MEC-E1070 Selection of Engineering Materials Harri Olli

Task 4: Hybrid materials

Task 4.1

As mentioned in the textbook, there are multiple subjective methods to solve a material selection task that involves multiple objectives. These methods are usually quick, but they are highly dependent on personal judgment. The nature of these methods can be eliminated by using an active constraint method and creating a single penalty function. The first step in material selection is to define the design requirements and translate them into a clear statement of functions, constraints, objectives and free variables. The design requirements are shown in table 1.

Table 1: The design requirements

Function:	Greenhouse door (Sandwich panel loaded in bending)
Constraints:	Sufficient bending stiffness ($S \geq S^*$) Width and length specified Strength specified* Symmetric sandwich structure
Objective:	Minimize mass (m) Minimize cost (C) Maximize thermal insulation
Free variables:	Panel thickness The choice of material

The objective function for the mass

$$m = l \cdot b \cdot t \cdot \rho \tag{1}$$

The bending stiffness of a panel

$$S = \frac{C_1 \cdot E \cdot I}{l^3} \geq S^* \tag{2}$$

where C_1 is a constant. The second moment of area for a panel

$$I = \frac{b \cdot t^4}{12} \tag{3}$$

Let's substitute I in equation (2) with the expression in equation (3)

$$S = \frac{C_1 \cdot E \cdot \frac{b \cdot t^4}{12}}{l^3} \tag{4}$$

Then, let's express t from equation (4)

$$\sqrt[3]{\frac{12 \cdot S^{*} \cdot l^{3}}{C_{1} \cdot E \cdot b}} \leq t \tag{5}$$

The elimination of t in equation (1) results in

$$m \geq \sqrt[3]{\frac{12 \cdot S^{*} \cdot l^{3}}{C_{1} \cdot E \cdot b}} \cdot l \cdot b \cdot \rho = \sqrt[3]{\frac{12 \cdot S^{*} \cdot l^{3}}{C_{1} \cdot E \cdot b}} \cdot l^{2} \cdot \frac{\rho}{\sqrt[3]{E}} \tag{6}$$

Equation (6) contains the material performance index, M_1, which can be read in equation (7), it needs to be minimized.

$$M_{1} = \frac{\rho}{E^{\frac{1}{3}}} \tag{7}$$

The material cost is C, which can be calculated by multiplying the cost per kilogram by the weight. Therefore the second performance index, M_2, can be created using equation (7). The second performance index, M_2, can be read in equation (8).

$$M_{2} = \frac{C_{m} \cdot \rho}{E^{\frac{1}{3}}} \tag{8}$$

To compare the materials, a penalty function is needed. It can be read in equation (9).

$$Z = \alpha \cdot M_{1} + M_{2} = \alpha \cdot \frac{\rho}{E^{\frac{1}{3}}} + \frac{C_{m} \cdot \rho}{E^{\frac{1}{3}}} \tag{9}$$

After creating the penalty function it is possible to draw the material comparison maps. The material comparison maps can be drawn with Granta EduPack. The penalty function needs to be applied two times. It is applied first to find candidate materials for the face sheet. The exchange constant is not specified in the task, so I approximated it. It was set to $\alpha = 1 \frac{€}{kg}$.

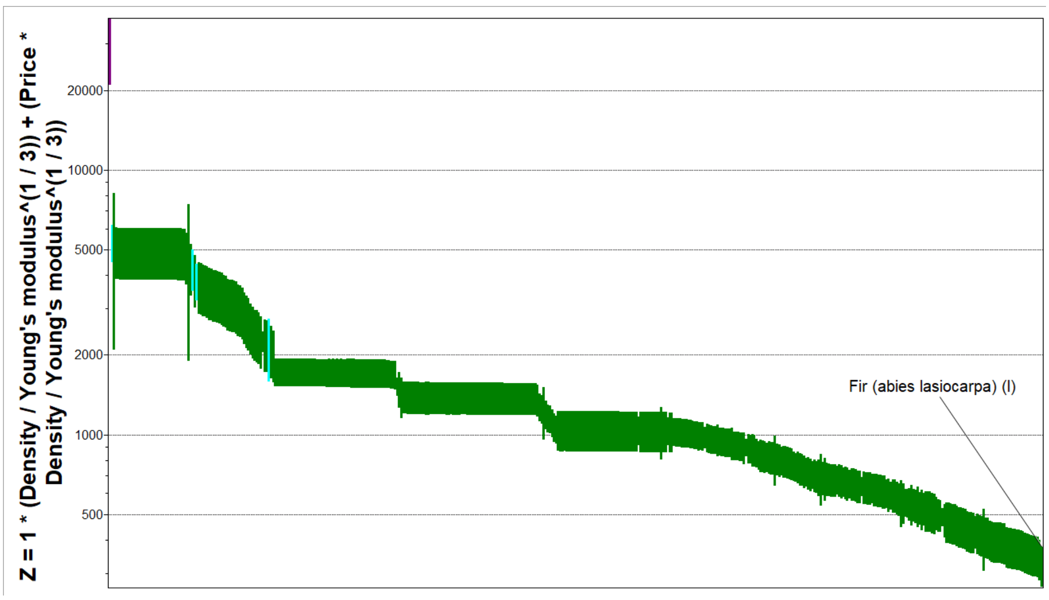

Figure 1: Penalty function for the face of the door (Level 3)

As seen in figure 1, a material comparison has been made between natural materials. The best material for the face of the door is Fir (abies lasiocarpa) (l) (wood). Material ranking is shown in table 2.

Table 2: The face material comparison

Rank	Material	*Z*-value
1.	Fir (abies lasiocarpa) (l)	266 – 378
2.	Fir (abies balsamea) (l)	281 – 400
3.	Spruce (picea glauca) (l)	289 – 411

Then, let's choose the core material.

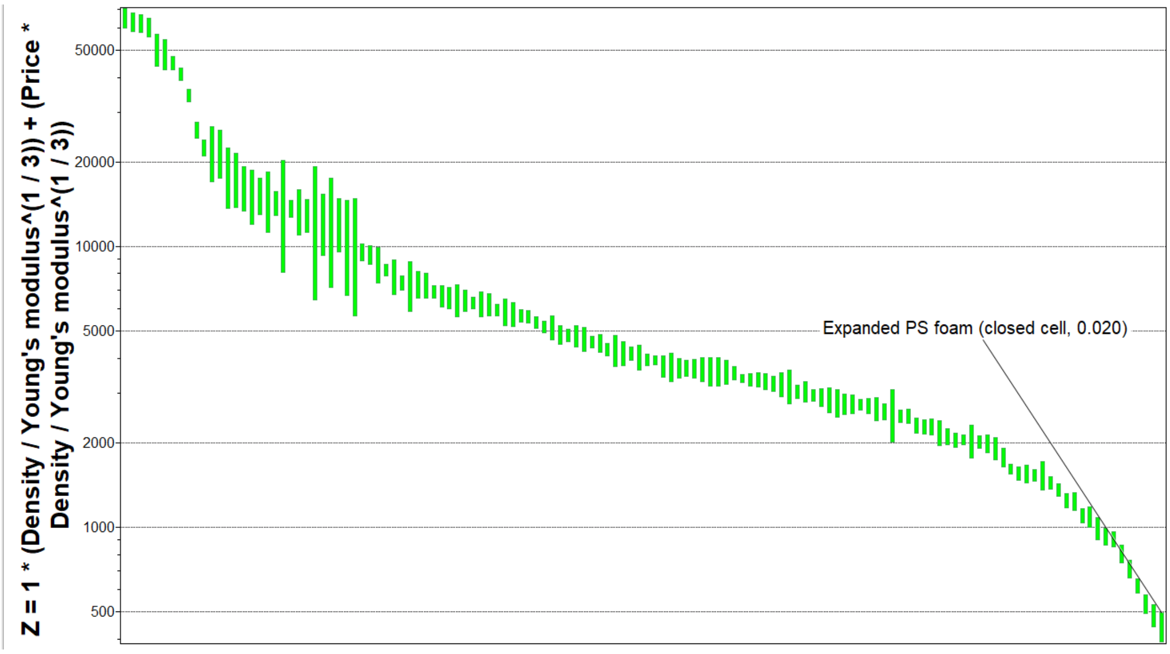

Figure 2: Penalty function for the core material (Level 3)

As seen in figure 2, a material comparison has been made between foams. The best material for the core of the door is Expanded PS foam (closed cell, 0.020). Material ranking is shown in table 3.

Table 3: The core material comparison

Rank	Material	*Z*-value
1.	Expanded PS foam (closed cell, 0.020)	388 – 496
2.	Expanded PS foam (closed cell, 0.025)	439 – 529
3.	Expanded PS foam (closed cell, 0.030)	490 – 573

Let’s use the synthetizer to find an optimum for the sandwich composition with these two materials. The dimensions of 2100 mm x 900 mm (height x width), thickness could be picked from a 10 mm to 100 mm range; a central load with 3.4 kN is applied to the door in terms of three-point bending (textbook Table 11.3). Intervals to ensure that we stay between 10 mm – 100 mm for the width of the door.

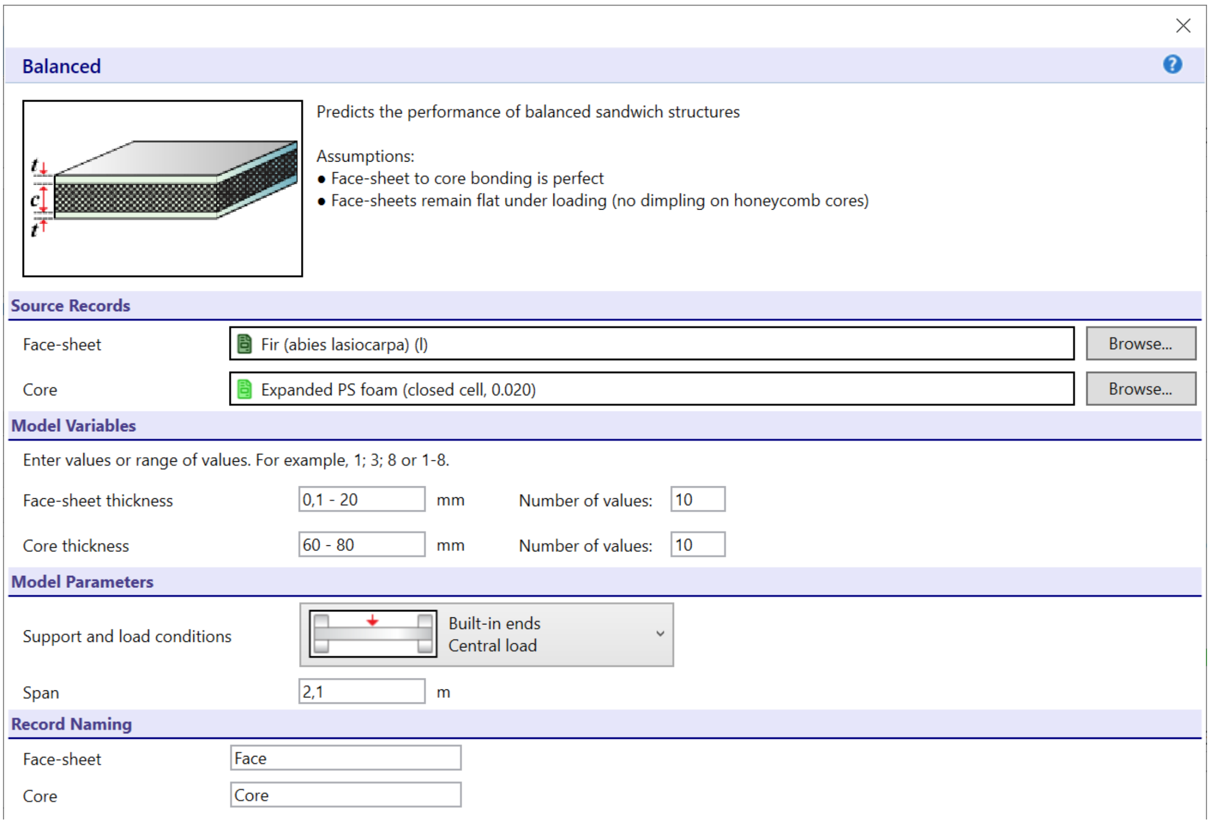

Figure 3: Configuration of the Sandwich system

Let’s generate 10 x 10 = 100 combinations of materials for the sandwich structure.

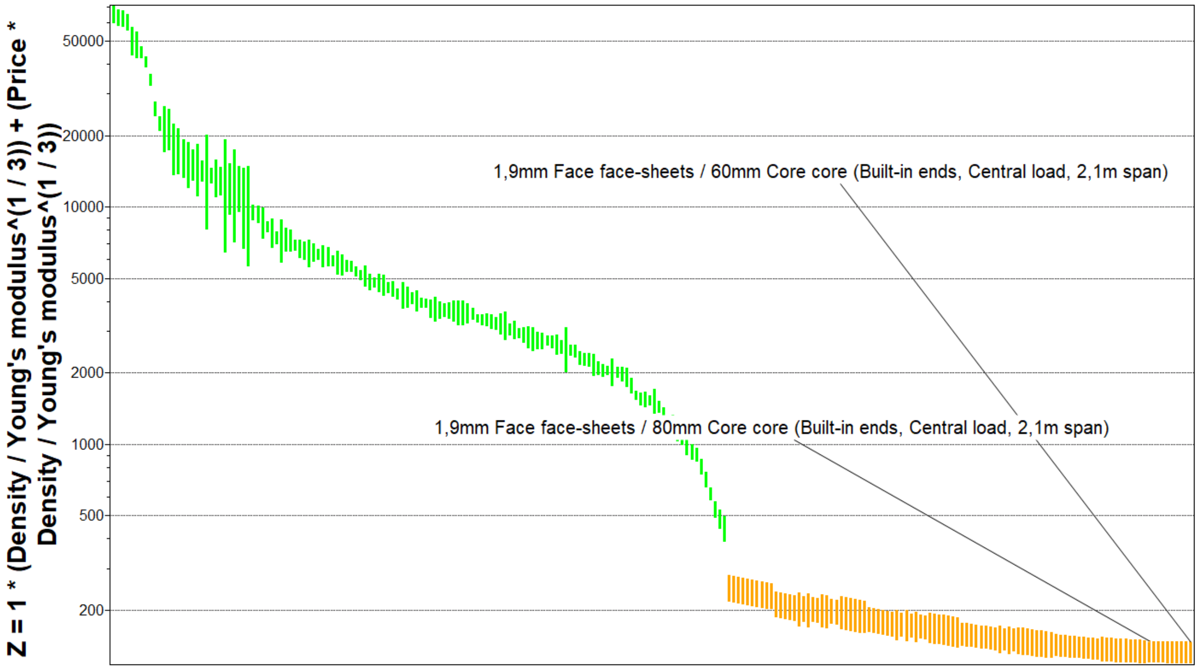

Figure 4: Value of the penalty function for different sandwich configuration

Table 4: Sandwich

Rank	Material	*Z*-value
1.	1,9mm Face face-sheets / 60mm Core core (Built-in ends, Central load, 2,1m span)	119 – 147
2.	1,9mm Face face-sheets / 61,9mm Core core (Built-in ends, Central load, 2,1m span)	119 – 147
3.	1,9mm Face face-sheets / 64mm Core core (Built-in ends, Central load, 2,1m span)	119 – 147

Task 4.2

The products that need to be created are winter gloves, that can be used with capacitive touch screens. Contains the design requirements are shown in table 5.

Table 5: Design requirements for winter gloves

Function:	Winter gloves for capacitive touch screens (Extreme conduction combinations)
Constraints:	Materials: copper and polyethylene
Objective:	Minimize thermal conductivity Maximize electrical conductivity (Maximize difference between electrical and thermal conductivities)
Free variables:	Configuration and relative volume fractions of the two materials

The function of this product is to improve the customers comfort in cold temperatures. This product is suitable for example for smartphone users in cold climate but it can be also used in cold workplace environments, for example in air-conditioned warehouses. It is used in cold temperatures, so it needs to have good thermal insulation properties. The function of it requires to provide good electrical conductivity. This means that we need to maximize difference between electrical and thermal conductivities.

Generally speaking, materials which have good electrical conductivity, also have good thermal conductivity. The same applies for the insulation properties. There are relatively few monolitic solutions to provide a low-high or high-low combination of electrical-, and thermal conductivity. To achieve these combinations, hybrid materials have to be used.

To make the selection less difficult, the two materials, copper and polyethylene are constrained. To maximize the electrical conductivity and minimize the thermal conductivity, a tangle of fine copper wires embedded in a PE matrix have to be used according to the textbook. The synthetyzer tool in Granta Edupack was used to calculate the results. The tool uses the above-mentioned equations to plot the materials on the map. *Figure 5* shows the settings in Granta EduPack, Level 3 Sustainability database was used.

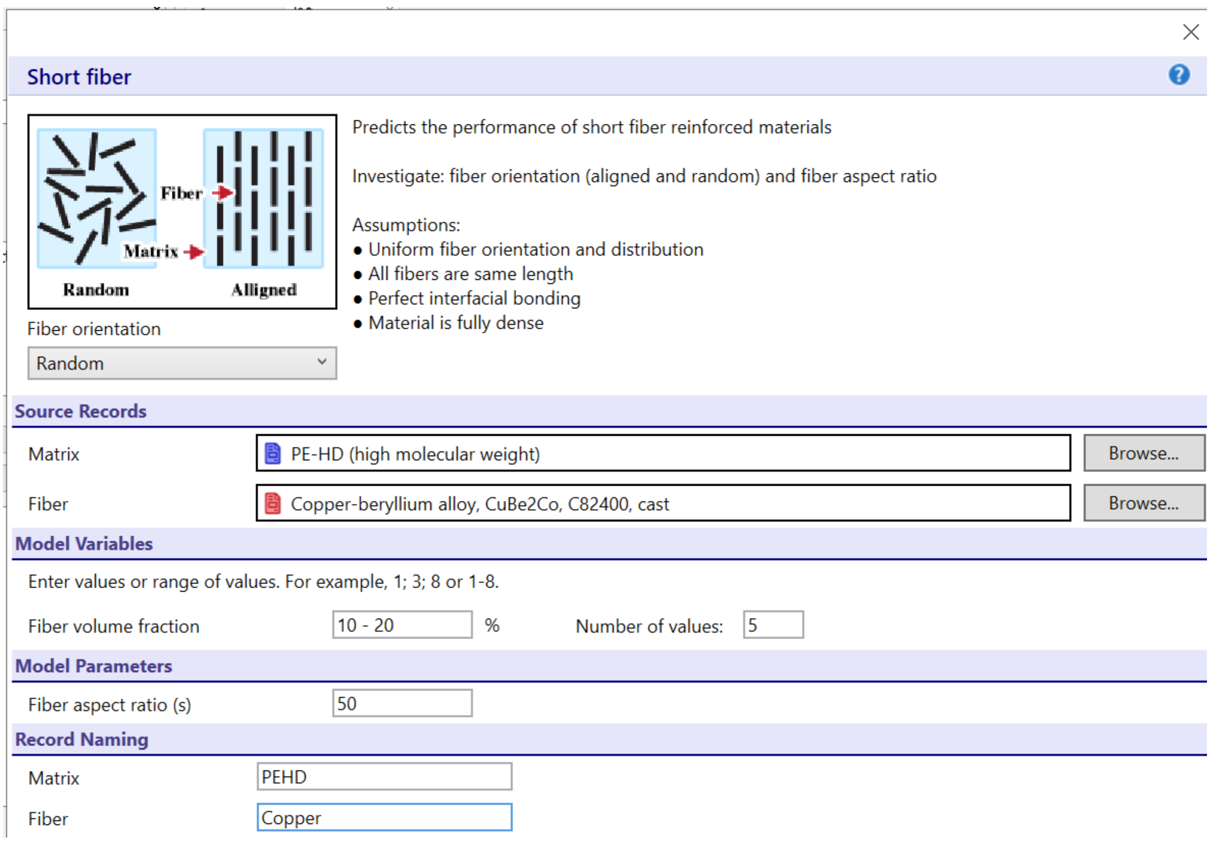

Figure 5: Synthesizer settings

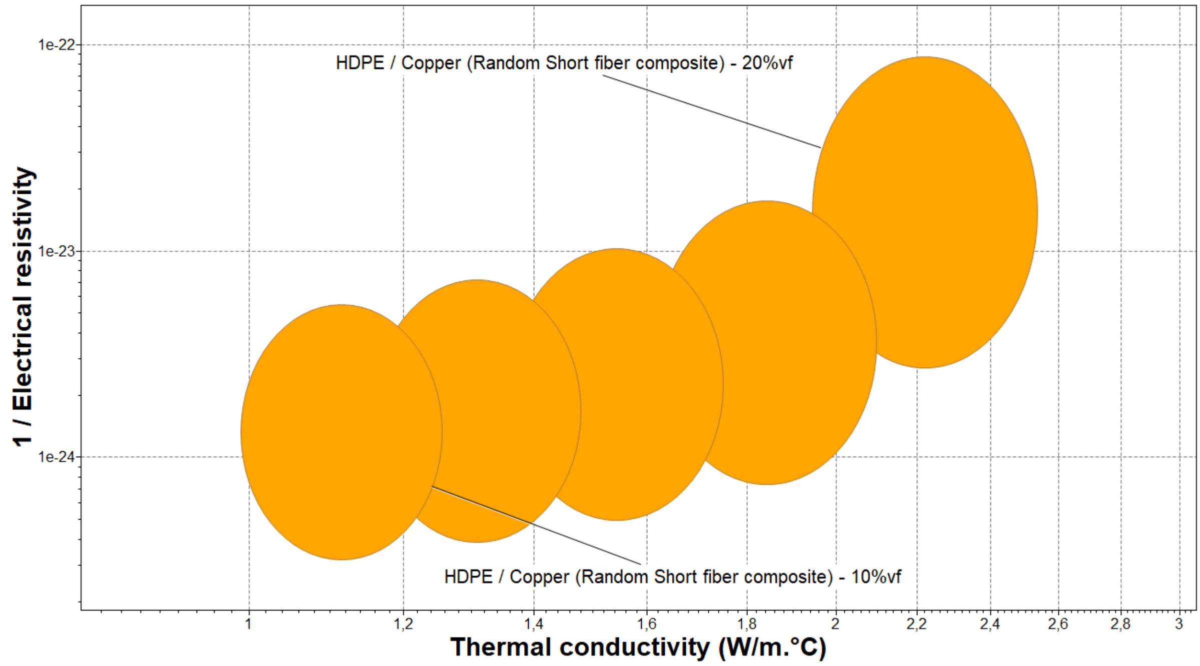

Figure 6: Thermal conductivity-1/electrical resistivity map

With the 10% vf combination, the gloves are able to keep the users hands warm, while using capacitive touch screens.