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ADVANCED INDUSTRIAL
CASE STUDIES

High-Performance Longboard Design

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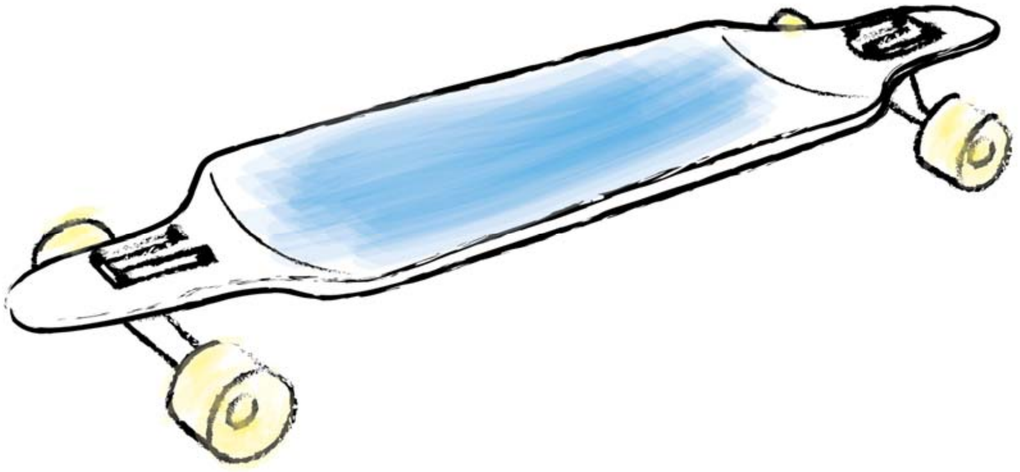


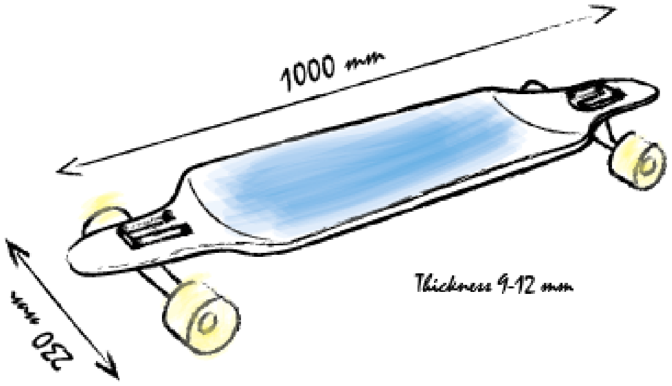
Summary

Granta Design develops software that is used for advanced materials selection in industry. CES EduPack is the Educational version that is specifically designed to guide and show the steps of the decision process for the purpose of teaching and training. It helps students to understand a rational and systematic approach which is invaluable to engineering and design. Our Advanced Industrial Case Studies, connected to a real product, promotes understanding and motivates students. Here we focus on the development and benchmarking of a double-curved sandwich panel of composite materials to improve the performance of a type of skateboard called a longboard.

Contents

1. What is the Scope?

When developing products, it is difficult enough to ensure that you have the best materials for your application, but when it comes to design variables to make a composite, the complexity reaches a new level. Yet being able to consider options early in design can allow you to achieve great improvements in performance, lightweighting, cost reduction and green credentials. The challenge is to determine what materials to use and how to combine them structurally so that you can maximize the benefits.



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.

Longboard decks are typically made from plywood with anything from two to eleven layers, each usually 2 mm (0.079 in) in thickness. These are composed of, for example, birch, bamboo, maple or oak 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 of the skateboarder.

The decks can be shaped in such a way that they 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. Moreover, some boards are designed to be flexible, usually intended for lower speed riding because when going faster, a flexible board can have torsional flex which is one cause of speed wobbles. Fiberglass is used in many new flexible boards as it is light like carbon fiber but more pliable.

In this case study, we have investigated the development of a layered structure for the double-curved deck of a longboard using CES EduPack. This builds on work done by FORCE Technology, an institute for industrial composite development in Denmark [1]. It describes the process of comparing materials, defining composite materials in the Synthesizer tool and then using these composite material records to build a competitive sandwich structure in the same tool. The procedure is described in detail and the results are benchmarked against actual structures materials used in commercial longboards.

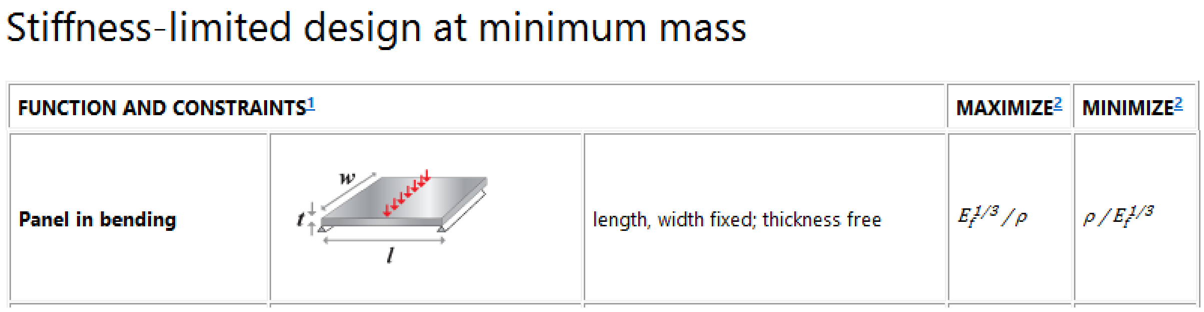
2. How to tackle the Problem

We will start the investigation by looking at different materials used for longboard decks and determine which properties are key to the performance. Strength will, of course, be one of the crucial parameters in the sense that the deck must be strong enough. However, it is not the property that limits the performance. Rather, like in other equipment used for sports and racing (skis, rackets, cars etc) it is a *Stiffness-limited design (to prevent deflection of the board)*. In the picture and charts below, some common types of deck materials are shown. We will focus on mechanical performance, so cost is not considered in this case study.

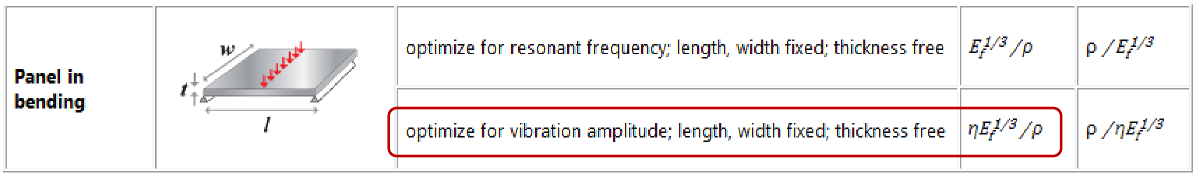
From the left: A traditional maple deck is shown. These typically have 5-8 cross-plies and are at the lower end of the price range. Next, a unidirectional bamboo deck is shown and to the right, a lightweight sandwich panel deck, consisting of carbon-fiber/maple/glass-fiber layers, is shown. These typically cost more than $100. 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 lower speed. It is thus natural to seek to minimize mass when selecting material for the deck. Another factor, that contributes to the comfort and safety of the ride, is the damping properties of the material. It is desirable to find a material that minimizes vibrations as they are disturbing. The objectives will therefore be to minimize mass and maximize damping.

3. How to use CES EduPack to Perform Material Selection

The longboard deck itself is very much a panel in bending. The material Index Tables available via the ***Help*** button in EduPack tell us to maximize the cubic root of the flexural modulus, E_f, over the density, ρ. In order to minimize vibrations, the same expression multiplied with the *Mechanical loss coefficient* (damping), η, should be maximized (see below). A summary (*Translation*) of *Design requirements* is given on page 4 [2].


Stiffness-limited design at minimum mass

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



Panel in bending		optimize for resonant frequency; length, width fixed; thickness free	$E_f^{1/3}/\rho$	$\rho/E_f^{1/3}$
		optimize for vibration amplitude; length, width fixed; thickness free	$\eta E_f^{1/3}/\rho$	$\rho/\eta E_f^{1/3}$

The basis of the selection is the data records for nearly 4000 engineering materials available in Level 3 of CES EduPack. These are not all candidates for the longboard deck. It is possible to put constraints in, to limit the number of materials. These constraints are based largely on the existing decks above.

Function:

The engineering application here is a ***panel in bending*** limited by ***stiffness*** (we do not want the deck to deflect too much). The free design variables are the thickness of the panel and the material combination.

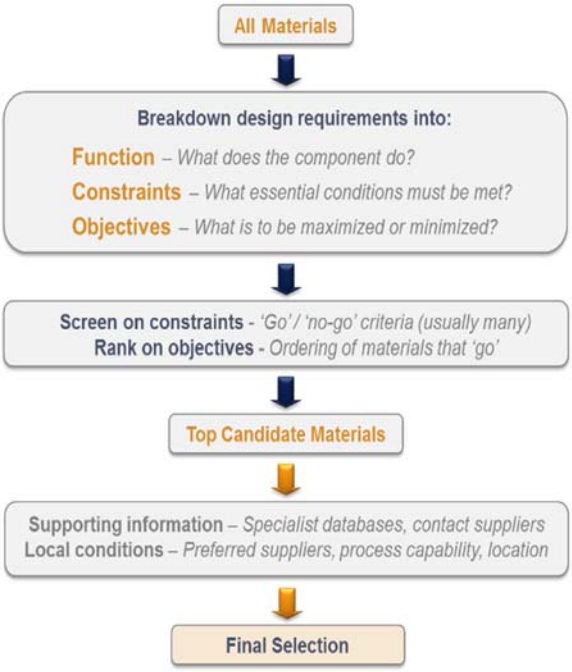
Constraints:

These constraints are based largely on existing decks

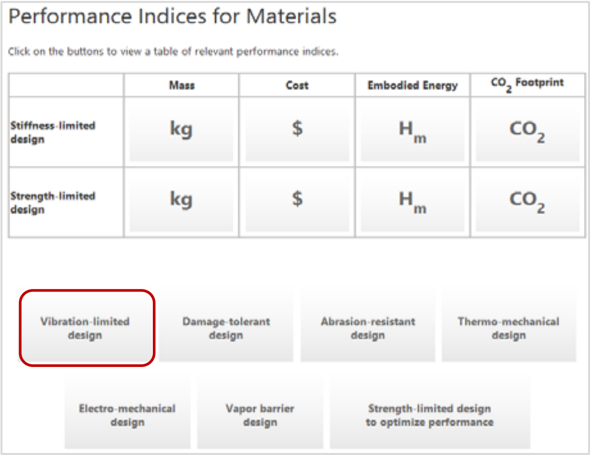
- *Service temperature*: **-20°C to +60°C**
- *Density:* **< 3000 kg/m**^{3}
- *Young's modulus:* **> 1 MPa**
- *Resistance to rain and salt water:*
  Limited/Acceptable/Excellent

Objectives:

A table of common performance indices can be found under the ***Help*** button embedded in the main toolbar of the software. For ***low mass*** in a stiffness-limited design and for ***vibration-limited*** design, we need to maximize M1= $E^{1/3}$ / ρ (mass) and M2= $\eta * E^{1/3}$ / ρ (damping).



For Vibration-limited design EduPack provides the performance indices in a separate button, as seen below.



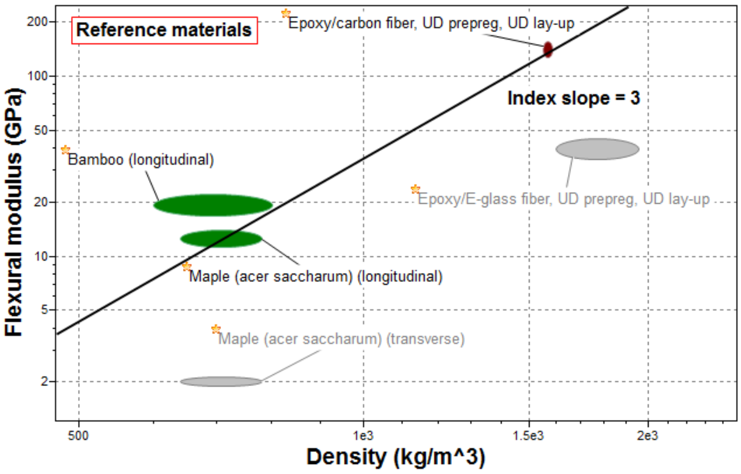
Performance Indices for Materials

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

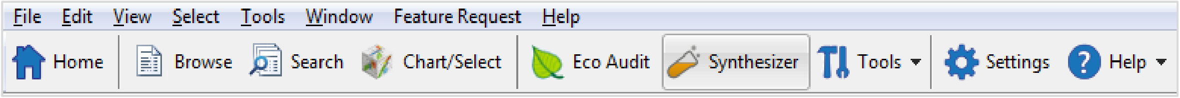
	Mass	Cost	Embodied Energy	CO_2 Footprint
Stiffness-limited design	kg	$	H_m	CO_2
Strength-limited design	kg	$	H_m	CO_2

A common approach for product development in industry, to improve on existing products, is to consider the currently used materials, such as the ones in the boards shown in page 3, as a starting point. These can be included as references in a user defined (define your own) subset, here marked as *Favourites*. An experienced developer would then try out new combinations and improvements and benchmark these against the existing ones. In this case study, we will follow this route and test structural configurations with only a few common material components, using *the Synthesizer tool* to guide our development.

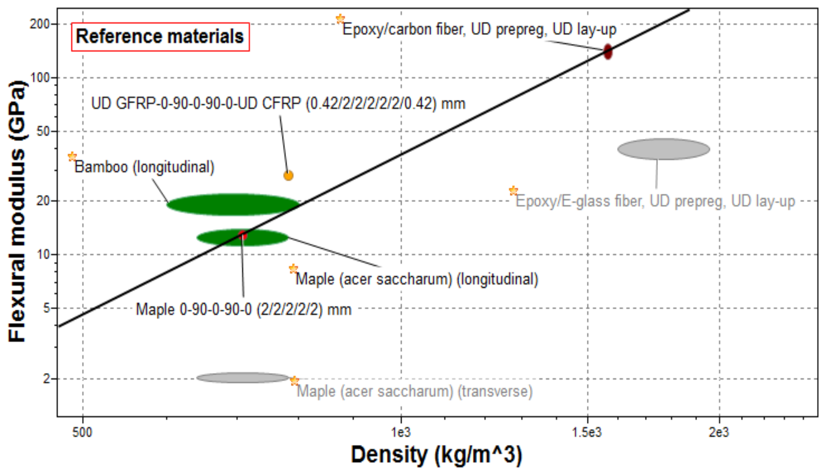
In order to judge performance and have an overview, it is useful to plot the custom subset generated by the materials involved in the reference decks above. Using an Index line of slope 3, corresponding to the exponent 1/3 of the index expressions, it can be seen that bamboo is the best performing material, even outperforming carbon-fiber reinforced epoxy (CFRP) composites and so does maple (longitudinal). Glass-fiber reinforced epoxy (GFRP) ranks the lowest in this comparison.



What would the effect of laminating the maple, or sandwiching these between composite layers be? This can be investigated using the synthesizer tool, available in all Advanced *Specialist* databases of CES EduPack.



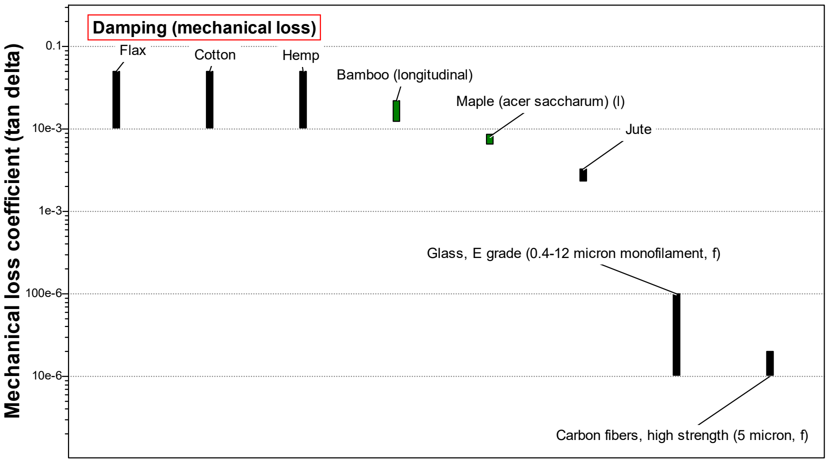
Both questions above can be answered using the multi-layer model in the Synthesizer tool. Alternating longitudinal and transverse 2 mm maple layers in the 5-layer model and a 7-layer model with the same structure sandwiched between 0.42 mm layers of unidirectional (UD) prepreg GFRP and CFRP, respectively, were created. The results are shown below.

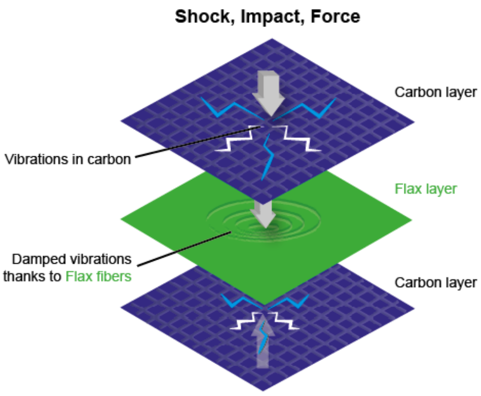


Neither lamination nor sandwiching maple multilayers between FRP face sheets improves the Material index much compared to bamboo. To improve on the performance of the bamboo skateboard deck, it is necessary to increase the bending stiffness and/or reduce the density. Any proposed structures can then be tested using the Synthesizer tool before building prototypes. This can be done (see below) in combination with improving damping properties.

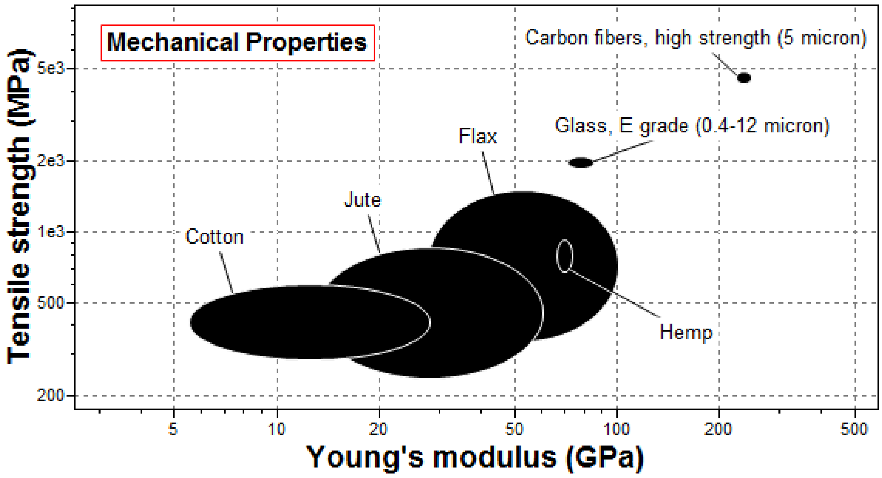
4. Damping

If we look at the second objective, associated with vibrational damping in the longboard, we can see that some natural fibers are quite superior to Carbon or Glass when it comes to the mechanical loss coefficient. Hemp or flax are readily available fibers that can be used as reinforcements in composites and will then help to reduce vibrations in the deck. The outcome is the same, plotting the full second objective, M2.



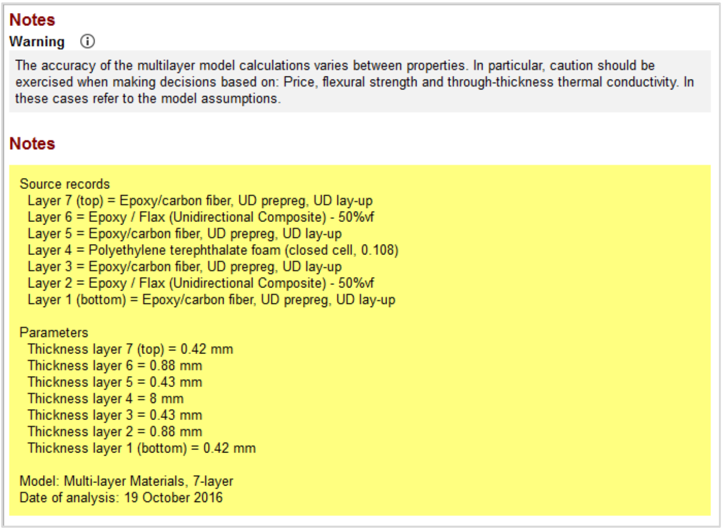


A commercial product based on this idea is marketed by Lineo [3]. If the natural fibers are sandwiched between CFRP layers both on the top and under the bottom of the skateboard deck, they can potentially contribute to both increased flexural modulus and damping. The reason for choosing flax fibers is that it has excellent damping performance as well as good mechanical properties, as can be seen below. Fractions of up to 50% flax in an epoxy resin is offered by this supplier: *FlaxTape*^{TM} and *FlaxPreg*^{TM} [3].



The tensile strength and stiffness for some common fibers are shown below. For stiffness, natural fibers are competitive with glass fiber, but not with carbon fiber. flax is, potentially, better than hemp both for stiffness and strength. The synthesizer can be used to estimate properties for Simple bounds composites based on Unidirectional flax fibers in a matrix of epoxy.

The Simple bounds Unidirectional model in the Synthesizer tool was used to generate two records with 40-50% flax in an epoxy matrix. These can be seen in the chart in the next section. We used the synthesized composite record for 50% (highest E_f and commercially available) in a new 7-layer model. To reduce the density, a rigid PET foam was used as the core material. The details are shown in the Notes, to the right, that comes with the output of the data record. For teaching purposes, it is important to discuss limitations of the models, hence the warning. All assumptions and equations can be found via the ***HELP*** button > ***Tools***.



Notes

Warning ⓘ

The accuracy of the multilayer model calculations varies between properties. In particular, caution should be exercised when making decisions based on: Price, flexural strength and through-thickness thermal conductivity. In these cases refer to the model assumptions.

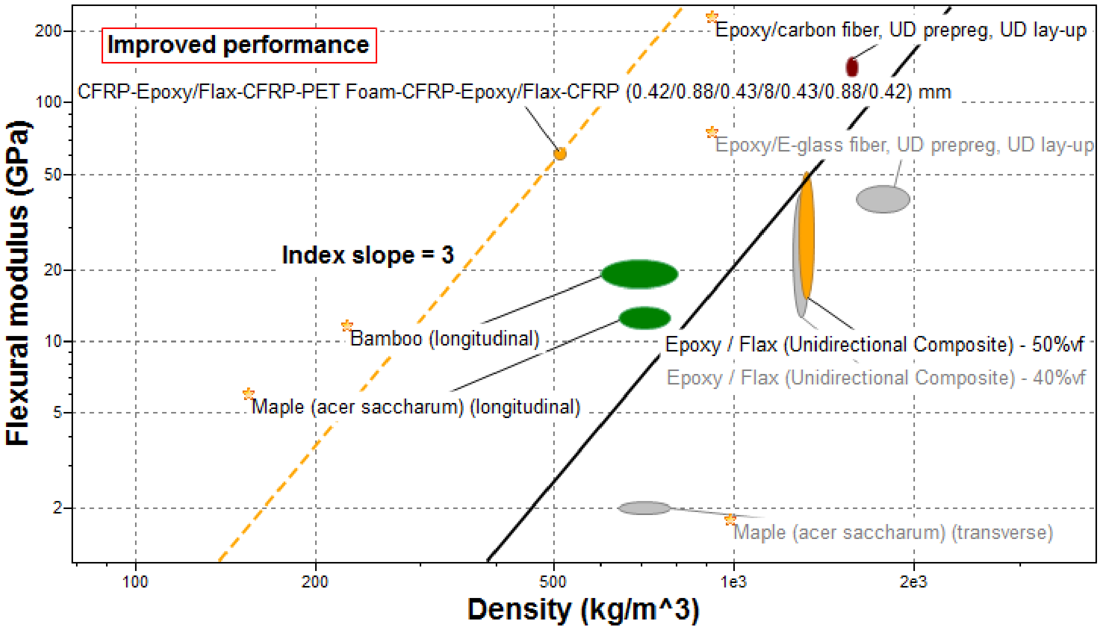
Notes

Source records
  Layer 7 (top) = Epoxy/carbon fiber, UD prepreg, UD lay-up
  Layer 6 = Epoxy / Flax (Unidirectional Composite) - 50%vf
  Layer 5 = Epoxy/carbon fiber, UD prepreg, UD lay-up
  Layer 4 = Polyethylene terephthalate foam (closed cell, 0.108)
  Layer 3 = Epoxy/carbon fiber, UD prepreg, UD lay-up
  Layer 2 = Epoxy / Flax (Unidirectional Composite) - 50%vf
  Layer 1 (bottom) = Epoxy/carbon fiber, UD prepreg, UD lay-up

Parameters
  Thickness layer 7 (top) = 0.42 mm
  Thickness layer 6 = 0.88 mm
  Thickness layer 5 = 0.43 mm
  Thickness layer 4 = 8 mm
  Thickness layer 3 = 0.43 mm
  Thickness layer 2 = 0.88 mm
  Thickness layer 1 (bottom) = 0.42 mm

Model: Multi-layer Materials, 7-layer
Date of analysis: 19 October 2016

5. Result and Reality Check

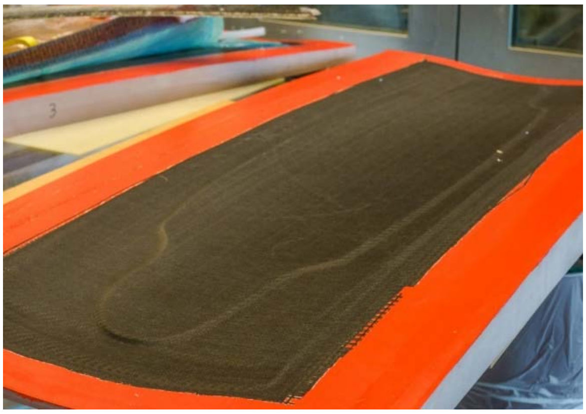


The resulting chart shows that the proposed 7-layer structure, with PET foam as the core material and the composite sandwiches as face sheets, provides a significant increase in performance. Further simulations, FE-calculations etc. are necessary but, the investigation using the synthesizer tool has provided guidance and can therefore reduce time, cost and effort in the development.

This case study has also shown how an engineer can use the data and charts of CES EduPack to make informed decisions about how to improve the design of a longboard deck. It serves as a realistic example for students, since it was used by an institute in Denmark, FORCE, to use composites to enhance performance. Prototypes of a very similar CFRP and flax/epoxy combination as face materials around a rigid PET foam were manufactured and tested by FORCE Technology and is being considered for commercial development. Some test data is included, below (Pictures supplied by Benjamin Hornblow, FORCE Technologies)

Longboard	**Thickness [mm]**	**Weight [g]**	**Deflection, 3-point bending [mm]**
Reference	9.8	1685	14
Carbon/flax sandwich panel	11	1180	15
Difference		505 (30% weight reduction)	

The manufacturing process of a CFRP/flax composite longboard with a PET foam core, by FORCE Technology is shown below. PET foam in the form, followed by curing at the top and a cross section of the final prototype and the user testing at the bottom.

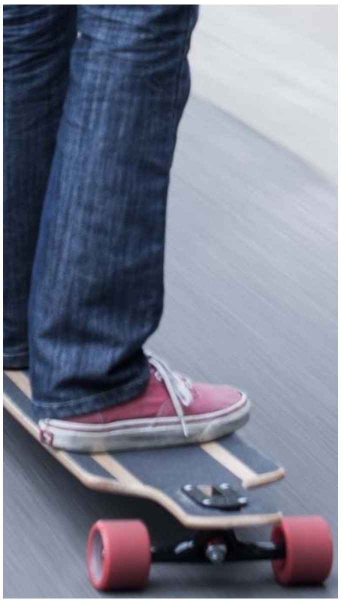


6. What does CES EduPack bring to the understanding?

CES EduPack produces quantitative and highly visual results interactively which, combined with the materials expertise of an educator, can help to teach the design process and how to make good materials decisions.

CES EduPack helps suggest the following conclusions:

- The software supplies the performance index, in this case for a stiffness-limited panel in bending, which enables an overview of the properties for existing materials. This provides a good starting point for the product development and a clear direction for improvements.
- The available maple or bamboo longboard decks are difficult to improve. Lamination or sandwiching with thin layers of fiber-reinforced composites does not improve performance.
- An idea from a commercially available flax/epoxy composite could be explored by first generating a simple bounds composite record and then using this in a 7-layer model in the Synthesizer tool with a PET foam core instead of wood. This results in significantly improved performance.
- CES EduPack was able to replicate a development path taken by FORCE Technology in Denmark to develop and manufacture a prototype longboard in their labs. Testing shows that a sandwich solution with CFRP and flax/epoxy composite faces and PET foam core gives 30% lightweighting with an improved skateboarding experience.



7. References

1. Benjamin Hornblow, Composites Specialist, FORCE Technology, www.forcetechnology.com

2. The methodology can be found, for example, in Ashby, M.F. (2005) “Materials Selection in Mechanical Design”, 3nd edition, Butterworth Heinemann, Oxford, UK. ISBN 0-7506-6168-2.

3. For homepage and product description, see: www.lineo.eu