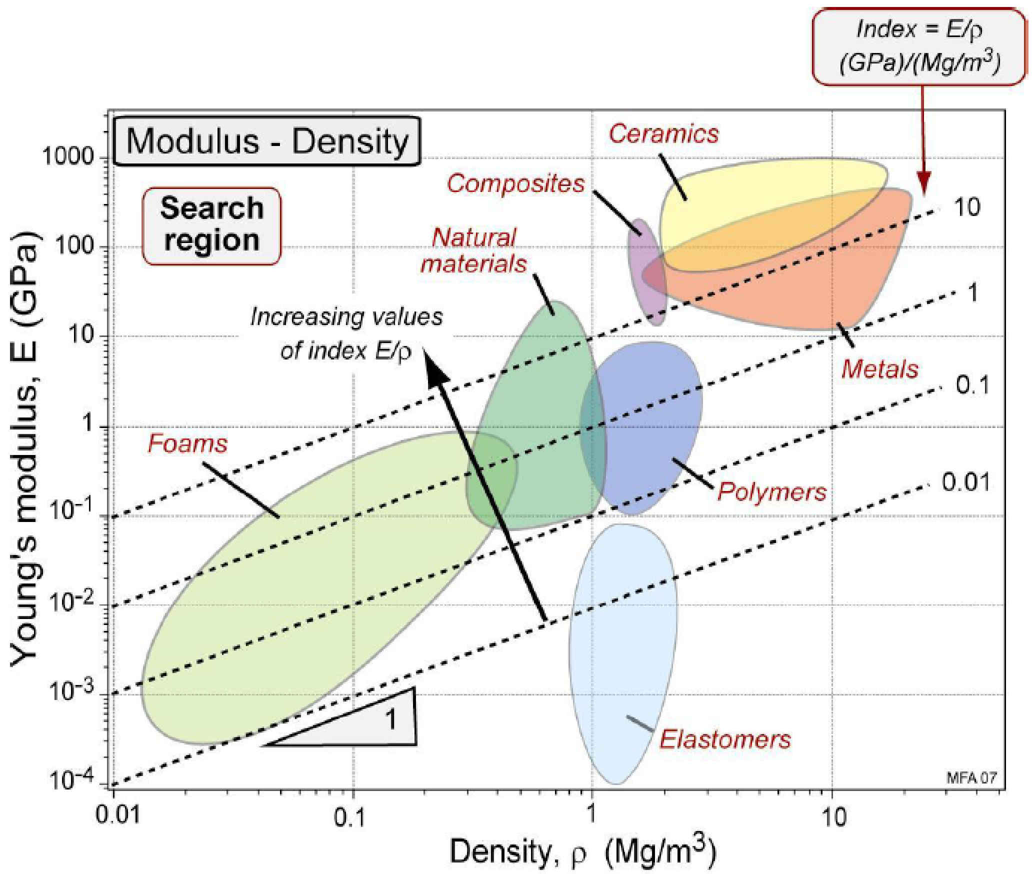


Figure 17. The index E/ρ, describing the objective of stiffness at minimum weight, plotted on a chart. The best choices are materials with the greatest value of E/ρ that at the same time meet all other constraints.

The logarithmic scales allow the index E / ρ and others like them, to be plotted. Consider the condition:

$$E / \rho = \text{constant, } C$$

Taking logs:

$$\log (E) = \log (\rho) + \log (C)$$

This is the equation of a straight line of slope 1 on a plot of log (E) against log (ρ). Figure 17 shows a grid of lines corresponding to values of E / ρ from 0.01 to 10 in units of GPa/(Mg.m^{-3}). It is now easy to read off the subset of materials that maximize performance, meaning that they have the highest values of E / ρ. All the materials that lie on a line of constant E / ρ perform equally well as a light, stiff component; those above the line perform better, those below, less well. A material with a value of E/ρ = 10 in these units gives a component with a one tenth the weight, for a given stiffness, of a material with a value of E/ρ = 1. In practice an index line is plotted on a chart and moved until a manageably small number of materials lie above it. The software presents a list of these, ranked by the value of the index, that also passed any constraints previously set during screening. Figure 18 summarizes the way in which the search engine works. On the left is the simple query interface for screening on single attributes. The desired upper or lower limits for constrained properties are entered; the search engine rejects all materials with attributes that lie outside the limits. In the center is shown a second way of interrogating the data: a bar chart, constructed by the software, for any numeric property in the database. It, and the bubble chart shown on the right, are ways both of applying constraints and of ranking. For screening, a selection line or box is superimposed on the charts with edges that lie at the constrained values of the property (bar chart) or properties (bubble chart). This eliminates the materials in the shaded areas and retains the materials that meet the constraints. If instead, ranking is sought (having already applied all necessary constraints) an index-line like that shown in Figure 17 is positioned so that a small number – say, ten – materials are left in the selected area; these are the top ranked candidates. The software delivers a list of the top-ranked materials that meet all the constraints, ranked by the value of the index. Figure 19 illustrates the Results list for such a selection. Selected candidates are ranked by their value of the index.

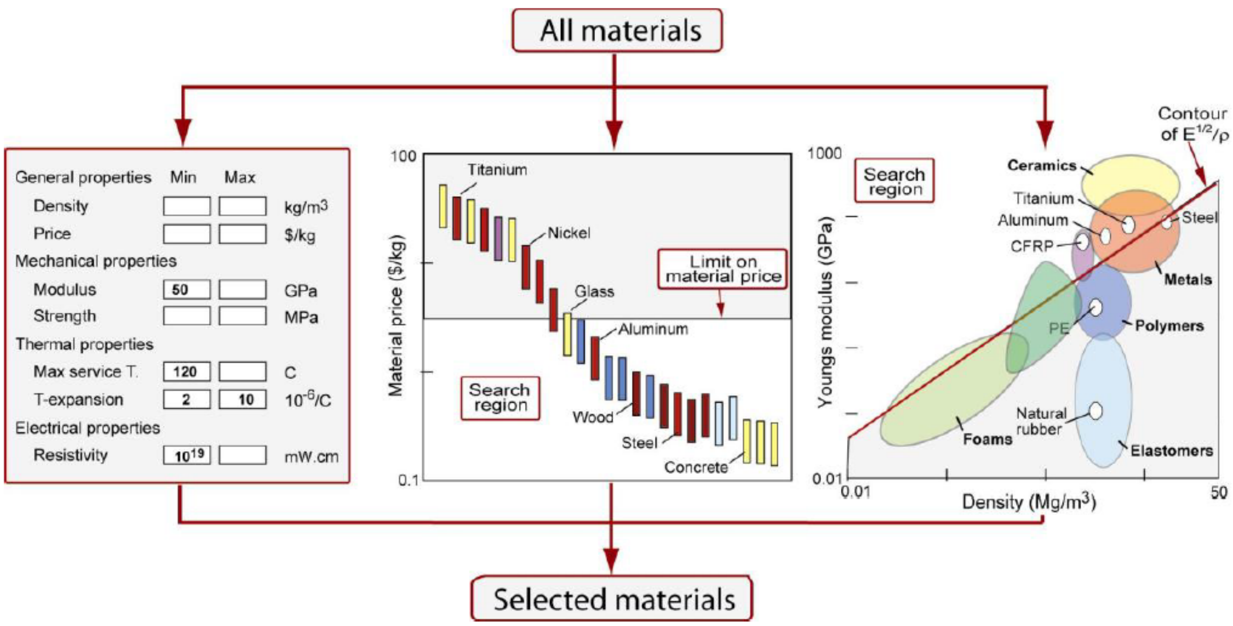


Figure 18. Computer-aided selection using Granta EduPack. The schematic shows the three types of selection window. They can be used in any order and any combination.
The selection engine isolates the subset of materials that pass all selection stages.

Material	**Ranked by Index E/ρ**
CFRP	65.7
Aluminum alloys	27.7
Low alloy steel	26.9
Medium carbon steel	26.5
High carbon steel	26.4
Low carbon steel	26.4
Stainless steel	25.4
Magnesium alloys	24.1
Titanium alloy	22.6

Figure 19. Selected materials ranked by the index E/ρ.

7. Developing the science: the Elements database

The Granta EduPack system builds an understanding of the science of materials as well as their selection. The embedded Science notes (Figure 14) have already been mentioned. The supporting texts (references [9] and [10]) develop this in greater depth, and a further text (reference [11]) explores the aesthetic and emotional qualities that materials can offer. In addition, the system includes, as standard, a further database, that for the elements of the Periodic Table. It contains data for all the elements that are stable enough permit characterization. There are 127 records for 111 elements (some have two or three allotropic forms requiring separate records).

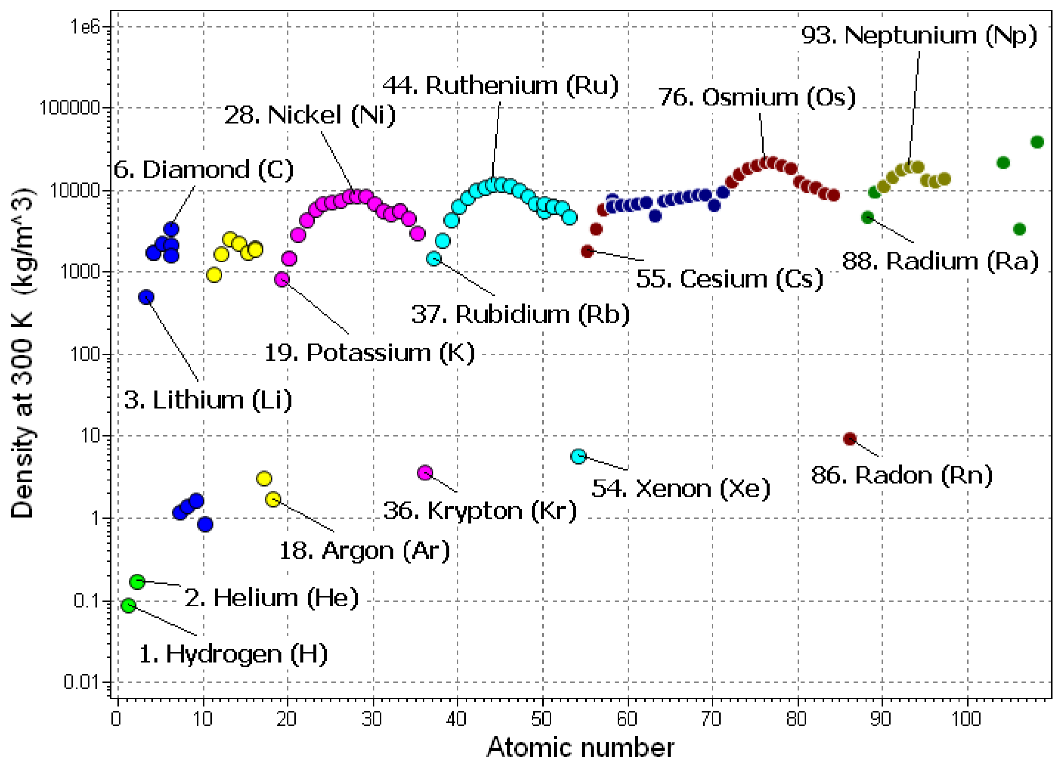


Figure 20. The variation of the density at NTP of the elements across the Periodic Table. The rows of the table are distinguished by color.

There are 56 fields listing position in the Periodic Table, crystallographic, structural, mechanical, thermal, electrical and magnetic properties, diffusion data and surface energies. Figure 20 and 21 illustrate some of the ways in which it can be used. The first (Figure 20) shows a property – here, density at NTP – plotted against atomic number, illustrating the periodic fluctuations across each row of the Table. The second (Figure 21) illustrates how fundamental relationships between properties can be demonstrated. Here the thermal conductivity of the metallic elements is plotted against the electrical resistivity. There is a clear inverse-linear relationship between them, known as the Wiedemann-Franz law, arising because, in metals, electrons are responsible both for thermal and electrical conduction. Many other fundamental relationships can be explored in this way.

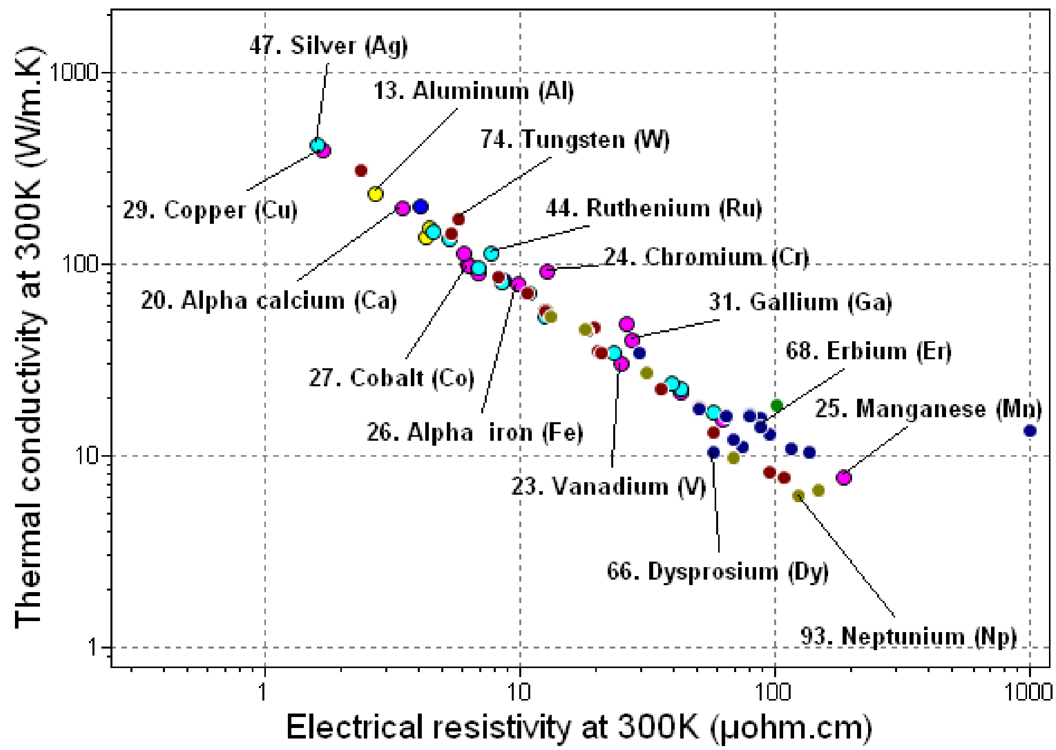


Figure 21. The thermal conductivity of the metallic elements plotted against their electrical resistivity. The inverse linear relationship is known as the Wiedemann-Franz law.

8. Granta EduPack and environmental impact

Granta EduPack enables a quick, early design overview of the environmental impact of products, looking at the different phases of the products' life cycle in terms of energy consumption and carbon footprint.

Distinguishing between the different phases of life (raw material production, product manufacture, transportation, use, disposal and end-of-life) allows students to assess which phases impact the most and how best to mitigate for that in the early stages of design [18]. The Eco-Audit tool can compare different alternatives to a reference design, showing improvements on either energy consumption or carbon footprint. This makes it much easier to identify where different materials or manufacturing processes impact the most and what can be done to minimize their impact. Figure 22 shows one such comparison for water bottles made of PET and glass. Granta EduPack provides some tips on how to minimize the impact for each phase of life, noting that any changes made can affect the other phases as well, enabling the introduction of design trade-offs at an early stage, and providing numerous opportunities for fruitful in-class discussions or deployment of data for project work.

9. Further adaptation to – and support for – teaching needs

The needs of a course for engineers working in aerospace design differ from those of one for the design of civil structures or for product design. A benefit of software is the ability to customize it, ensuring that the materials information to which the student has access is relevant to the specifics of the subject being studied. Thus a course on materials science is strengthened by a database for the elements, spanning the

Periodic Table and providing crystallographic data, data on cohesion and physical properties. Aerospace engineering requires access to data for light alloys and composites, and perhaps for materials that meet US military specifications (MMPDS for metals and MIL-HDBK-17 for composites). A course for civil engineers requires data for cement, concrete, structural grades of steel, aluminum and wood, and for structural sections made from these. One on product design might benefit from access to a large amount of grade-specific polymer data that meets ISO or ASTM standards. All of these data sets exist and can be provided with the basic EduPack system allowing easy adaptation both to the level of the course and its subject matter.

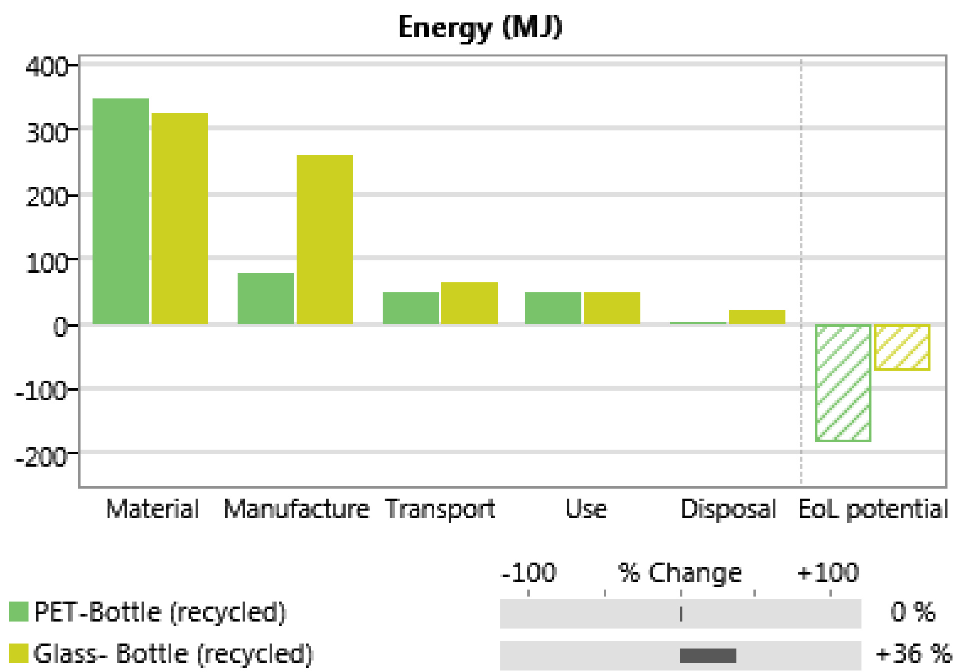


Figure 22. A comparison of different materials for the manufacturing of water bottles. The context is the following: 100 bottles (1 liter each) are manufactured in France, filled and shipped to the UK, where they are refrigerated for two days, and drunk. The picture shows the comparison between a PET bottle and a glass bottle, both recycled at their respective end-of-life.

For advanced courses on Materials, Granta Selector is available with specific tools and databases adapted for advanced teaching and research. As a further aid to instructors teaching a course on any of these subjects, a comprehensive set of PowerPoint presentations (Table 3) with supporting notes for the lecturer, case studies, and problem sets is also available. These presentations provide valuable material for lectures and classes. They dovetail with the texts [9, 10 and 11] in which the design-led approach to learning about materials is developed in full. Project files, also accompany the lecture units and problem sets, with worked solutions to some of the problems, using Granta EduPack.

Finally, a number of white papers explain in detail each database and tool available, with an in-depth look into what you can do with them and how you can enhance your teaching and get the most out of Granta EduPack. In this series of white papers you can also find some that are not directly related to Granta EduPack, but look instead at broader subjects related to the teaching of materials. Granta Edupack levels 1 and 2 are also offered in French, German and Spanish, with some of the accompanying resources.

10. Closing notes

The number and variety of materials available today is increasing at a rate faster than at any previous time. The next generation of engineers – the ones we are educating now – will need the ability to use materials of all sorts (conventional as well as advanced) in ways that meet more demanding technical, environmental, economic and aesthetic requirements than ever before. Forward-looking engineering education aims to provide the student with understanding, with methods to apply the understanding, and with tools to facilitate this application; examples of the last is a facility with FE, solid modeling and other CAD software.

The aims of materials teaching should, in our view, be the same. This paper describes our approach to realizing these aims, an approach that is implemented in Granta EduPack. EduPack is a complete set of resources, with the central software supported by supplementary databases, textbooks, lectures, projects, and exercises. Academics teaching at different levels can find support within the various levels and Editions of Granta Edupack. The progression through the three levels of Granta EduPack provides students with the knowledge and confidence to select materials for mechanical, thermo-mechanical and electro-mechanical design, as well as processes for forming, joining and surface treating the materials.

Name of Lecture Unit
The materials and processes universe: families, classes, members, attributes
Materials charts: mapping the materials universe
The Elements: Property origins, trends and relationships
Manipulating Properties: Chemistry, Microstructure, Architecture
Designing New Materials: Filling the boundaries of materials property space
Translation, Screening, Documentation: the first step in optimized selection
Ranking: refining the choice
Objectives in conflict: trade-off methods and penalty functions
Material and shape
Selecting processes: shaping, joining and surface treatment
The economics: cost modeling for selection
Eco Selection: the eco audit tool
Advanced Eco design: systematic material selection
Low Carbon Power: Resource Intensities and Materials Use
Architecture and the Built Environment: materials for construction
Structural sections: shape in action
CES EduPack Bio Edition: Natural and man-made implantable materials
Materials in Industrial design: Why do consumers buy products?
Advanced Databases: Level 3 Standard, Aerospace and Polymer
Hybrid Synthesizer: Modelling Composites, Cellular structures and Sandwich panels
Sustainability: Sustainability and Materials Selection
CES EduPack Polymer Edition
CES EduPack Aerospace Edition

Table 3. PowerPoint lecture units to accompany Granta EduPack.

And the methodology applies not only to these functional aspects of design, but also to commercial (e.g., cost) and environmental (e.g., CO2 footprint or energy of production) aspects. The application of such materials information technology is becoming increasingly important in industry as materials and manufacturing organizations seek to optimize their materials strategies in order, for example, to control costs in global markets, to incorporate eco-design principles in response to market demand and increased environmental regulation, or to limit the use of restricted substances. Use of Granta EduPack thus provides students with experience of a relevant tool that they take with them when they leave the University and start a professional career.

Acknowledgements

Many colleagues have been generous in discussion, criticism and constructive suggestions that have contributed to Granta EduPack over many years. We particularly wish to acknowledge the contribution of the staff of Granta Design Ltd. who are responsible for the software and data for Granta EduPack, but also to the growing academic community that actively contributes with ideas and resources, available in Granta Design's Teaching Resources Website, with the proper acknowledgment of authorship [19].

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[19] www.ansys.com/education-resources

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Document Information
This white paper is part of a set of teaching resources to help introduce students to materials, processes and rational selections.

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