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# Materials selection and case studies

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## ABSTRACT

In the most general sense, everything that people need is called a material. In a specific sense, we can say that all kinds of tools and equipment that engineers use to produce are called materials. Materials Science studies the various properties of materials such as mechanical and physical; It is also a branch of science that deals with their application to various scientific and technological fields and is in the interest of almost every technical staff member. A technical staff member who does not have sufficient knowledge about the structure and properties of the materials cannot choose the most suitable material for his usage area. Errors can reach large dimensions; this can put the choice of the material and other relevant units in a difficult situation. Understanding materials has led to progress in design since ancient times. The process of replacing old materials with new ones has occurred from time to time, as there is so much material today than before. The importance of material selection as part of the design process is growing, especially due to industrial competition. Therefore, design and material engineering and scientists are in close relationship for the design and selection of economical materials that will best respond to the desired service conditions. More than 200 thousand materials used in the industry are used. These materials should be selected in accordance with their usage areas. If the materials are chosen incorrectly, this causes loss of life and property. In this study, diagrams used in material selection are introduced and 3 examples are given on the subject.

**Keywords**: Selection of materials, Property charts, Modulus & density, Strength, Specific stiffness

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## 1. Introduction

Design and material selection are two important issues in engineering. Since humans first made clothes, built shelters, and wars began, materials were of limited design. People still do this. However, the materials and processes that will shape them are developing faster than any other period in history; the challenges and opportunities they present are greater than ever.

Design is the process of transforming a new idea or market need into detailed information by which a product can be produced. Each of its stages requires decisions about the materials from which the product will be made and the process of making it. Normally, the choice of material is determined by the design. However, sometimes the opposite is done.

There are more than 200,000 materials that engineers can use in industry. However, the constant appearance of new materials with new and usable properties further expands the options. So how do engineers choose the most suitable material for their purposes from this comprehensive menu? Do they trust their experience? Experience has no value. Apprentice-based learning has a finished timescale. The specialist who is here today due to business activity may go elsewhere tomorrow. Also, there is a rapid improvement in material information. An experience-based strategy is not compatible with today's computer-based environment. Therefore, we need a systematic procedure [1,2].

The material selection cannot be made independently of the choice of the process in which the material will be shaped, joined and finished. Cost enters the equation both in material selection and in the way the material is processed. The form, texture, color and beauty of the product - the satisfaction it gives to the user - are important in almost everything from home appliances to cars and airplanes. This feature, known as industrial design, is a feature that can lose the market if neglected.

There are many factors such as strength, toughness, electrical conductivity, thermal conductivity that should be considered in material selection. The role of aesthetics in engineering design is discussed. Aesthetics should be considered especially in jewelry used by women.

Approximately 20 material selection diagrams were developed by Ashby. These are very useful, but take time. In recent years Ashby and his team have developed a material selection platform called CES [1,2].

Throughout history, materials were in limited design. The ages of man are named according to the materials he used: stone, bronze, iron. And when a man died, the materials he valued would be buried with him; For example, he was buried in an enameled sarcophagus with Tutankhamun bronze sword and gold mask. These materials represented the high technology of the living age. If there was such a tradition today, what would people be buried with? Titanium watches; carbon fiber reinforced tennis rackets; metal matrix composite mountain bikes; shape memory alloy eyeglass frame; polyether-ethyl-ketone crash helmets?

This is the age of an enormous range of materials. The menu of ingredients has expanded so rapidly that some designers who left college 20 years ago may not know many of them. But not knowing poses a disastrous risk for the designer. Innovative design means the creative use of features often offered by new or improved materials. This evolution and increasing velocity is illustrated in Figure 1. Prehistoric materials (before 10,000 BC, before the Stone Age) were ceramics and glass, natural polymers and composites. Weapons, which have always been the pinnacle of technology, are wood and flint; stone and wooden buildings and bridges. The development of primitive thermochemistry encouraged immense advances in technology, first allowing the extraction of copper and bronze, followed by iron (Bronze Age, 4000-1000 BC and Iron Age, 1000 - 1620 BC). Cast iron technology (1620s) ensured the dominance of metals in engineering; Since then the evolution of steels (from 1850), light alloys (from the 1940s) and specialty alloys have consolidated their positions. In the 1950s "engineering materials" meant "metals". Metallurgy courses were given to engineers; Little mention of other materials.

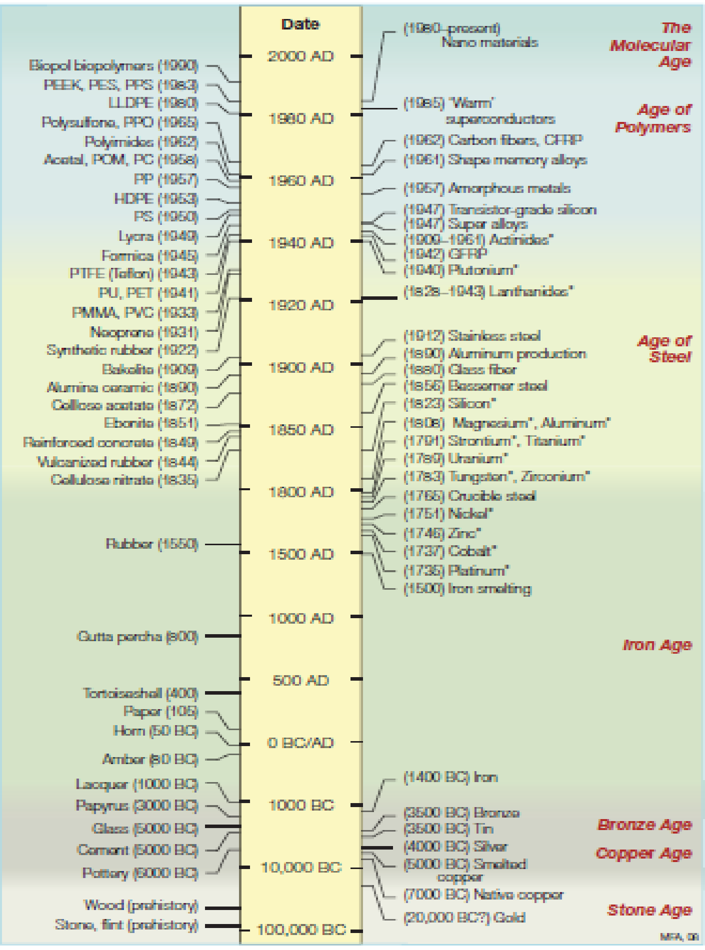


Figure 1. A materials timeline [1,2]

Of course, there have been improvements in other material classes. Improved cements, refractories and glasses; and polymers include rubber, Bakelite, and polyethylene; however, their share in the total materials market was small. Everything has changed since 1950. The rate of development of new metal alloys is now slow; Demand for steel and cast iron has actually declined in some countries. On the other hand, the polymer and composite industries are growing rapidly, and growth projections in new high performance ceramic production show that expansion continues here as well.

Significant improvements documented in the timeline in Figure 1 resulted from a desire for higher performance than ever before. One way to demonstrate this progress is to watch how the properties evolve in material-property charts. Figure 2 shows one of them - a force-density chart. Oval bubbles indicate the strength and density range of materials; larger colored envelopes cover families. The chart is plotted for six consecutive points in the past tense and ends with the present. The prehistoric materials shown in (A) cover only a small portion of this power-density space [3,4].

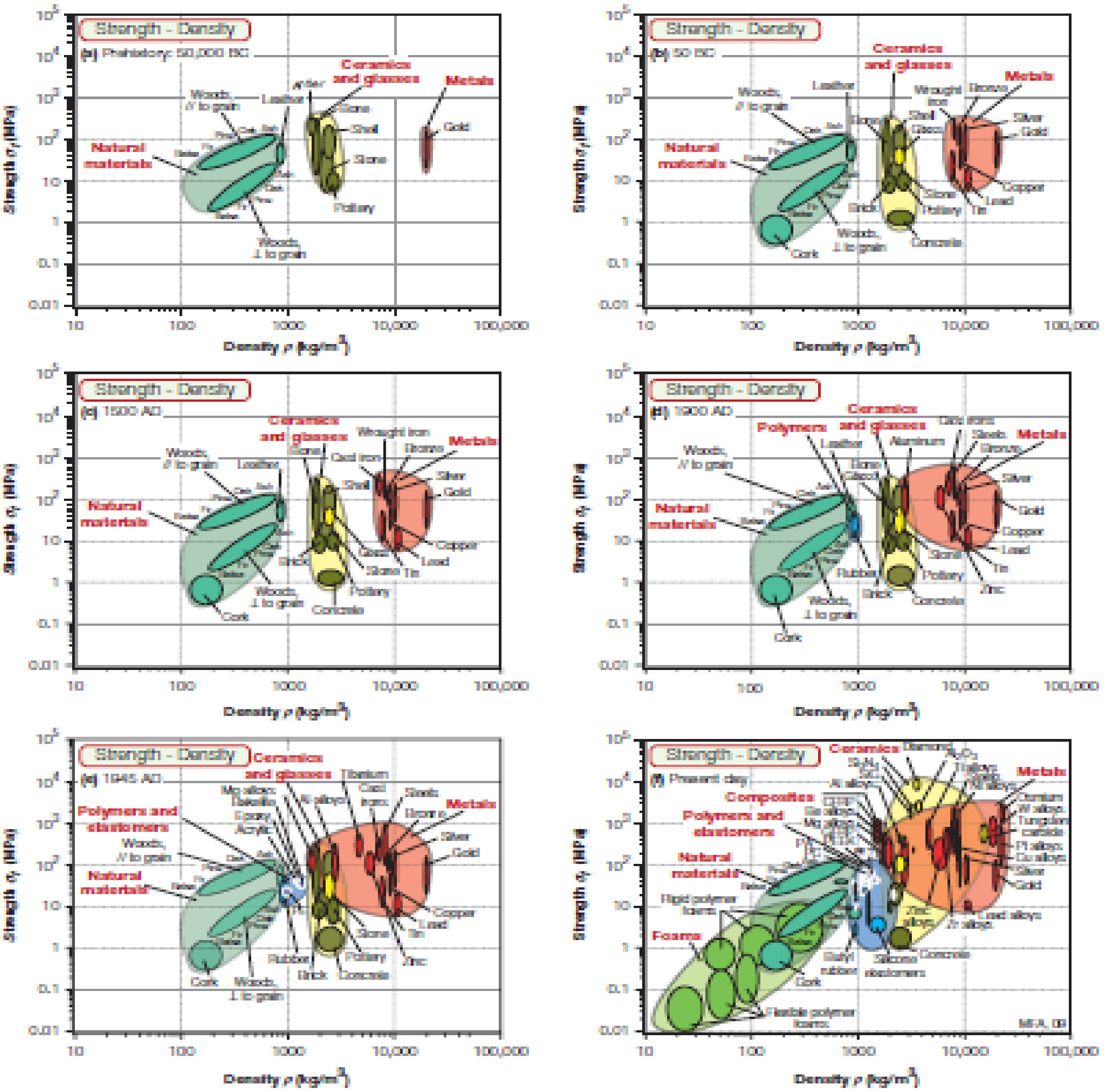


Figure 2 shows how materials have been developed over time to meet the strength and density demands of the material-property area [1,2]

## 2. Material property charts

Material properties limit performance. A feature can be displayed as an ordered list or bar chart. However, the performance of a component is often not dependent on one feature alone. Often looked at a combination of properties: for example, the need for low hardness, heat conduction combined with corrosion resistance, or strength combined with durability. This suggests the idea of plotting one feature against another, mapping the areas in the feature area occupied by each material class and sub-areas occupied by individual materials. The resulting graphics are useful in many ways. They concentrate a large chunk of information into a compact but accessible format; they reveal correlations between material properties that help control and predict data.

### 2.1. The modulus–density chart

Modulus and density are known properties. Steel is hard; rubber compatible: These are the effects of the module. Lead is heavy; cork flotation: these are the effects of density. Figure 3 shows Young's modulus, E and density, ρ range for engineering materials. Data for members of a particular material family are clustered together and can be surrounded by a colored envelope.

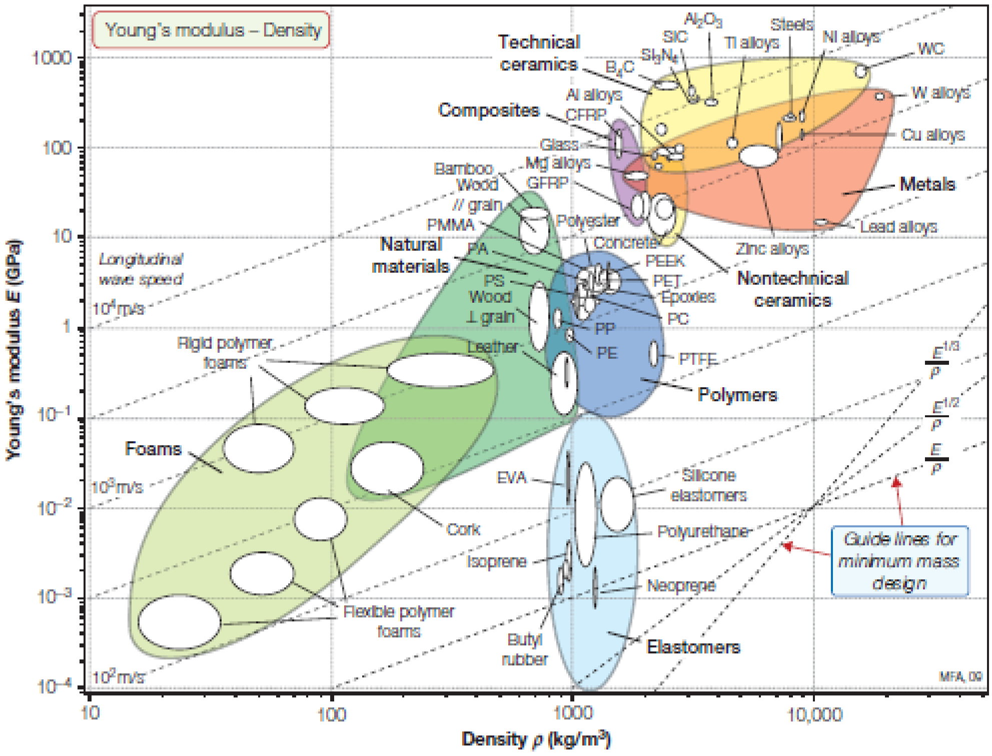


Figure 3 Young's modulus E plotted against density ρ. The heavy envelopes enclose data for a given class of material. The diagonal contours show the longitudinal wave velocity. The guide lines of constant E/ρ, E1/2/ρ, and E1/3/ρ allow selection of materials for minimum weight, deflection-limited, design [1,2].

The density of a solid depends on the atomic weight of its atoms or ions, their size, and the way they are packed. Metals are dense because they are made of heavy atoms packed closely together; Polymers have low densities because they are made in amorphous or crystalline packages that are substantially lighter than carbon (atomic weight: 12) and hydrogen (atomic weight: 1). Ceramics often have lower densities than metals because they contain light O, N or C atoms. Even the lightest atoms packaged in the most obvious way yield solids with a density of about 1000 kg / m3, like that of water. Materials with lower density than this are foams - materials composed of cells that contain most of the pore space.

Metals have high modulus because close stacking provides a high bond density and the bonds are strong although not as strong as diamond. Polymers contain both strong diamond-like covalent bonds and weak hydrogen or Van der Waals bonds (S = 0.5-2 N / m). They are weak bonds that stretch when polymer is deformed and give low modulus.

But even large atoms (ro = $3 \times 10^{-10}$ m) bonded by the weakest bonds (S = 0.5 N / m) have a rough modulus.

$$E = 0.5/3 \times 10^{-10} \approx 1 \text{ GPa} \qquad (1)$$

This is the lower limit for true solids. The table shows that many materials have lower modulus than this: These are either elastomers or foams. Elastomers have low E because they have weak secondary bonds [5].

The graph shows that the modulus of engineering materials spans twenty years from 0.0001 GPa (low density foams) to 1,000 GPa (diamond). Density covers a factor of 2,000 from 0.01 to 20 Mg / m$^3$. As a family, ceramics are very hard, metals slightly less - but none of them modulus less than 10 GPa. Polymers, by contrast, all cluster between 0.8 and 8 GPa.

The chart helps with common material selection problem for applications where mass needs to be minimized. Guide lines corresponding to the three common loading geometries are shown in Figure 3.

The modulus of a solid is a well-defined quantity with a sharp value. It is plotted against ρ density in Figure 4.

The strength range for engineering materials extends over decades: from 0.01 MPa (foams used in packaging) to 10$^4$ MPa (strength of diamond). Plastic shear in a crystal involves the movement of dislocations. In non-crystalline solids, we think of it as the relative shift of two parts of a polymer chain or the shear of a small molecular cluster in a glass mesh, rather than the energy associated with the unit step of the flow process. The strength of non-crystalline solids has the same origin as underlying lattice resistance.

An important use of the table is the material selection for light strength limited design. Guidelines are shown for efficiency-limited design of moving components where material selection and inertia forces are important in the minimum weight design of bonds, columns, beams and plates [6].

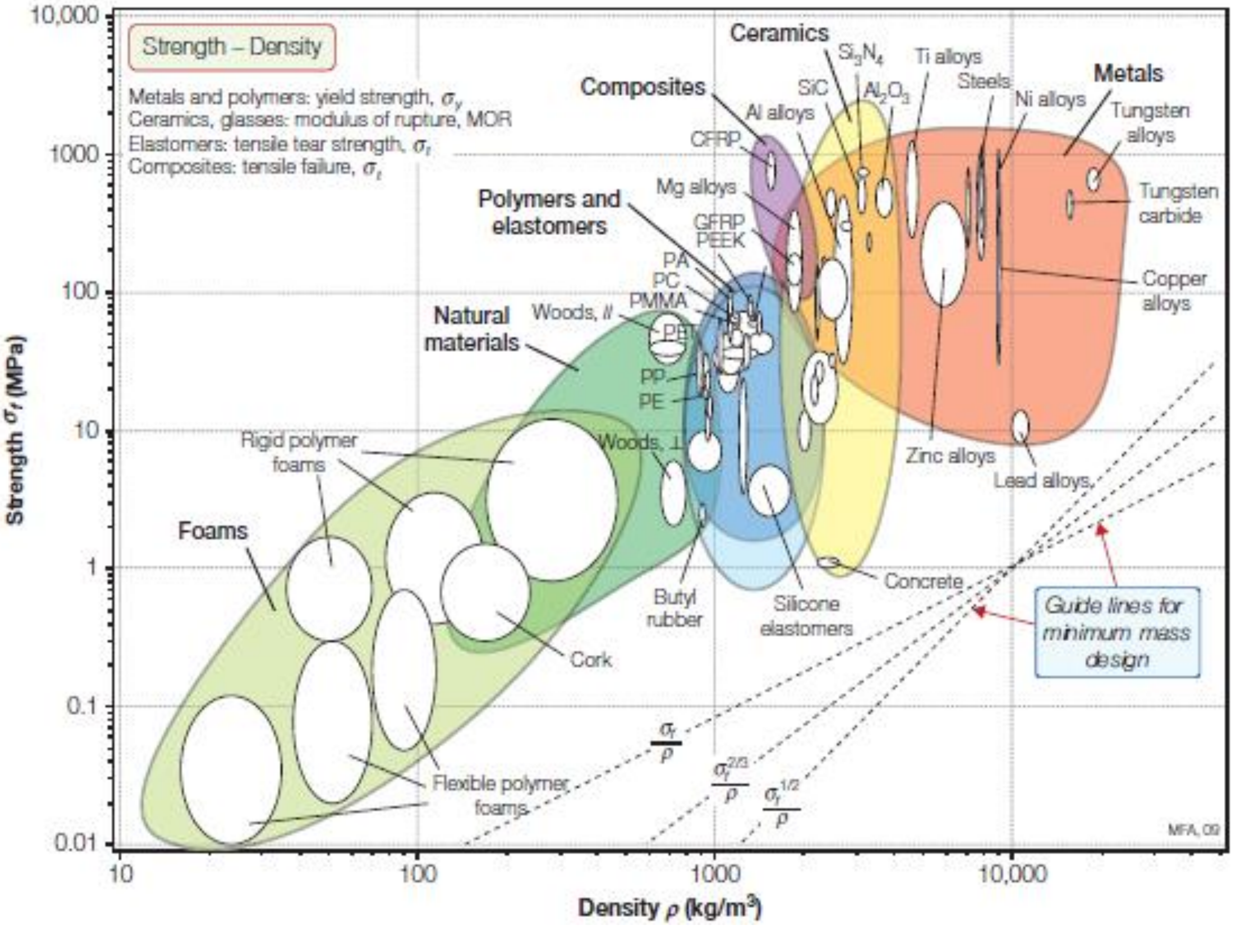


Figure 4. Strength $\sigma_f$ plotted against density ρ (yield strength for metals and polymers, compressive strength for ceramics, tear strength for elastomers, and tensile strength for composites). The guide lines of constants $\sigma_f / \rho$, $\sigma f^{2/3} / \rho$, and $\sigma_f{}^{1/2} / \rho$ are used in minimum weight, yield-limited, design [1,2].

## 2.2. The modulus–strength chart

Good spring is made from high tensile steel. However, a spring operating under low load is also made of rubber. How is it that two such different materials are both suited to the same task? These and other questions are answered in Figure 5, one of the most useful of all charts. This shows Young's modulus E of the force plotted against $\sigma_f$. For metals and polymers yield strength means flexural strength (modulus of rupture) for ceramics, tear strength for elastomers and tensile strength for composites and woods; The symbol $\sigma_f$ is used for all [6,7].

Engineering polymers have large yield strains between 0.01 and 0.1; the values of metals are at least 10 times smaller. Composites and woods are found on a 0.01 contour which is as good as the best metals. Due to their extremely low modulus, elastomers have greater $\sigma_f$ / E values than any other material grade: typically, 1 to 10.

The graph shows that the failure strain approaches this value for some polymers. For most solids it is less for two reasons. First, non-localized bonds do not break when the structure is cut. This is how the ionic bond acts for the metallic bond and for certain shear directions. Very pure metals, for example, need strengthening mechanisms to yield at stresses as low as E / 10,000 and make them useful in engineering. The covalent bond is localized, and therefore covalent solids have yield strengths as high as E / 10 at low temperatures.

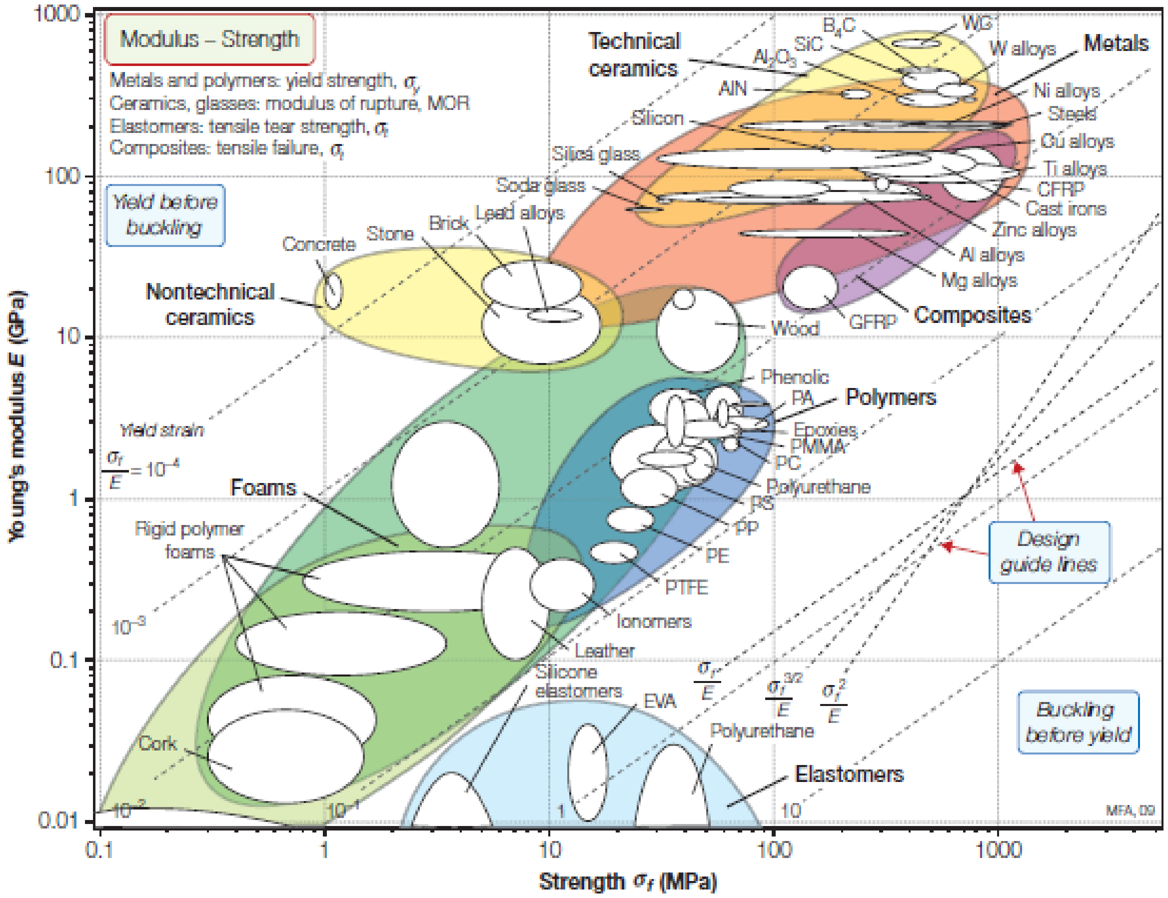


Figure 5. Young’s modulus E plotted against strength $\sigma_f$. The design guide lines help with the selection of materials for springs, pivots, knife-edges, diaphragms, and hinges [1,2].

## 2.3. The specific stiffness–specific strength chart

Many designs, especially those for moving objects, require a minimum of stiffness and strength. To assist this, the data of the previous chart is repositioned in Figure 6 after dividing by density for each material; Shows a graph of $\sigma_f$ / ρ versus E / ρ. These are measures of "mechanical efficiency", meaning that the least mass of material is used to do the most structural work.

Composites, especially CFRP, are found at the top right. They are emerging as a class of materials with the most attractive specific properties, one of the reasons for their increasing use in aviation. Ceramics have an exceptionally high hardness per unit weight, and their strength per unit weight is as good as those of metals, but their brittleness excludes them from many structural uses [7]. Metals are penalized due to their relatively high density. Polymers perform better on this chart than the previous one, as their density is low. The chart previously shown in Figure 6 has application in material selection for the following.

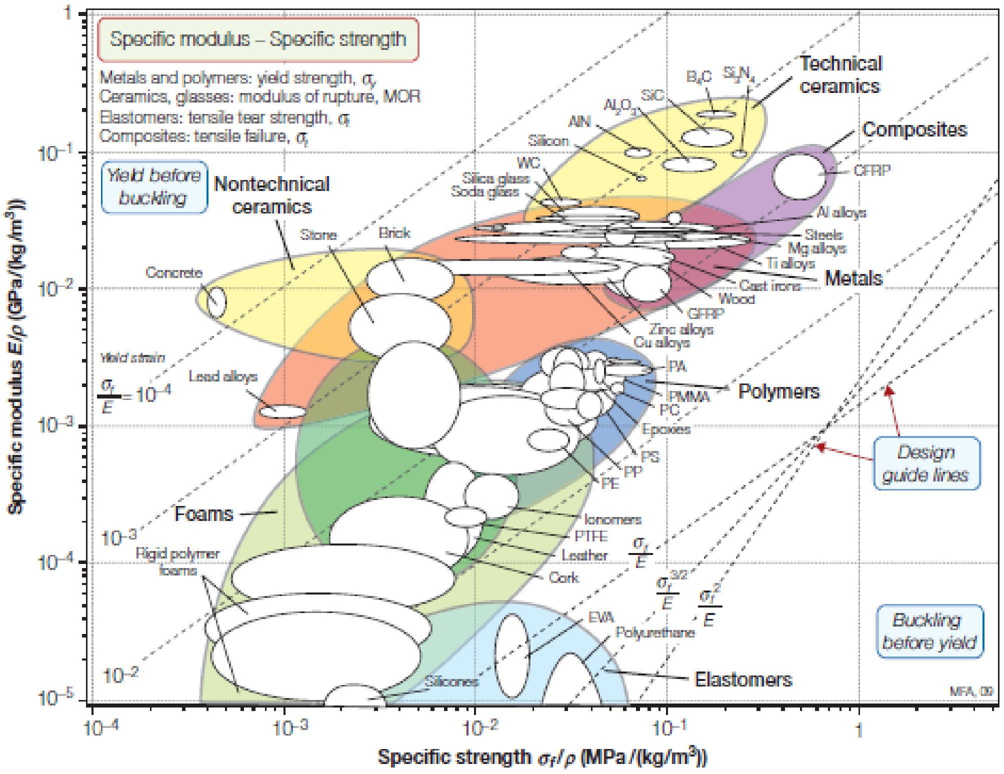


Figure 6. Specific modulus E/ρ plotted against specific strength $\sigma_f/\rho$. The design guide lines help with the selection of materials for lightweight springs and energy-storage systems [1,2].

## 3. Materials Selection (Steps)

This section lays out the basic procedure for selection, establishes the link between material and function (Figure 7). A material has its qualities: density, strength, cost, corrosion resistance, etc.
The selection task specified in two lines,
1. Define the desired attribute profile and then
2. Comparing it with real engineering materials to find the best match.
The first step in considering selection is to examine the design requirements to determine the constraints they place on material selection. The extremely wide selection has shrunk, first, by eliminating materials that do not meet the restrictions. Further narrowing is achieved by ranking the candidates according to their performance [3,4,8].

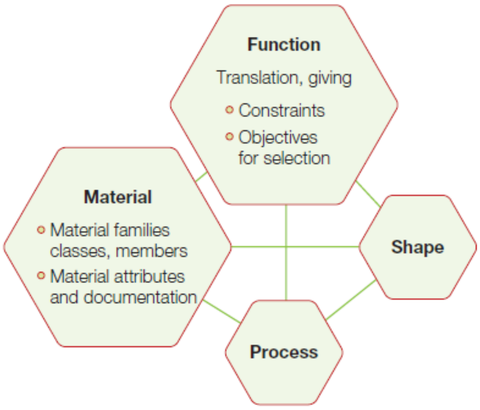


Figure 7. Material selection is determined by function. Shape sometimes influences selection. This section deals with materials selection when this is independent of shape [1,2]

### 3.1. Selection strategies

Selection strategies will be mentioned in this section. It is easier to start with a product selection than the material; the ideas are the same, but the material has additional difficulties. Let's say you need a new car. It should be a mid-size, four-door family sedan with a gas engine that provides at least 150 horsepower enough to tow your powerboat to meet your needs. With all this in mind, you want it to be as cost-effective to own as possible (Figure 8, left).

- The requirements of the four-door sedan family and throttle power are simple constraints; A car must have these in order to be a candidate. Requirement of at least 150 hp imposes a lower limit
- All vehicles with a power limit of 150 hp or more may be accepted.
- The desire for minimum cost of ownership is a goal, a criterion of excellence. Among those that meet the constraints, the most desirable cars are those that minimize this goal.

To continue, you need information about available tools (Figure 8, right). Car magazines, car manufacturers' websites, and dealers list such information. It includes car type and size, number of doors, fuel type, engine power and price. Now: decision time (Figure 8, center). The selection engine uses restraints to distinguish it from all existing cars that are not family sedans with at least 150 hp four-door gas. The best options will be at the top, meaning those with the lowest price will be at the top.

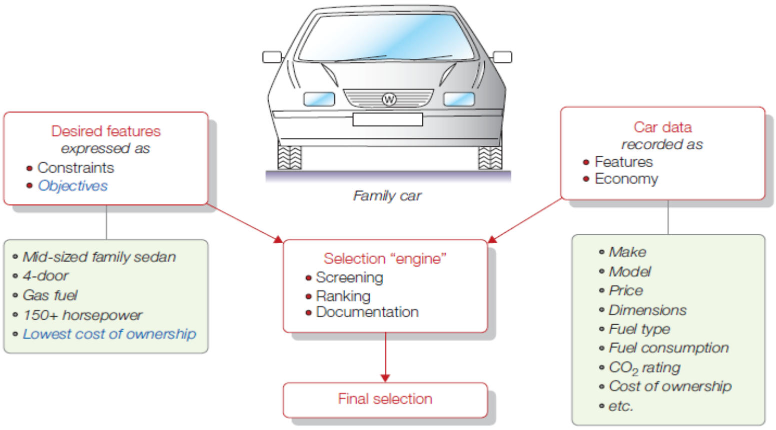


Figure 8. Choosing a car—an example of the selection strategy. Required features are constraints; they are used to screen out unsuitable cars. The survivors are ranked by cost of ownership [1,2]

Selecting materials involves looking for the best match between design requirements and the properties of the materials that can be used to make the design. Figure 9 shows the strategy of the last part applied to the choice of material for a helmet's protective visor. On the left are the requirements the material must meet, expressed as constraints and targets. Constraints: ability to mold and of course transparency. Purpose: If the visor is to protect the face, it should be as break resistant as possible, that is, it should have as high a fracture toughness as possible [9].

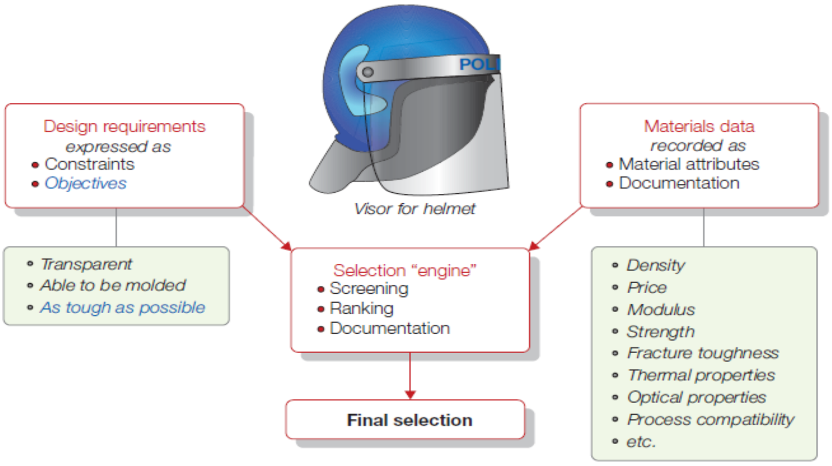


Figure 9. Choosing a material. Design requirements are first expressed as constraints and objectives. The constraints are used for screening. The survivors are ranked by the objective, expressed as a material index [1,2]

## 4. Case studies

Three case studies are given here. Each case study is organized as follows:

- Definition of the problem
- Variables revealing translation, definition function, constraints, targets and material indexes
- Selection in which the menu of materials is reduced by browsing through a short list of suitable candidates
- Post process allowing comment on results and philosophy

### 4.1. Materials for oars

Let us take the example of the shovel.
Mechanically speaking, the paddle is a beam that is forced to bend.
It must be strong enough to bear the bending moment applied by the rower without breaking; It must have a hardness to suit the rower's own characteristics. The paddles are designed to provide stiffness, i.e. a certain elastic deflection. Figure 10 (above) shows a shovel.
In addition, the shovel should be light; The extra weight increases the body's wetted area and the resistance that comes with it. A paddle is a beam of certain stiffness and minimum weight. The material index we want is derived as Equation (2). For a light, rigid beam:

$$M = E^{1/2} / \rho \tag{2}$$

Where E is Young's modulus and ρ is density. There are other obvious restrictions. Shovels fall and blades sometimes collide. The material must be hard enough to withstand this, so brittle materials (those with G1c toughness less than 1 kJ/m$^2$) are not acceptable. Given these requirements summarized in Table 1, what materials would you choose to make the shovel?

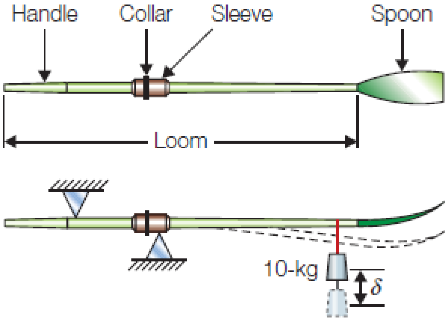
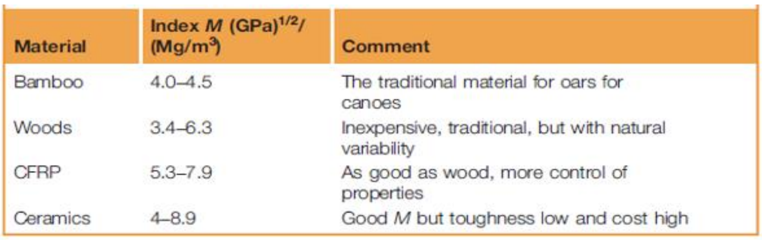


Figure 10. An oar. Oars are designed on stiffness, measured in the way shown in the lower figure, and they must be light [1,2].)

Selection Figure 3 shows the appropriate chart: Graph with Young's modulus plotted against density ρ. The selection line for index M has a slope of 2; it is positioned so that a small group of material remains on it. They are the materials with the largest M values and represent the best choice provided they meet the other constraint. They contain three classes of materials: woods, carbon reinforced polymers, and certain ceramics [10,11,12] (Table 1). Ceramics are fragile; The toughness modulus table in Figure 11 shows that the design failed to meet its requirements. The proposal is clear. Make your paddles out of wood or better still from CFRP.

Table 1. Materials for Oars



| Material | Index *M* (GPa)$^{1/2}$/(Mg/m$^3$) | Comment |
|---|---|---|
| Bamboo | 4.0–4.5 | The traditional material for oars for canoes |
| Woods | 3.4–6.3 | Inexpensive, traditional, but with natural variability |
| CFRP | 5.3–7.9 | As good as wood, more control of properties |
| Ceramics | 4–8.9 | Good *M* but toughness low and cost high |

Postscript Now we know what material the shovels should be made of. What is actually used? Race paddles and paddles are made of either wood or a high performance composite material: carbon fiber reinforced epoxy. Wooden shovels are made today by craftsmen who are predominantly handcrafted as they were 100 years ago. Usually spruce wood is used. When finished, a spruce shovel weighs between 4 and 4.3 kg.

Composite blades are slightly lighter than wood for the same hardness [13,14]. The component parts are manufactured from a mixture of carbon and glass fiber in an epoxy matrix, joined and bonded. The advantage of composites lies partly in the weight saving (typical weight: 3.9 kg) and partly in greater performance control: Until recently, a CFRP shovel was more expensive than a wooden shovel, but the price of carbon fibers dropped enough that the two cost approximately the same.

Can we do better? The chart shows that wood and CFRP offer the lightest shovels, at least when using normal construction methods. New composites not shown in the table may allow further weight savings; and functional grading can do this. However, both are currently unlikely.

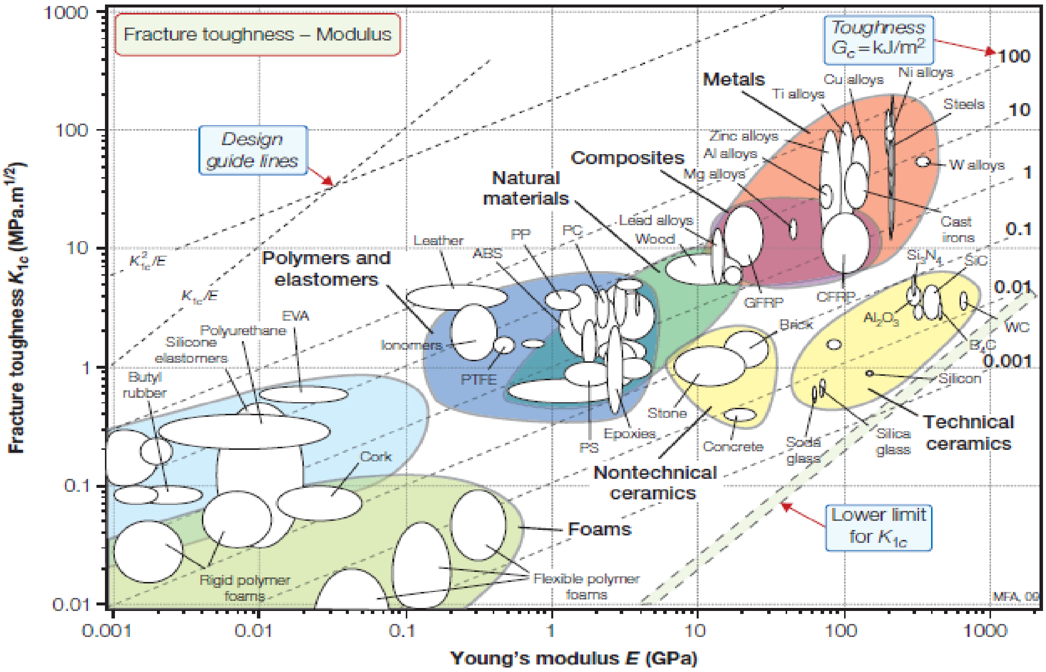


Figure 11. Fracture toughness $K_{1c}$ plotted against Young's modulus E. The family of lines is of constant $K^21c/E$ (approximately $G_{1c}$, the fracture energy or toughness). These, and the guide line of constant $K_{1c}/E$, help in design against fracture. The shaded band shows the lower limit for $K_{1c}$ [1,2].

## 4.2. Materials for table legs

Suppose a furniture designer has designed a table with a flat toughened glass sheet supported on thin uncrossed cylindrical legs (Figure 12). The legs should be strong and light as possible. They must support the table top and everything placed on it without bending. What materials can be recommended?

This is a problem with two purposes1: Weight
it has been reduced in size and delicacy has been maximized. There is a limitation: resistance to buckling. Consider minimizing the weight first. Leg is a thin column of material with density ρ and modulus E. Its length, L, and maximum load, F, are determined by the design it must bear: They are fixed. The radius r of a leg is a free variable. We want to minimize the mass m of the leg given by the objective function

$$m = \pi r^2 L \rho \qquad (3)$$

It is subject to the restriction of supporting a load P without buckling. The elastic buckling load $F_{crit}$ of a column of length L and radius r.

$$F_{crit} = \pi^2 EI/L^2 = \pi^3 E r^4/4L^2 \qquad (4)$$

It is the second moment of the column area using $I = \pi r^4 / 4$. The F load should not exceed $F_{crit}$. Finding the free variable r and putting it into equation m

$$m \geq (4F/\pi)^{1/2} (L)^2 [\rho/E^{1/2}] \qquad (5)$$

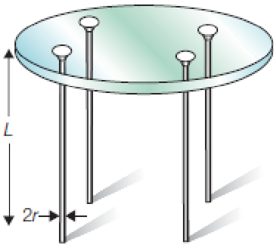


Figure 12. A light table with thin cylindrical legs. The best choice is a material with high $E^{1/2} / \rho$ and E values [1,2].

Material properties are grouped together in the last pair of brackets. Weight is minimized by selecting the subset of materials with the largest value of the material index [15]

$M_1 = E^{1/2} / \rho$

Delicacy now. Inverting equation (6) with $F_{crit}$ equal to F gives an equation for the thinnest leg that will not bend:

$$r \geq (4F/\pi^3)^{1/4} (L)^{1/2} [1/E]^{1/4} \qquad (6)$$

The thinnest foot is the one made of material with the highest value of the material index.

$M_2 = E$

Selection We are looking for the subset of materials with high $E^{1/2} / \rho$ values and we need the E. E vs. ρ plot again (Fig.13). A slope 2 guide is drawn on the diagram; defines the slope of the grid of lines for $E^{1/2} / \rho$ values. The guide is shifted upward (maintaining the slope) until a reasonably small subset of material is isolated on it; displayed in position M1 = 5 GPa $^{1/2}$ / (Mg / $m^3$). Materials above this line have higher $M_1$ values. In the figure it is defined as wood (traditional material), composites (especially CFRP) and certain engineering ceramics. Polymers on the outside: They are not hard enough; metals too: they are very heavy (even the lightest magnesium alloys).

The choice is further narrowed by the requirement that E be large for delicacy. A horizontal line in the diagram connects materials with equal E values; the above are harsher. Figure 13 shows that placing this line at $M_1$ = 100 GPa eliminates wood and GFRP. If the legs are to be really thin, the short list is reduced to CFRP and ceramics: They give legs that weigh the same as wooden ones but are almost half as thick. We know that ceramics are fragile: They have low fracture toughness values.

Table legs are abused - hit and kicked on the floor; Common sense indicates that an additional restriction, such as sufficient endurance, is required. This can be done using the fracture toughness-young modulus diagram; It releases CFRP, eliminating ceramics. The cost of CFRP can cause Snr.

It's a good idea to organize the results as a table, showing not only the best ingredients but also the second best - as far as other considerations are concerned, they may be the best option. Table 2 shows the way to do this.

Postscript Tubular legs should be lighter than sturdy ones. True; but they will also be fatter. Hence, it depends on the relative importance of Snr. It depends on two goals of the furniture designer: lightness and delicacy, and only he can decide. The choice of material may be different if one can be persuaded to live with fat legs.

Due to the low toughness, ceramic feet have been removed. If the goal is to design a lightweight, slim-legged table for use in high temperatures, ceramics should be rethought.

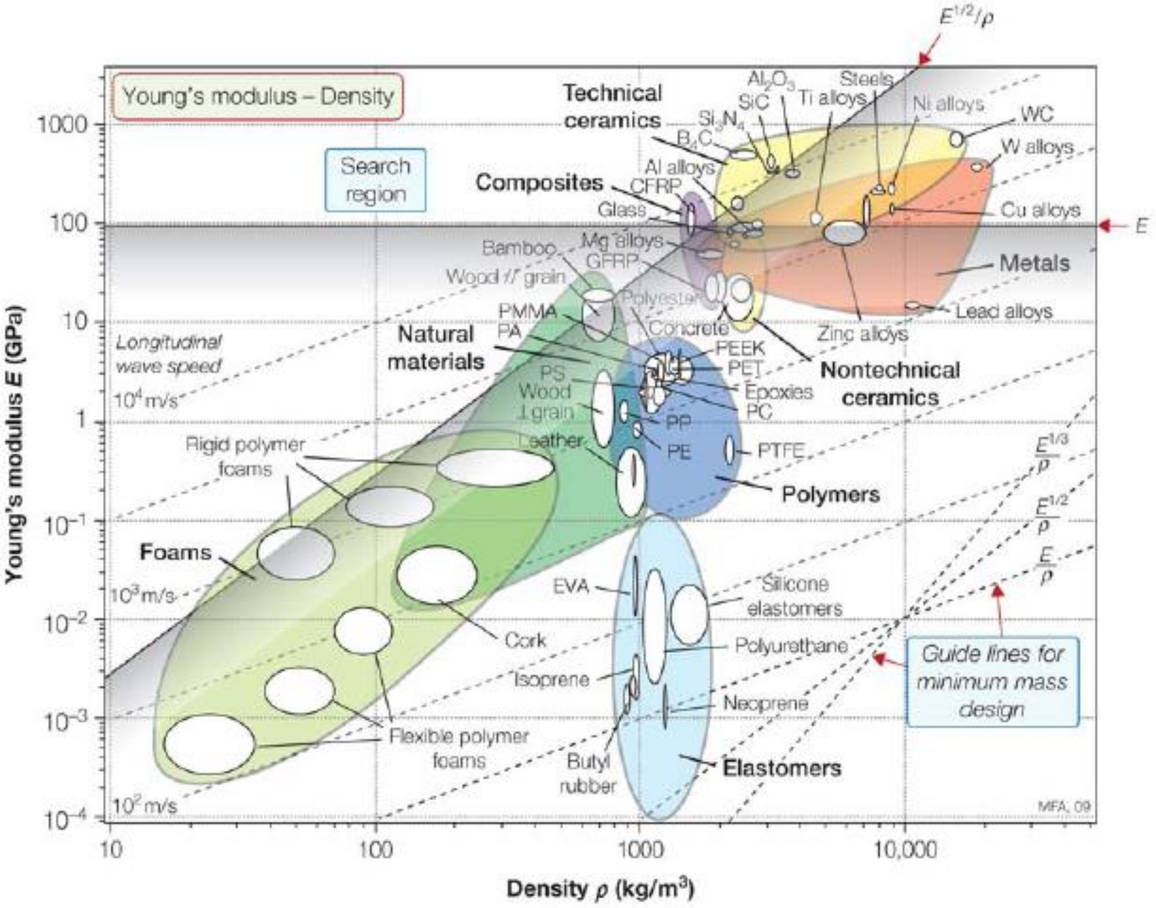


Figure 13. Materials for light, slender legs. Wood is a good choice; so is a composite such as CFRP, which, having a higher modulus than wood, gives a column that is both light and slender. Ceramics meet the stated design goals, but are brittle [1,2].

Table 2. Materials for Table Legs

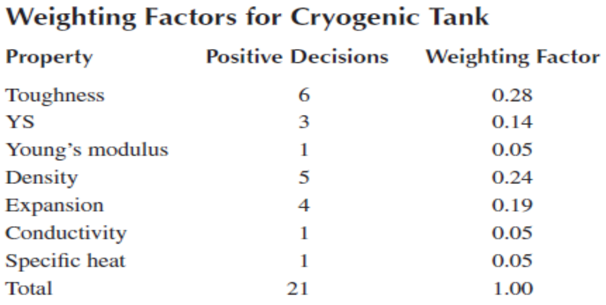
| Material | Typical $M_1$ (GPa$^{1/2}$.m$^3$/Mg) | Typical $M_2$ (GPa) | Comment |
|---|---|---|---|
| GFRP | 2.5 | 20 | Less expensive than CFRP, but lower $M_1$ and $M_2$ |
| Woods | 4.5 | 10 | Outstanding $M_1$; poor $M_2$<br>Inexpensive, traditional, reliable |
| Ceramics | 6.3 | 300 | Outstanding $M_1$ and $M_2$<br>Eliminated by brittleness |
| CFRP | 6.6 | 100 | Outstanding $M_1$ and $M_2$, but expensive |

### 4.4 Materials Substitution for a cryogenic tank

Consider the case of the cryogenic tank. The results of the analysis show that SS 301-FH is the optimum material and is therefore used in making the tank. Suppose that at a later date a new fiber-reinforced material is available and it is proposed to manufacture the tank from the new material by the filament-winding technique. The properties of the new fiber-reinforced material are given in Table 10.5 together with the properties of SS 301-FH [16.]

Here, the properties are first scaled. Using the same weighting factors as in Table 3, the performance index is calculated and the results in Table 4 show that the composite material is technically better than the stainless steel. Final comparison between the original and candidate materials will be carried out according to the CPF method. The basis of comparison is chosen as the figure of merit. Then, the cost of unit strength is calculated as shown in Table 5.

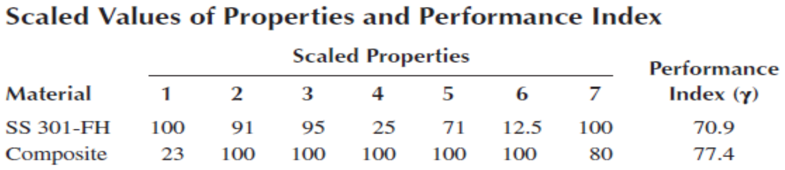
Table 3. Weighting factors for cryogenic tank



**Weighting Factors for Cryogenic Tank**

| Property | Positive Decisions | Weighting Factor |
|---|---|---|
| Toughness | 6 | 0.28 |
| YS | 3 | 0.14 |
| Young's modulus | 1 | 0.05 |
| Density | 5 | 0.24 |
| Expansion | 4 | 0.19 |
| Conductivity | 1 | 0.05 |
| Specific heat | 1 | 0.05 |
| Total | 21 | 1.00 |

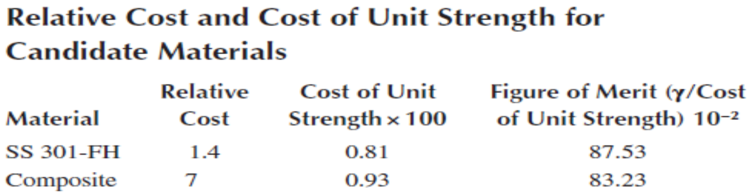
Table 4. Scaled values of properties and performance index



**Scaled Values of Properties and Performance Index**

| | Scaled Properties | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Material | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Performance Index ($\gamma$) |
| SS 301-FH | 100 | 91 | 95 | 25 | 71 | 12.5 | 100 | 70.9 |
| Composite | 23 | 100 | 100 | 100 | 100 | 100 | 80 | 77.4 |

Table 5. Relative cost for candidate materials



**Relative Cost and Cost of Unit Strength for Candidate Materials**

| Material | Relative Cost | Cost of Unit Strength × 100 | Figure of Merit ($\gamma$/Cost of Unit Strength) $10^{-2}$ |
|---|---|---|---|
| SS 301-FH | 1.4 | 0.81 | 87.53 |
| Composite | 7 | 0.93 | 83.23 |

As the figure of merit of SS 301-FH is higher than that of the composite material, the basis material still gives better value than the new material and no substitution is required.

If, however, the increasing use of the new composite material causes its relative cost to decrease to 6.6 instead of 7 (Table 5), the cost of unit property becomes 0.837 × 100 instead of 0.93 × 100. In this case, the figure of merit of the composite material becomes $92.5 \times 10^{-2}$, which means that it gives better value and is, therefore, a viable substitute [16].

## 5. Conclusions

Engineering properties of materials are shown useful in material selection diagrams. These diagrams summarize the information intensively, have an easily accessible method and show the area of any accessible feature given to the designer and determine the material class related to the parts of this area [1,2]. The most striking feature of the diagrams is the clustering of the members in a material group. Despite the wide area of density and strength, metals, for example, occupy a separate space from polymers or ceramics or composites. The same is true for strength, toughness, thermal conductivity, and so on. Fields sometimes overlap, but materials always occupy a characteristic place in the entire diagram. The position and relationship of the fields can be understood in simple physical terms: such as the nature of the bonds, packing density, cage resistance and vibration modes of the structure (their binding and packing function), and the like. It may seem odd that there is little reference to microstructure in determining properties. However, the diagrams clearly show that the first difference between the properties of materials is the origin of the atoms in mass, the nature of the inter-atomic forces and the packing geometry. Alloying, heat treatment and mechanical hardening affect the microstructure and longitudinal areas are formed in many diagrams within these properties; however, the effect of these properties is 10 times smaller than the bonding and structural properties. These diagrams have many applications: data control, composite design, and determination of applications for new materials [17,18]. But the most important of these is that these diagrams form the basis of the material selection procedure.

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