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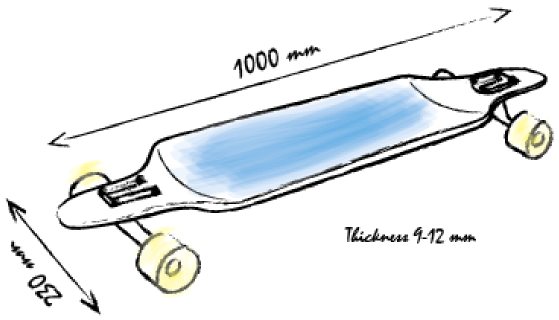
1. Material Selection in Design

When developing products, material options should be considered early in the design to allow great performance. Usually, lightweighting, cost reduction and sometimes green credentials are important aspects. The challenge is to select materials rationally to maximize benefits. In this Case Study, we look at materials for a longboard.



A longboard is a type of skateboard designed for downhill and slalom racing but also for simple cruising and transport. Because it is longer than a regular skateboard and normally has bigger wheels, it promotes higher speeds. Their greater weight and bulk makes them less suitable for many skateboarding tricks but contributes to stability and a fluid motion by providing more momentum. The decks can bow up or down along the length of the board. They can also be double-curved; concave in the width direction and convex in the length.

Longboard decks are typically made from plywood with several layers, each usually 2 mm in thickness. These are composed of, for example, maple wood. Longboards are commercially available in a variety of shapes and sizes. Each one has its advantages and disadvantages, depending on the technique or personal preferences.

2. How to tackle the Problem

The systematic way to select materials by Ashby *et al*. involves identifying the *Function*, *Objectives* and *Constraints* for the design. It is good to determine which mechanical properties are key to the performance for longboard decks. Strength will, of course, be one of the crucial parameters in the sense that the deck must be strong enough. However, it is not that property that limits the performance. Rather, like in other equipment used for sports and racing (skis, rackets, bikes etc) it is the *Stiffness* that we want to promote.

Whereas the mass of the deck provides stability to the board, it does not contribute to higher speeds when going downhill, due to higher inertia. Instead, it is low friction and air resistance that promote speed. Uphill, on the other hand, the mass definitely contributes to harder work, which inhibits speed. It is thus natural to seek to minimize mass when selecting material for the deck. We will focus on stiffness/mass performance in this case study, but cost will also be considered. The Learn button (Learn > Material Selection > Performance Indices) shows the options:

Table of performance indices

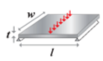
Click the buttons to view a table of relevant performance indices.

	Mass	Cost	Embodied Energy	CO_2 Footprint
Stiffness-limited design	kg	$	H_m	CO_2
Strength-limited design	kg	$	H_m	CO_2

Function:

The longboard deck itself is very much a ***panel in bending*** limited by ***stiffness*** (we do not want the deck to deflect too much). The free design variable is the thickness of the panel. In EduPack (Learn), we can find:

Stiffness-limited design at minimum mass

FUNCTION AND CONSTRAINTS[1]			MAXIMIZE[2]	MINIMIZE[2]
Panel in bending		length, width fixed; thickness free	$E_f^{1/3}/\rho$	$\rho/E_f^{1/3}$

Objective:

The material Index Tables (see above) available via the ***Learn*** button in EduPack tell us to maximize the cubic root of the flexural modulus, E_f, over the density, ρ. E_f, is the flexural modulus, which means stiffness in bending. Since this parameter is only available in Level 3 databases, we use ***Young's modulus*** as a measure of the stiffness at Level 2 instead. Our objective is thus:

Maximize: $\mathbf{M=E^{1/3}/\rho}$ (selection line of slope=3 in E *vs* ρ)

Constraints:

These constraints are based largely on existing decks. They are inserted via a ***Limit stage*** in CES EduPack,

- *Service temperature*: **-20°C to +60°C**
- *Yield strength:* **> 10 MPa**
- *Young's modulus:* **> 11 GPa**
- *Resistance to rain and salt water:* **Acceptable+Excellent**

3. The material selection

The basis of the selection is the data records for around 100 engineering materials available in Level 2 of CES EduPack.

- Click the *Chart/Select* button (*All materials*) on the toolbar and plot ***Young's modulus*** vs ***Density***
- Put a selection line of slope 3 using a *Chart* stage
- Place the line through the Plywood bubble
- Add the constraints via a *Limit stage* (can be tricky)

The Young's modulus constraint can also be put in as a selection line with slope 0, as shown in the Chart below:

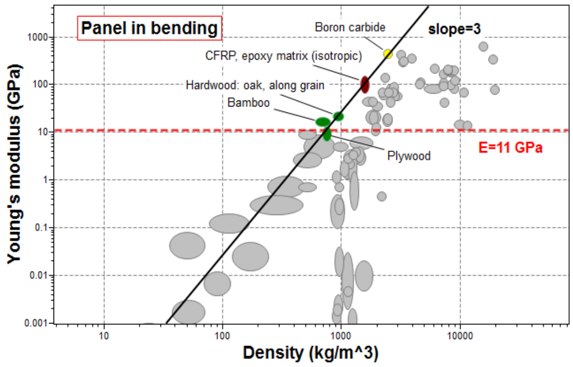


Chart: Several materials have a performance as good as plywood, or better (above the selection line).

Using an Index line of slope 3, corresponding to the exponent 1/3 of the index expressions, it can be seen that bamboo is the best performing natural material, even outperforming carbon-fiber reinforced epoxy (CFRP) composites, and so does hardwood, like oak (see Rank by: *Index value*).

In the picture above, some common types of deck materials are shown. From the left: A traditional maple plywood deck is shown. These typically have 5-7 cross-plies and are at the lower end of the price range. Next, a unidirectional bamboo deck is shown and to the right, a lightweight sandwich panel deck, consisting of carbon-fiber/maple/glass-fiber layers, is shown. These typically cost more than $100. Our results indicate that the cheaper Mapel and Bamboo longboards should still provide a very good performance. But what about Boron Carbide, that also rank very well in the selection? This technical ceramic has relatively high fracture toughness.

One indication as to why there are no skateboards made of this material is the price. A comparison of the price per volume (price per kg * density) is shown below:

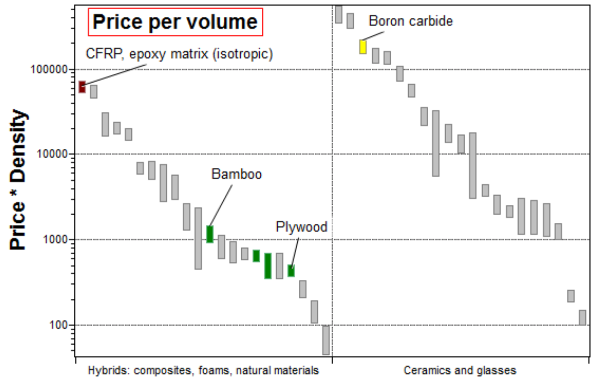


Chart: Boron carbide (and CFRP) usually have very good performance but are also very expensive. Wood costs less.

A plot of the more advanced Performance Index for cost from the Help menu shows the same picture. It is too costly. Other reasons for not using ceramics, that you can explore using the datasheets, are the higher embodied energy and CO_2-footprint, as well as poor recyclability. A search for "*skateboard*" at Level 2 in EduPack gives the plywood datasheet with a picture of a skateboard as an example.

Left. Close-up of the material. © Chris Lefteri
Right. Skateboard made with plywood. © Chris Lefteri

4. Conclusions

The traditional wood materials, particularly Bamboo, compare very well in the mechanical performance with more expensive composite materials. Considering additional factors, such as cost, CO_2-footprint or recyclability supports this decision.

Using CES EduPack enables systematic and rational material selection. It provides the necessary information and tools for an interactive and visual investigation of interesting real engineering problems.