Granta EduPack White Paper

Architecture and the Built Environment

Mike Ashby[1], John Fernandez[2], and Aileen Gray[3]

[1]Department of Engineering, University of Cambridge
[2]Department of Architecture, MIT
[3]Ansys Materials Education Division

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1. Introduction

The Ansys Granta EduPack Built Environment database is a tool for exploring and selecting material of interest to Architects and Civil Engineers. The software contains an array of useful information including physical, environmental and processing attributes of many materials incorporated in the designs of buildings. It is documented in this White Paper. Section 2 describes the database structure, illustrated with typical records. Section 3 defines the material attributes contained in the database. Section 4 illustrates some of the ways in which the data can be presented. The use of the Granta EduPack software for browsing, searching and selecting is outlined in the Appendix.

A full description of the Ansys Granta EduPack system for materials education and data management is available from online at www.ansys.com/products/materials/granta-edupack. More information about materials for architecture, complementary to this database, can be found in the text by Fernandez (2006). Methods for material selection, implemented in the Granta EduPack system, are developed in two texts by Ashby (2004, 2005).

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2. The databases and the data-tables

The database contains four data-tables (smaller, linked databases). Its structure is shown in Figure 1: a datatable for Materials; one for Processes able to shape, join or process them; one containing References for the sources of data and further reading; and one listing Suppliers. The four are linked in the manner suggested by the figure. Thus a record for a given material is linked to those processes that can in some way manipulate it, and the reverse. Records in both the Materials and the Process data-tables are linked to records in the data-tables of References and Suppliers that give information about them.

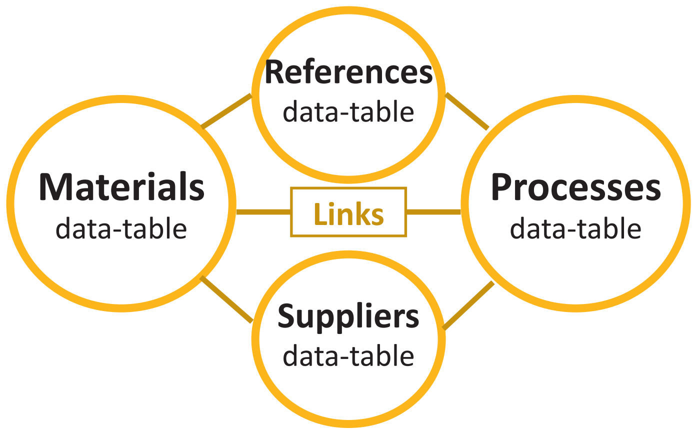

Figure 1: The database consists of four linked "datatables", allowing cross-referencing. The data-tables are explored and manipulated for selection using the Granta EduPack search engine.

Material records

The families of materials contained in the Materials data-table are:

- Composites
- Concrete, Stone, Ceramic, Brick, Glass, Bitumen
- Foams, Fabrics, and Fibers
- Metals, Ferrous, and Non-Ferrous
- Polymers and Elastomers
- Wood, Plywood, Glulam, Bamboo, Straw, and Cork

Figure 2 illustrates the hierarchical organization of the records in this data-table (the "materials tree"). The families expand into classes, sub-classes and members. Each member is characterized by a set of attributes: its properties. As an example, the family 'Metals' contains the class 'Non-ferrous metals' with the particular member 'Aluminum alloy 6061'. It, and every other member of the data-table, is characterized by a set of attributes that include its mechanical, thermal, hygro-thermal, electrical, optical and environmental properties, its processing characteristics, its approximate price and its uses. We call this the property profile of the material.

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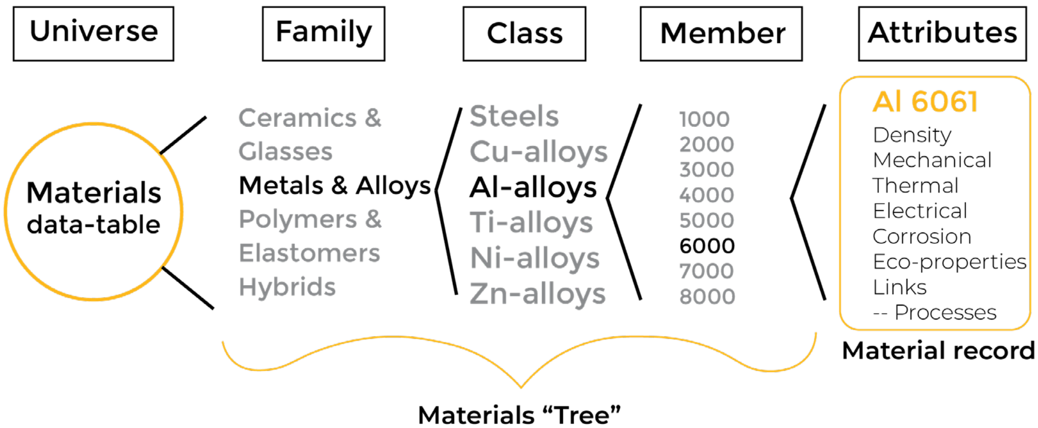
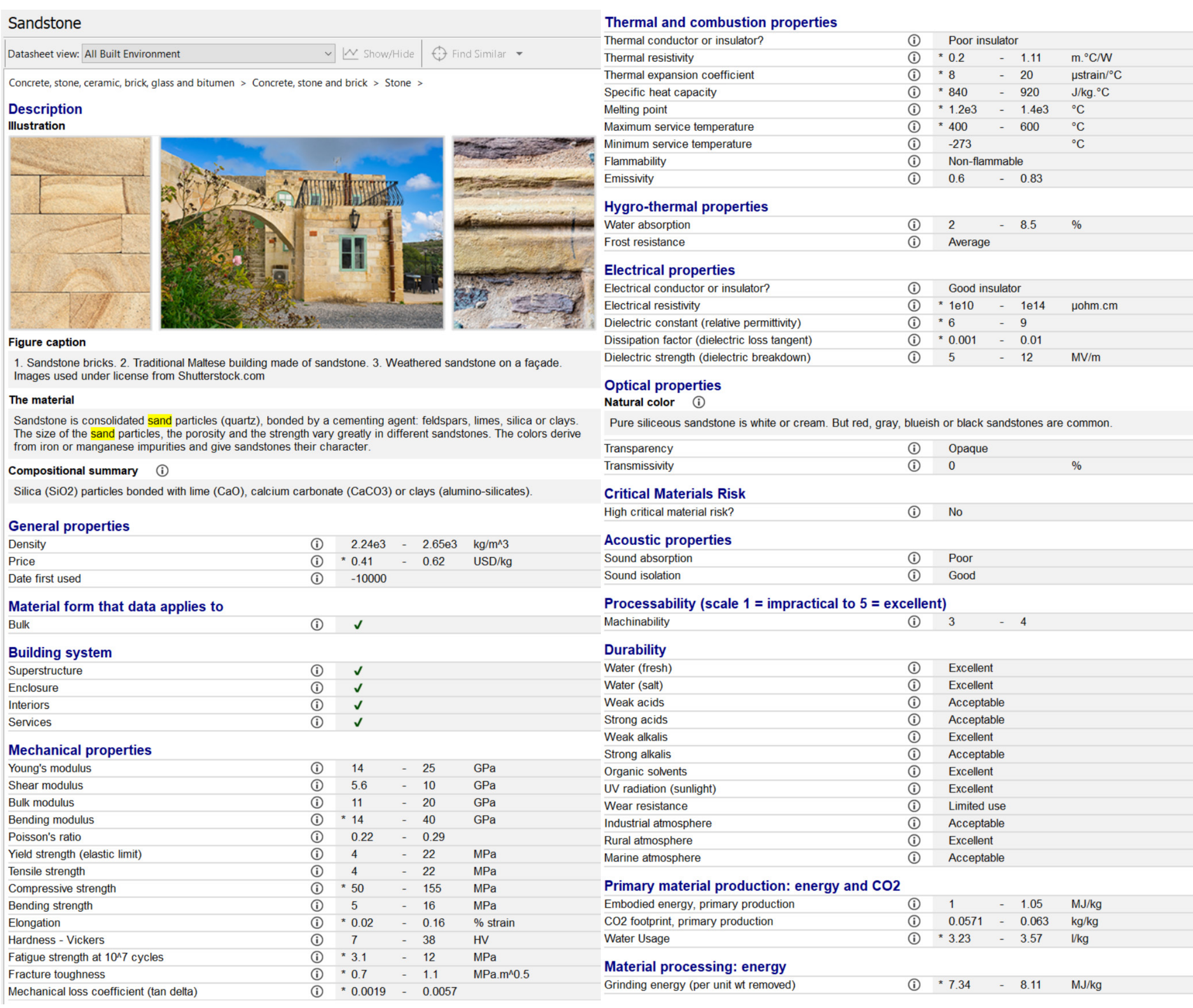


Figure 2. The tree-like organizational structure of the Materials data-table.

Figure 3 shows part of a typical record: here, that for sandstone. Each property is presented as a range, reflecting the variation that can be expected in its value. The units can be toggled between metric, cgs and imperial. The currency is selectable. The properties themselves are defined in Section 3 of this White paper.



Sandstone

Datasheet view: All Built Environment | Show/Hide | Find Similar

Concrete, stone, ceramic, brick, glass and bitumen > Concrete, stone and brick > Stone >

Description

Illustration

Figure caption

1. Sandstone bricks. 2. Traditional Maltese building made of sandstone. 3. Weathered sandstone on a façade. Images used under license from Shutterstock.com

The material

Sandstone is consolidated sand particles (quartz), bonded by a cementing agent: feldspars, limes, silica or clays. The size of the sand particles, the porosity and the strength vary greatly in different sandstones. The colors derive from iron or manganese impurities and give sandstones their character.

Compositional summary

Silica (SiO_2) particles bonded with lime (CaO), calcium carbonate ($CaCO_3$) or clays (alumino-silicates).

General properties

Density	2.24e3	-	2.65e3	kg/m^3
Price	* 0.41	-	0.62	USD/kg
Date first used	-10000			

Material form that data applies to

Bulk	✓

Building system

Superstructure	✓
Enclosure	✓
Interiors	✓
Services	✓

Mechanical properties

Young's modulus	14	-	25	GPa
Shear modulus	5.6	-	10	GPa
Bulk modulus	11	-	20	GPa
Bending modulus	* 14	-	40	GPa
Poisson's ratio	0.22	-	0.29	
Yield strength (elastic limit)	4	-	22	MPa
Tensile strength	4	-	22	MPa
Compressive strength	* 50	-	155	MPa
Bending strength	5	-	16	MPa
Elongation	* 0.02	-	0.16	% strain
Hardness - Vickers	7	-	38	HV
Fatigue strength at 10^7 cycles	* 3.1	-	12	MPa
Fracture toughness	* 0.7	-	1.1	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.0019	-	0.0057	

Thermal and combustion properties

Thermal conductor or insulator?	Poor insulator			
Thermal resistivity	* 0.2	-	1.11	m.°C/W
Thermal expansion coefficient	* 8	-	20	µstrain/°C
Specific heat capacity	* 840	-	920	J/kg.°C
Melting point	* 1.2e3	-	1.4e3	°C
Maximum service temperature	* 400	-	600	°C
Minimum service temperature	-273			°C
Flammability	Non-flammable			
Emissivity	0.6	-	0.83	

Hygro-thermal properties

Water absorption	2	-	8.5	%
Frost resistance	Average			

Electrical properties

Electrical conductor or insulator?	Good insulator			
Electrical resistivity	* 1e10	-	1e14	µohm.cm
Dielectric constant (relative permittivity)	* 6	-	9	
Dissipation factor (dielectric loss tangent)	* 0.001	-	0.01	
Dielectric strength (dielectric breakdown)	5	-	12	MV/m

Optical properties

Natural color

Pure siliceous sandstone is white or cream. But red, gray, blueish or black sandstones are common.

Transparency	Opaque	
Transmissivity	0	%

Critical Materials Risk

High critical material risk?	No

Acoustic properties

Sound absorption	Poor
Sound isolation	Good

Processability (scale 1 = impractical to 5 = excellent)

Machinability	3	-	4

Durability

Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Acceptable
Strong acids	Acceptable
Weak alkalis	Excellent
Strong alkalis	Acceptable
Organic solvents	Excellent
UV radiation (sunlight)	Excellent
Wear resistance	Limited use
Industrial atmosphere	Acceptable
Rural atmosphere	Excellent
Marine atmosphere	Acceptable

Primary material production: energy and CO2

Embodied energy, primary production	1	-	1.05	MJ/kg
CO2 footprint, primary production	0.0571	-	0.063	kg/kg
Water Usage	* 3.23	-	3.57	l/kg

Material processing: energy

Grinding energy (per unit wt removed)	* 7.34	-	8.11	MJ/kg

Figure 3. Part of a Typical Material Record

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Process records

Figure 4 shows the parallel hierarchical organization of the Processes data-table (the "process tree"). As in the Materials data-table, processes are segregated into families, classes, sub-classes and members. Each member is characterized by a set of attributes: its properties. As an example, the Shaping-process family contains the class 'Molding', the sub-class 'Injection molding' and finally the particular member 'Injection molding'. The attributes describe its characteristics: the function it performs, the dimensions it can handle, the shapes it can make or join, its economics and the materials to which it can be applied. Like those for materials, the process attributes are stored as ranges and units are selectable.

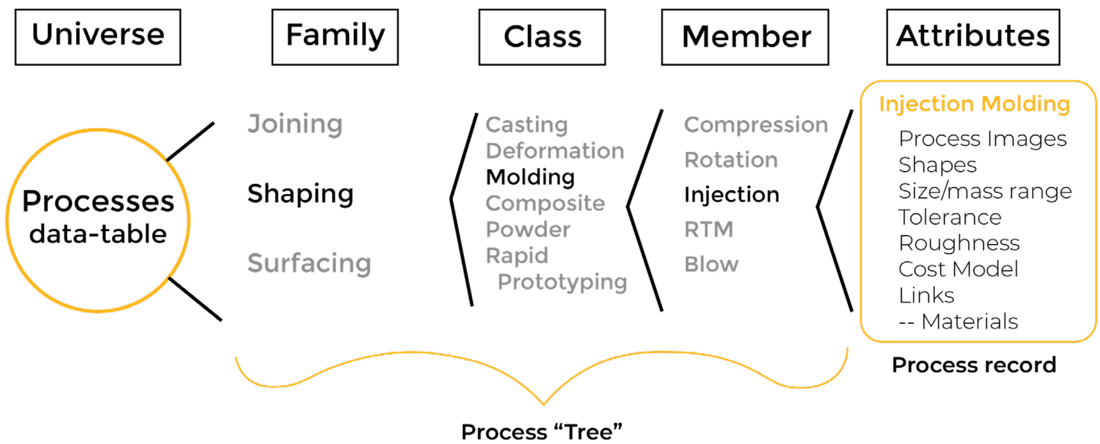

Figure 4. The organizational structure of the Processes data-table

3. The material attributes

3.1 General properties

Density ρ. The density is the weight per unit volume, and thus has units of kg/m3 or lb/in3. It is this that is stored in the database. (The Specific gravity is the density divided by that of water (1000kg/m3) and is dimensionless. Its value is Density/1000.)

Price P (units: US$/lb, Euros/kg, £/kg–selectable). The price of materials depends on many factors, among them the influence of supply and demand, the amount you wish to purchase and the relationship you have with your supplier. The prices of commodity materials given in the database are derived from London Metal Exchange, Bullion Market and Commodity Market values. Where this is not possible prices are derived from a price model. Prices update yearly.

3.2 Building system

Superstructure. The superstructure is the collection of elements - columns, beams, slabs and other components - that transfer static and dynamic loads from the building down to the foundation (or the substructure). Most building superstructures are hidden from view, covered by interior and exterior finish materials. Other superstructures are an integral aspect of the architecture of the building, such as the Eiffel Tower or the Centre Pompidou, both in Paris.

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Enclosure. The enclosure includes all components that contribute to a durable and reliable weather barrier between the ever-changing exterior climate and the need for a stable interior environment. Windows, doors, vapor and air barriers, brick masonry, wood siding, copper flashing and many other components are assembled together to control the flux resulting from air pressure, water vapor and thermal gradients between the inside and the outside. In addition, the enclosure is the 'face' of a building and thus plays an important symbolic role – the facade of the White House in Washington DC or that of the Houses of Parliament in London certainly communicate this aspect of the enclosure.

Interior. The interior building system includes all of the non-structural components that spatially define the habitable space of buildings such as floor assemblies and surfaces, ceilings and wall materials, partitions, interior glazing, doors and other space-defining elements. Interior systems, while mostly functional assemblies, can be grand and symbolically powerful, such as the vault of the constellations of Grand Central Terminal in New York City or the main hall of large Opera Houses.

Services. The building services are a set of elements that provide a constant stream of air, heating and cooling, electricity, water and data delivered from central utility plants within the building to all spaces within the interior volume. This diverse group of components includes metal ducts to deliver heated or cooled air, copper and PVC plumbing to transport water, insulated copper wiring, glass optical fiber cables, etc. and many kinds of devices that serve these delivery systems including, chillers, boilers, pumps, valves, etc. These systems are material intensive, requiring not only all kinds of metals and ceramics to store and deliver water and air but a great variety of polymers and composites for seals, adhesives, gaskets and other joint conditions.

3.3 Mechanical properties

Strength is measured in many ways depending on the nature of the applied force and the family to which the material belongs. All have units of MPa in the Metric system, 103 psi in the Imperial system.

Elastic Limit σ_{el} is the stress at which it first suffers permanent (inelastic) deformation in tension.

Compression strength σ_c is the stress at which it first suffers permanent (inelastic) deformation in compression.

Bending strength σ_b is the stress at which it first suffers permanent (inelastic) deformation in bending.

Tensile Strength σ_{ts} is the nominal stress at which a round bar of the material, loaded in tension separates. For brittle solids – ceramics, glasses and brittle polymers – it is equal to the elastic limit. For metals, ductile polymers and most composites it is larger than the elastic limit by a factor ranging from 1.1 to 3.

Fracture toughness K_c, is a measure of the resistance of a material to the propagation of a crack. It can be measured by loading a sample containing a deliberately introduced crack of length 2c and then recording the tensile stress σ at which the crack propagates.

$$K_c = Y\sigma\sqrt{\pi c}$$

where Y is a geometric factor, near unity, which depends on details of the sample geometry.

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Moduli measure stiffness. All have units of GPa in the Metric system, 106 psi. or 103 ksi in the Imperial system.

Young's modulus E is the slope of the initial, linear elastic part of the stress-strain curve in tension or compression. Shear modulus G is the slope of the initial, linear elastic part of the stress-strain curve in shear.

Bulk modulus K is the slope of the initial, linear-elastic part of the stress-strain curve under hydrostatic pressure.

Bending modulus E_b is the modulus measured in flexure. For isotropic materials it is the same as Young's modulus, but for anisotropic materials like plywood, chipboard, GFRP and CFRP it differs from E.

Hardness H is measured by pressing a spherical or diamond-shaped indenter into the surface of the material. The unit of hardness in the SI system is MPa, but it is seldom quoted in these units. The commonest measure is Vickers hardness Hv, and that is what is used here (Hv = Hardness in MPa/10), but Brinell and Rockwell hardnesses are also used. GRANTA in depth gives conversion tables.

Elongation ε is the extension in the length of a tensile specimen at fracture, expressed as a percentage of the original gauge length $\varepsilon = (L_x - L_o) / L_o$ where L_o is the original gauge length and Lx is the final gauge length.

Mechanical loss coefficient η measures the degree to which a material dissipates vibrational energy. It is dimensionless.

3.4 Thermal and combustion properties

Thermal resistivity R is the rate at which heat is conducted through a solid at 'steady state' (meaning that the temperature profile does not change with time) is governed by the thermal conductivity λ. It is measured by recording the heat flux J (W/m2) flowing from surface at temperature T_1 to one at T_2 in the material, separated by a distance X:

$$J = -\lambda \frac{T_2 - T_1}{X}$$

The thermal resistivity is the reciprocal of the thermal conductivity with units m.K/W, or h.ft.F/Btu.

Thermal expansion coefficient α. Most materials expand when they are heated. The linear thermal expansion coefficient α is the thermal strain per degree K (Metric units: µstrain/K; Imperial: strain/F).

Specific Heat C_p is the specific heat capacity at constant pressure. It specifies the amount of heat required to raise the temperature of 1 kg of material by 1°C (K). It is measured by the standard technique of calorimetry (Metric units: J/kg.K; Imperial: Btu/lb.F). The Melting point Tm is the temperature at which a material turns abruptly from solid to liquid. The melting temperature of an alloy is usually less than the melting temperature of the parent metals.

The Glass temperature T_g is a property of non-crystalline solids that do not have a sharp melting point. It characterizes the transition from true solid to viscous liquid in these materials. Semi-crystalline plastics

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have both T_m and T_g. Tm refers to the melting of the crystalline component and Tg refers to softening of the amorphous component. Amorphous plastics have no Tm, only a T_g.

The Maximum service temperature T_{max} is the highest temperature at which the material can reasonably be used in a load-bearing component without oxidation, chemical change or excessive creep becoming a problem. T_{max} is typically $T_m/3$ for Metals and $T_m/2$ for Ceramics. For Polymers, T_{max} is more narrowly defined as the maximum service temperature for long-term, continuous use. Where data is available, it is the range of the three UL 764 relative thermal index (RTI) tests.

Flammability. The flammability of building products is defined by the Flame Spread Classification of a material. To determine the Flame Spread Classification (FSC) of a material, burners are ignited and the advance of the flame front along the test specimen is recorded for ten minutes. The FSC of noncombustible materials is zero, and that of red oak is 100. The values for all other products are determined in comparison with these materials. ASTM E 1264 defines three ranges that correspond directly to building Classes I, II and III: Class A: 0-25, Class B: 26-75 and, Class C: 76-100. Here we rank flammability on a 3-point scale as *Non-flammable, Self-extinguishing and Flammable*.

3.5 Hygro-thermal properties

Water absorption is defined here as the increase in mass as a result of moisture absorption when a major surface of a specimen is placed in contact with liquid water.

Water vapor permeability is defined here as the mass of water vapor transmitted in unit time, under unit pressure difference, through a unit area of material of unit thickness. This database uses values quoted for relative humidity of 50% and room temperature. (Metric units: kg/m.s.Pa; Imperial: lb/ft.s.in.Hg). A number of databases include rate of permeability values that use SI units of nanograms of water per second for each square meter of area divided by the Pascals of vapor pressure difference per thickness in meters.

Air permeability is the mass of air transmitted in unit time, under unit pressure difference, through a unit area of material of unit thickness. (Metric units: kg/m.s.Pa; Imperial: lb/ft.s.in.Hg).

Frost resistance. Resistance to water absorption is the most important aspect of resisting damage due to freeze-thaw cycles. Brittle and porous materials, such as lime mortars, brick and concrete, may be critically damaged by absorbing liquid water that then freezes and expands within the solid. Here we rank Frost resistance on a 5-point scale ranging from Very good to Very poor.

3.6 Electrical properties

The Electrical resistivity ρ_e is the resistance of a unit cube of the material. Its units in the SI system are Ω.m but it is usual in both Metric and Imperial notation to use µΩ.cm. Its value varies over an immense range: from a little more than 1 in units of µΩ.cm for good conductors, to more than 1024, in the same units, for the best insulators. The electrical conductivity is simply the reciprocal of the resistivity.

Dielectric constant (dimensionless). When a material (such as that used in a capacitor) is placed in an electric field, it becomes polarized and charges appear at its surfaces that tend to screen the interior from the external field. The tendency to polarize is measured by the dielectric constant. For polymers,

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the dielectric constant is generally recorded in the frequency range 50–1000 Hz.

Dielectric loss tangent (dimensionless). When an alternating voltage (V) is applied to a 'perfect' dielectric, current (I_{real}) flows that is 90° out of phase with the voltage. No insulating material is perfect, and a degree of polarization occurs, with the result that the current leads the voltage by something less than 90°.

3.7 Optical properties

Transparency is described by four ratings:
- Optical quality – outstanding transparency, suitable for lenses for imaging
- Transparent – good transparency though with some slight loss of optical clarity.
- Translucent – diffuse light is transmitted but lacking optical clarity
- Opaque – Completely non-transparent

The dimensions and processing of a polymer can affect its transparency. For instance, many polymers are translucent with a thin section thickness but opaque when the section thickness is increased. In assigning Transparency ratings we have attempted to reflect typical conditions.

Refractive index a dimensionless property defined as the ratio of the speed of light in vacuum to that in the material.

Transmissivity is a measure of the optical transparency of a material. Transmissivity is the proportion of radiation in the visible light range (380-780 nm) that passes through a material.

Emissivity is a measure of the heat radiation emitted by a material. An ideal black body is assigned an emissivity of 1.0. The emissivity is highly dependent on the surface condition of the material – whether it is polished, painted or coated. Here we refer to the emissivity of the material in its natural state.

Natural Color is a description of the natural color and appearance of the material, without the application of paints or dyes.

3.8 Acoustic properties

The Sound absorption coefficient measures the proportion of incident sound that is absorbed by a material. A material with a coefficient of 0.8 absorbs 80% of the sound; one with a coefficient 0.03 absorbs only 3%, and thus is a sound reflector.

Sound insulation measures the effectiveness of a material in preventing airborne noise entering a room, either from outside or from another room. It is almost proportional to the mass, per unit area, of the wall through which the sound must pass, and thus the density and thickness of the material.

3.9 Eco properties

Embodied energy is the energy required to make 1 kg of the material from its ores or feedstocks. Data are approximate, but still useful in ranking materials by the energy they have required. Many materials are very energy intensive to produce (Metric units: MJ/kg; Imperial: kcal/lb).

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CO_2 footprint. The mass of carbon dioxide (CO_2), in kg, produced and released into the atmosphere, as a consequence of the production of one kg of the material. Metric: kg/kg; Imperial: lb/lb

Recycle, Downcycle, Biodegrade, Incinerate, Landfill simply record whether or not the material can be processed in these ways.

3.10 Processability

Processing by casting, forming, molding, machining, welding and brazing is ranked on a scale of 1 to 5. The ranking 1 indicates that the process is impractical; 5 indicates that it is routine and can be performed without difficulty. Rankings of 2 to 4 indicate increasing levels of ease of processing.

Castability deals with a complex combination of liquid metal properties and solidification characteristics that promote a sound and accurate casting. Factors in include fluidity, shrinkage and resistance to hot tearing.

Formability describes the ability of sheet metal to be deformed to shape. It is limited by tearing, buckling, wrinkling or excess thinning. Good formability means good resistance to these failure modes.

Moldability is an indicator of the ease with which a polymer can be molded.

Machinability is the relative ease of difficulty of a material to be machined. A material has good machinability *if the tool wear is low, the cutting forces are low, the cutting speed is high and the surface finish is good.* Weldability describes the ease or difficulty with which a weld can be made and the quality and soundness of the resulting joint.

Solder/Brazability describes the ease or difficulty with which a a material can be brazed or soldered and the quality and soundness of the resulting joint.

3.11 Durability

Of the material exposed to a number of standard operating environments is categorized qualitatively on a 5-point scale: Very poor, Poor, Average, Good, and Very good. . ‘Very good’ means highly resistant to the environment, ‘Very poor’ means completely unresistant or unstable in the environment. The categorization is designed to help with screening; further information should always be sought if environmental attack is a concern. The environments are:

Fresh water	Weak Acid	Weak Alkalis	Organic Solvents
Salt water	Strong Acid	Strong Alkalis	(UV Radiation)

Durability in industrial atmosphere. Along with marine atmospheres, industrial atmospheres represent a challenging environment for the durability of building components. The combination of airborne particulates and acidic discharges from industrial sites can be the most damaging elements that a building’s components may face during their service life. Especially vulnerable are metals used as building enclosure cladding, flashing, railings, fascias, and soffits.

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Durability in rural atmosphere. Rural atmospheres contain few challenges to the durability of building components, therefore this particular context is least damaging to a building's overall service life.

Durability in marine atmosphere. The prevalence of salts, high humidity, exposure to storms and high winds make marine environments a challenging context for many buildings. Hurricanes and high-energy storms are only the most dramatic events that pose real risk to the service life of building components. Continual wetting and drying of surfaces with salt saturated water and intense solar radiation can be just as damaging over the lifetime of the building.

3.12 Supporting information

Points the user to additional information about the material. It is catalogued under the following headings.

Design guidelines contains advice about design with the material.

Technical notes give further technical background about the material.

Typical uses lists common applications of the material.

Related standards refer to standards where these are relevant.

Trade names is a list of alternative names.

Further reading lists further sources of information about the material.

Links to References lists sources of information about the material.

Links to Suppliers list suppliers of the material.

Links to ProcessUniverse retrieves records for processes that can shape, join or surface-finish the material.

4. Exploring the database

The Granta EduPack software allows three principal functions: *Browsing, Searching and Selection*. *Browse* opens the chosen data-table (that of Materials or of Processes) and allows the tree to be expanded until a chosen record is exposed. The *Search* facility enables a full-text search of all the records in a chosen data-table, or all of them. In addition, the Granta EduPack system offers a range of *Selection tools*, allowing materials to be chosen to meet specific needs. Figures 5, 6, and 7 are examples of the ways in which the data can be presented. Figure 5 is bar-chart, here for *Thermal resistivity*.

Each bar shows the range of the property for a material. Materials with high, low or specific values of thermal resistivity are selected by placing a selection box (not shown) on the chart. All the numeric properties in the database can be plotted and selected in this way.

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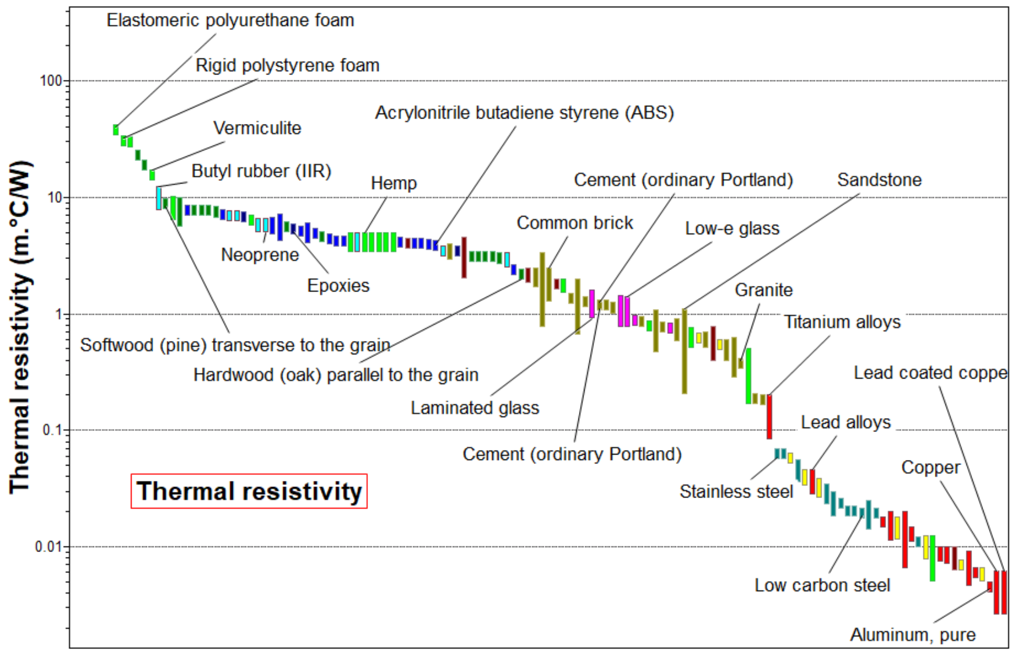

Figure 5. Granta EduPack Bar Chart of Thermal Resistivity of Materials

Numerical properties can also be plotted into Bubble (Ashby) Charts, comparing two material properties with one another. Figure 6 compares thermal resistivity with density, two important properties to consider in building materials. Notice how many foam and natural materials have a high thermal resistivity and a low density, existing in the upper left-hand corner of the chart.

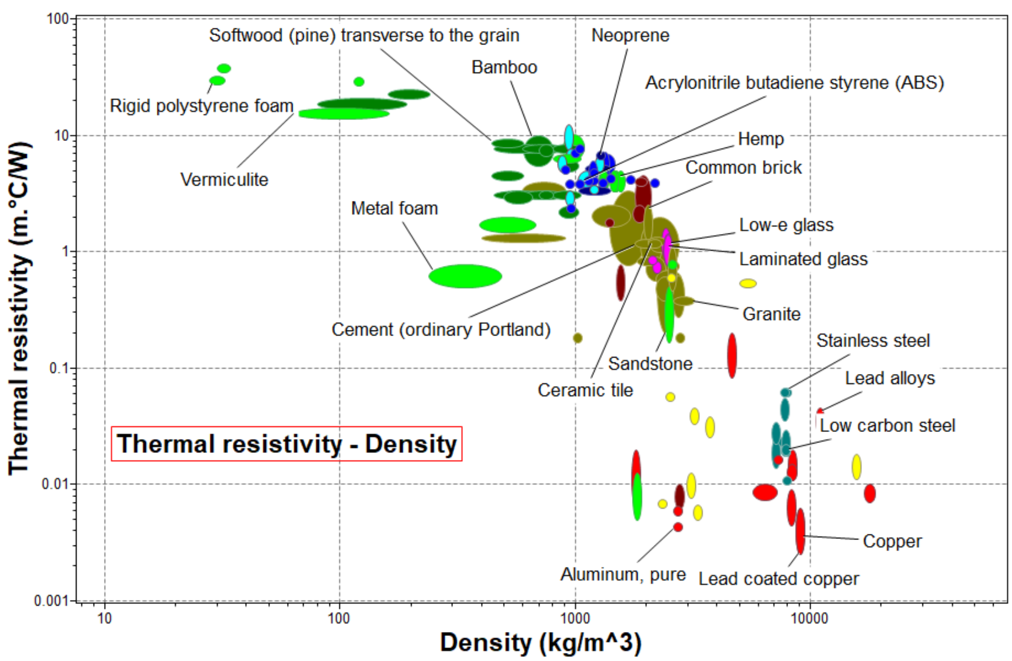

Figure 6. Ashby Chart of Thermal Resistivity vs. Density

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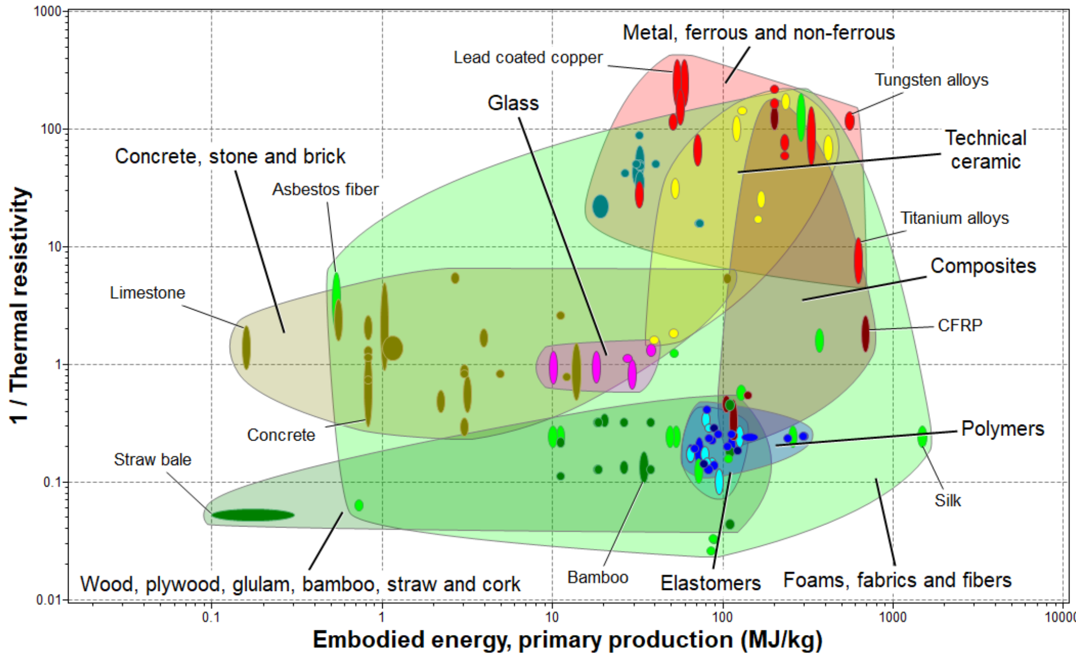

Figure 7. Ashby Chart of Thermal Conductivity vs. Embodied Energy

Selection stages can be stacked to meet multiple criteria. Figure 7 shows a more informative chart, one giving insight into energy-related aspects of material choice. The embodied energy of materials is plotted on the X-axis – it allows a measure of the material-related energy commitment in construction. The reciprocal of Thermal resistivity (Thermal conductivity) is plotted on the y-axis – high resistance implies the ability to insulate, one way of conserving energy during the use of the structure. Materials that have low embodied energy and high thermal resistivity lie at the lower left.

Not surprisingly, Straw bale construction (see the record for Straw bale) is particularly good by both measures. In contrast to Figure 6, materials of a given family cluster together; in Figure 7 families have been enclosed in envelopes to bring this out. All the numeric properties can be plotted in this way, and (as with the bar-charts) a range of selection tools allow materials lying in a particular part of the charts to be isolated and identified.

5. Further reading

Ashby, M. F. (2016) "Materials Selection in Mechanical Design" 5th edition, Butterworth Heinemann, Oxford UK.

Ashby, M.F. and Johnson, K.J. (2010) "Materials and Design", 2nd edition, Butterworth Heinemann, Oxford UK.

Ansys Granta EduPack, 2022R1 Release (https://www.ansys.com/products/materials/granta-edupack)

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ANSYS, Inc.
Southepointe
2600 Ansys Drive
Canonsburg, PA 15317
U.S.A.
724.746.3304
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