GRANTA EduPack MicroProjects with Solutions:
Mechanical Properties of Metals and Alloys

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These ***MicroProjects*** are short investigations of an aspect of Materials Science and Engineering that can be completed in less than an hour. Each poses a set of questions that can be answered using the GRANTA EduPack Material Science and Engineering (MS&E) database. All start at a level that is readily accessible, using the SEARCH function to find records, creating charts using the CHART/SELECT function, and extracting relevant data from a Record and its linked SCIENCE NOTES. Hints in gray help with any difficult step.

Each MicroProject has an attached ***Discussion Point*** – a challenge to go further – highlighted in red and separated from the MicroProject by this separator:

The Discussion Point poses a question linked to or arising from the MicroProject. Responding to the Discussion point requires independent thought and research, takes longer, but is rewarding if followed. It is an add-on for more advanced study.

Each MicroProject and its Discussion point has a fully worked ***Sample Response***, available to the instructor. The charts shown in the responses are reproduced here exactly as produced by GRANTA EduPack.

Example Use: In-class activities, homework assignments, activity to introduce students to functionalities of GRANTA EduPack

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Phase Diagram Teaching Package Files:

- Lecture PowerPoint
- Student Lecture Notes
- Exercises
- Quiz Questions (Word and GIFT Format)
- Concept Maps
- Misc.

GRANTA EduPack Introductory MSE Teaching Package Topics:

- Bonding and Material Families
- Crystallography and Crystal Defects
- Mechanical Properties
- Phase Diagrams

Mechanical Properties MicroProject 1

Shields for Viking invaders

Imagine yourself to be a 12th century Viking seeking a light, tough materials to make shields to protect yourself while you pillage and plunder. The only materials available to you are those that occur naturally, derived from plants or animals.

- "Light" means low density, ρ. What does "Tough" mean? (Fracture toughness, K_{1c}, and Toughness, G_{1c}, differ. The first is in the database, the second is not but can be circulated from the properties that are.)
- How is the property "Toughness" defined in term of the properties that are in the database? (The science note (*i*) for Fracture Toughness may help here.)
- Make a bar chart of the Toughness of natural materials. Which three have the highest toughness? (First apply a Tree stage to limit the selection to Biological materials – woods, soft and hard tissue. Then use the Advanced option in the axis-choice panel to create G_{1c},)
- That deals with toughness, but what about lightness? Add Density ρ to the x-axis. Apply a selection line with a slope of 1 describing light, tough materials (G_{1c} / ρ) and move it upwards to find the two best natural materials for shields. What are they?

Discussion point (requiring wider investigation or thought):

Which of the materials that you have identified really been used for shields in the past? Use the internet to research materials for shields. What do you find?

Answers and Sample Responses

Shields for Viking invaders

What does "Tough" mean?

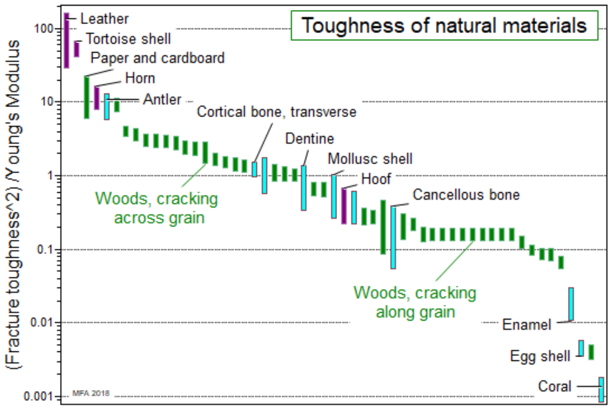
"Tough" means that the propagation of a crack dissipates a lot of energy. It is measured by the property G_{1c}, with units of Joules per square meter.

How is toughness related to other properties?

From the science note("*i*") for Fracture toughness we find that Toughness is related to the other properties by $G_{1c} = K_{1c}^2 / E$, where K_{1c} is the Fracture toughness and E is Young's modulus.

Bar chart of the Toughness of natural materials.

The bar chart appears on the left. The three natural materials with the greatest toughness are tortoise Leather, Tortoise shell and Paper (try tearing a phone directory in half).



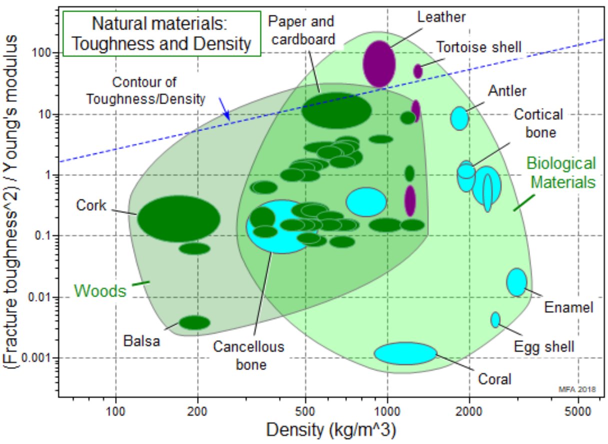


Chart of

Toughness and Density.

The chart appears on the right. Two materials stand out as having high toughness at low weight: leather and tortoise shell

***Discussion point:* materials used for shields[1,2].**

There are many web entries on shields. Both tortoise shell and leather shields were used in medieval times and are still used today, as these pictures below indicate.

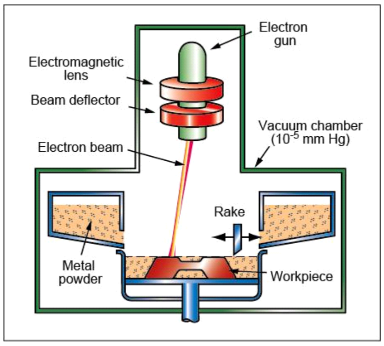
Tortoise shell shield from the Sudan, about 1950

Maasai shield from Kenya, made of cattle hide

Mechanical Properties Micro-project 2

Are materials made by additive manufacture any good? (metals)

- ***Additive Manufacture (AM)*** technologies use computer-controlled deposition to build shapes layer-by-layer. All can create shapes of great complexity without the need for dies molds. The precision and surface roughness, at present, are limited to ±0.1mm at best and the process is slow (typically 20 hours per part) but the freedom of choice of shape is enormous. What about the properties of metals shaped in way: are they as good as those of materials made by conventional methods such as casting or forging?



Electron beam melting (metals)

or

1 to

this

linked

- Which metals can be shaped by AM? (Open the record for the process shown in the figure and copy the materials to which it is from the tab at the bottom of the record.)

- Explore the properties of conventional Titanium alloys, for which there is a record in the MS&E DB, by making a chart with Tensile Strength (MPa) on the y-axis and Elongation (%) on the x-axis. (Use the "Define your own subset" option or use a Tree stage to isolate Titanium alloys. Just one big bubble appears on the chart.)

- AM methods are new – there are not yet many measurements of the properties of AM materials. The alloy Ti-6Al-4V is one of the most studied. The table lists data from five independent tests.

AM method	Tensile strength (MPa)	Elongation (%)
Renishaw Ti-6-4 (annealed 750 C)	1120 - 1150	6 – 8.5
Renishaw Ti-6-4 (annealed 850 C)	1030 - 1070	6.5 - 10
SLM Solutions Ti-6-4 (annealed)	965 - 985	9 – 10.5
Optomec Ti-6-4 (no post processing)	1060 - 1080	10 - 12
ARCAM Ti-6-4 (hot-isostatic pressed)	960 - 985	13.5 - 16

Add these materials to the MS&E database. (Adding a new record: Right-click on a chart. Select "Add record". Enter a name: Renishaw Ti-6-4. Enter the data. Return to the chart – Renishaw Ti-6-4 now appears on it).

- Add a title to the chart, reset both axes from log to linear to give a fair comparison and adjust the range of both to give a well-proportioned chart. How do the properties of Ti-6Al-4V made by AM compare to those of conventionally cast Ti-6-4? (To adjust an axis, double click on the axis name, then make the changes in the Axis settings box.)

- ***Discussion point (requiring wider investigation or thought):***
  AM is seen as a component of the evolving "4th Industrial Revolution" (following the revolutions of steam, electricity and information technology). The spectrum of materials that can be shaped successfully by additive manufacture is increasing rapidly. Carry out a survey of reports on materials for additive manufacture, linking them to the industrial sector to which they contribute.

Answers and Sample Responses

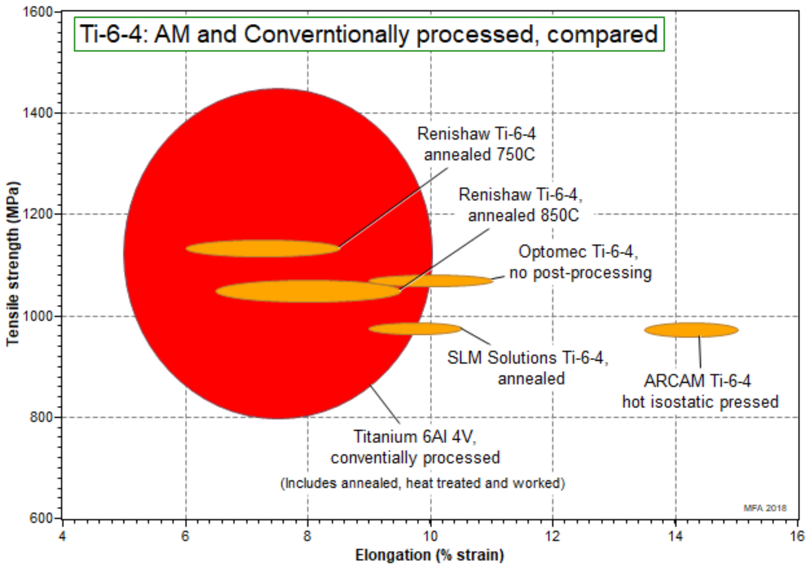
Are materials made by additive manufacture any good? (metals)

Which metals can be shaped by AM?

The "Materials" link in the record for Electron Beam Melting gives the following list:
Commercially pure titanium
Titanium alloys (basically Ti-6AL-4V)
Steels

Strength and elongation of conventional ABS

Conventionally cast Ti-6-4 appears as a large red bubble on axes of Tensile Strength and Elongation. (Both have a wide range of values because the single record for Ti-6-4 encompasses a number of different variants and heat treatments. These grades have separate records in the CES EduPack Level 3 database.)



Adding records for AM Titanium 6Al 4V

When the data for the three AM materials are added, they appear on the chart as orange bubbles, shown here. The axes have been set to linear and the ranges adjusted in the ways suggested in the question.

Property comparison

AM processes differ so greatly from conventional casting methods that one might expect the resulting properties to differ also. The chart shows that the reported strengths of the AM samples span the same range as those that are conventionally cast, but that the elongations of the AM samples have a wide spread and depend on both the primary AM process and the subsequent post-processing.

The scatter in the properties plotted in the chart reflect the present immaturity of additive manufacturing methods, that the characterization of AM materials is in its infancy and that reproducibility is largely untested. That will change: this is a rapidly evolving field.

Discussion point: ***Material that can be shaped by Additive Manufacture.***

A search on "Materials for additive manufacture" generates many leads; some are listed below. A survey gives the following industrial sectors and materials.

Early AM used easily-formed materials – polymers and waxes – focussing on shape, not properties. Today's rapidly expanding AM technologies focus on markets. The materials that are now commercially available reflect the business opportunities in aerospace, medical engineering and defence.

Sector	Materials
Aerospace, Transport Defence	Titanium alloys: CP titanium, Ti-6Al-4V
	Aluminium alloys: Al-Si-Mg alloys; 6061
	Stainless steels: 316, 420, PH 17-4
	Superalloys: IN625, Stellite
	Tool steels: H13
	Ceramics: Alumina
Medical and Dental	Titanium
	Nylon, ABS, PP, PLA, proprietary plastics and elastomers
	Calcium phosphate
	Cartilage and other living tissue
Other	Paper
	Food: chocolate, sugar, pasta, meat
	Art, Design, Jewellery: gold, silver, plastics, glass
	Archaeology, Construction: stone

https://www.azom.com/article.aspx?ArticleID=8132

http://www.spilasers.com/application-additive-manufacturing/additive-manufacturing-materials/

Document Information

This exercise unit is part of a set of teaching resources to help introduce students to materials, processes and rational selections.

Accuracy

The author(s) try hard to make sure that these resources are of a high quality. If you have any suggestions for improvements, please contact the author(s) by email. You may also write to the Ansys Granta Education Team with your suggestions at granta-education-team@ansys.com.

Ansys Granta Education Hub

For more information on Ansys GRANTA EduPack software and related teaching resources, please visit https://www.ansys.com/products/materials/granta-edupack/

Teaching Resources Website

The Teaching Resources website aims to support teaching of materials-related courses in design, engineering and science. Resources come in various formats and are aimed primarily at undergraduate education. Visit grantadesign.com/education/teachingresources/ to learn more.

There are 350+ resources on the Ansys Granta Education Hub. The resources include:

- Lecture presentations with notes
- Case studies
- Exercises with worked solutions
- Microprojects
- Recorded webinars
- White papers
- Solution manuals
- Interactive exercises

Some of the resources are open access and students can access them. Others are only available to educators using GRANTA EduPack.

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