Task 4: Hybrid materials

Instructions: Check the following questions and exercises. Read chapters 11 and 12 in the 4th edition of the course textbook about hybrid materials.

Criterion: A good report on this task demonstrates a good understanding of:

- how materials can be combined in different ways to create structures that may be viewed as materials with a combination of the properties of the constituent materials (Task 4.1)
- the role of the geometrical arrangement of the constituent materials within a hybrid material, in determining the properties of the hybrid material (Task 4.2)

Task 4.1: For a greenhouse, the most amount of heat loss is through the gate. To be economical and consider sustainability, as well as the energy efficiency assessment, a greenhouse door made from a light and stiff sandwich panel structure, shall be designed. The basic need is a combination of stiffness, strength, low weight, low price, and thermal insulation. Estimate plausible dimensions and design loads for the door. Use the Hybrid Synthesizer tool in GRANTA to design the sandwich structure. Make sure that the materials you choose are generally available.

A greenhouse door. Source: https://sturdi-built.com/sturdi-built-features-of-greenhouses/greenhouse-door/

Hint: To make your design well demonstrated, try to consider the requirements, generating the objectives, constraints, and free variables. Step by step, all the necessary procedures for your selection methods, the explanation and derivation of the material indices, penalty function if there is any, diagrams, tables, etc. These shall all be included in your report for a better understanding.

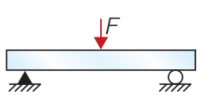
One reference case example for you to think about: with dimensions of 2100 mm x 900 mm (height x width), thickness could be picked from a 10 mm to 100 mm range; a central load with 3.4 kN is applied to the door in terms of three-point bending (see textbook Table 11.3). When considering the thermal insulation of the hybrid materials, one simple assumption could be made that each layer is glued together as an assembly, so that the heat conduction passes through the thermal insulating layer easily. You are very much recommended to design the case with your desire and creativity.

Note: The synthesizer tool works with the level 3 Sustainability, Eco-design, Aerospace, Polymers, and Energy databases. Select suitable core and skin materials, as well as the core and skin thickness.

The requirement tables for the greenhouse door is as follows:

Function	❖ Greenhouse door under a central load of 3.4 kN as three-point bending
Constraints	❖ Fixed door height = 2100mm ❖ Fixed door width = 900mm ❖ Fixed door thickness = 100mm ❖ Fixed stiffness, fixed strength
Objective	❖ Minimizing mass ❖ Minimizing cost ❖ Maximizing thermal insulation
Free variables	❖ Choice of material ❖ Any other material properties

The load of 3.4kN can be visualized as below (image from textbook)

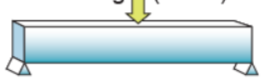
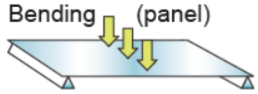
Mode of Loading	Description	B_1	B_2	B_3	B_4
	Three-point bend, central load	48	4	4	2

Additionally, the door can be considered as a 3D panel in bending according to the requirements. From the dimensions of the door, we can calculate its volume

V_{door} = height x width x thickness = 2100mm x 900mm x 100mm

=> $V_{door} = 189000000\ mm^3 = 0{,}189\ m^3$

This value will be used as a tradeoff-parameter alpha in the penalty function

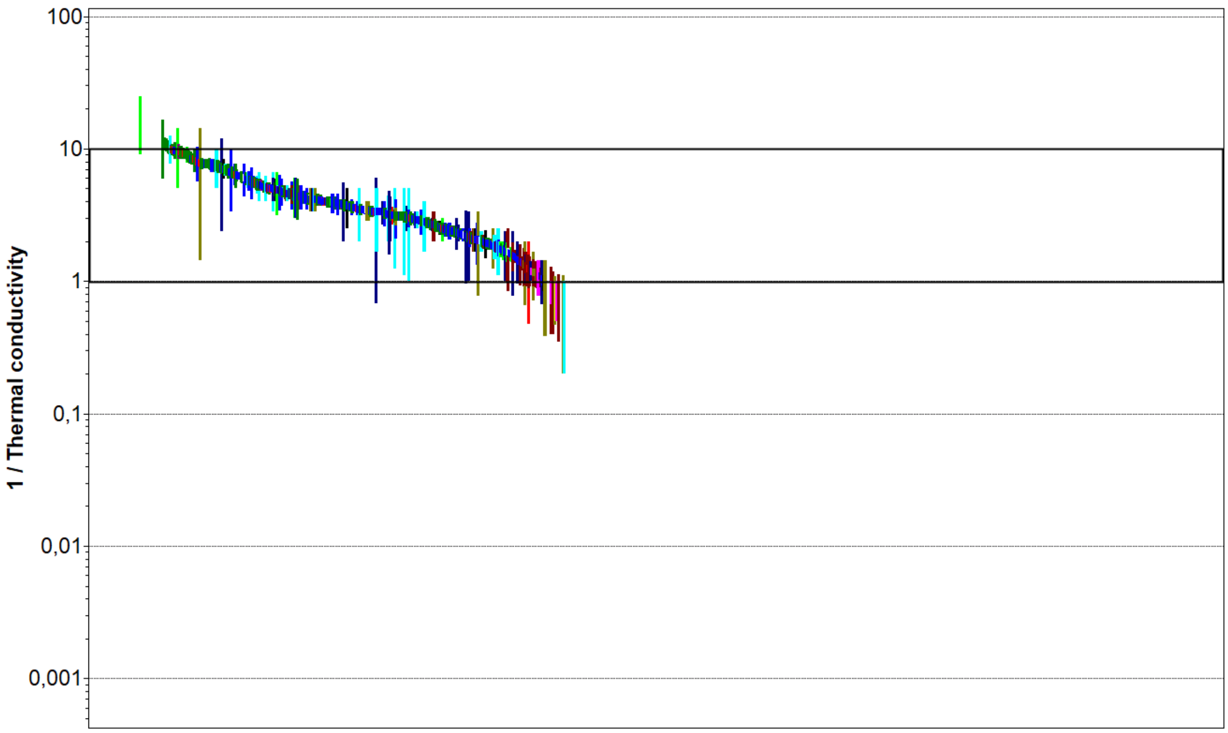
Objective minimise **mass**	**Constraints** Stiffness	 Strength
Tension (tie) 	E/ρ	σ_y/ρ
Bending (beam) 	$E^{1/2}/\rho$	$\sigma_y^{2/3}/\rho$
Bending (panel) 	$E^{1/3}/\rho$	$\sigma_y^{1/2}/\rho$

According to the lecture slides, the material index for minimizing mass with the stiffness constraint is $M_1 = E^{1/3}/\rho$ and for strength constraint is $M_3 = \sigma_y{}^{1/2}/\rho$. Similarly, the material index for minimizing cost with the stiffness constraint is $M_2 = (C_m E^{1/3})/\rho$ and for strength constraint is $M_4 = (C_m \sigma_y{}^{1/2})/\rho$.
In total, we have four material indices that need to be maximized.

The penalty function for stiffness constraint is
$P_{stiff} = M_1 + \alpha M_2$
The penalty function for strength constraint is
$P_{strength} = M_3 + \alpha M_4$
In which $\alpha = 0{,}189$

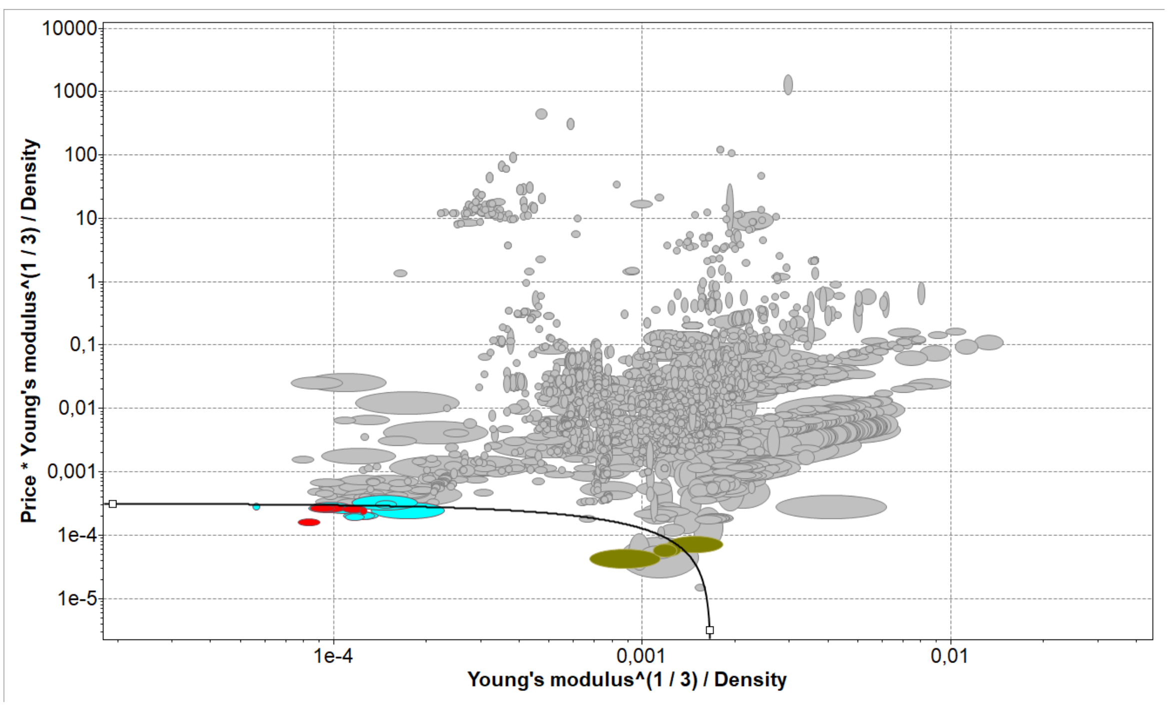
To optimize thermal insulation, we need to consider the material's thermal conductivity, measured in W/m.K unit. A material with low thermal conductivity is a good thermal insulator.

In the first stage, I select the materials with lowest thermal conductivity for good insulation. I dont choose the top materials because they are unrealistic and hard to obtain. The range of 1-10 for (1/Thermal conductivity) offers the most sensible choices of materials.



After the good insulated materials are filtered out, I proceed to plot the first graph with respect to the constant stiffness that minimizes both the mass and the cost

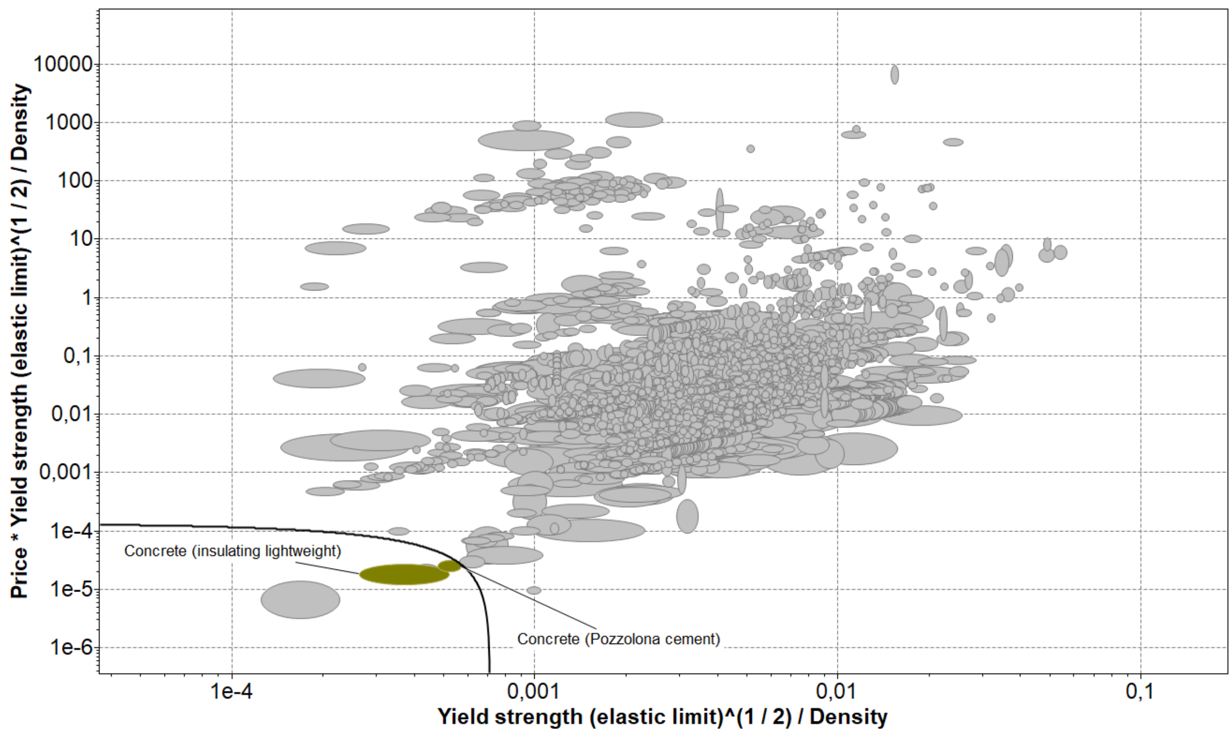
The penalty function for stiffness constraint as the black line is
$P_{stiff} = M_1 + \alpha M_2$, $\alpha = 0.189$



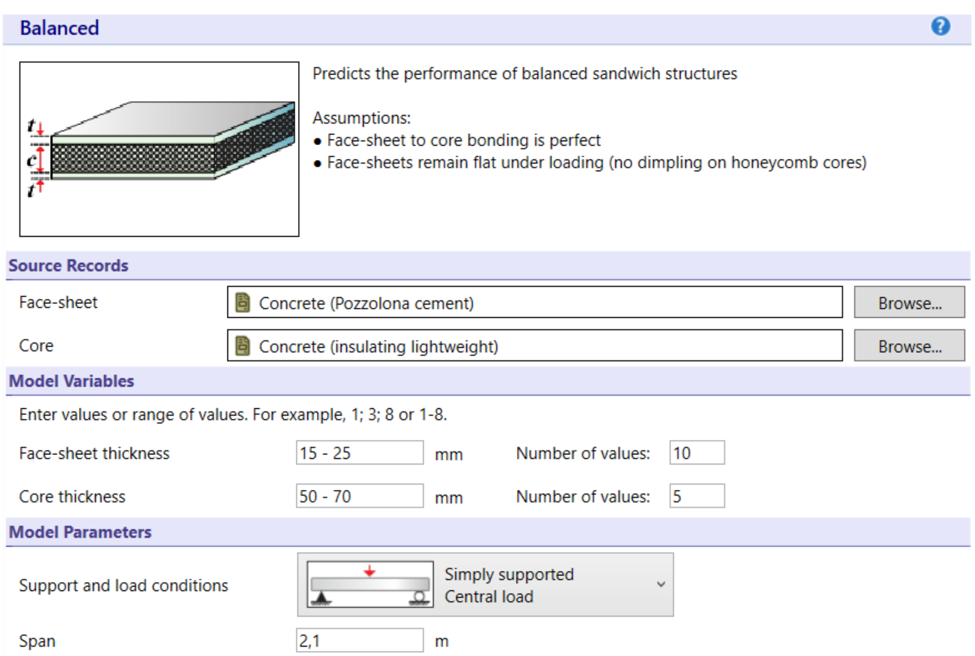
We can observe that a few materials are filtered out. Next, we need to choose the two materials with the lowest cost and mass with respect to constant strength

The penalty function for strength constraints the black line is

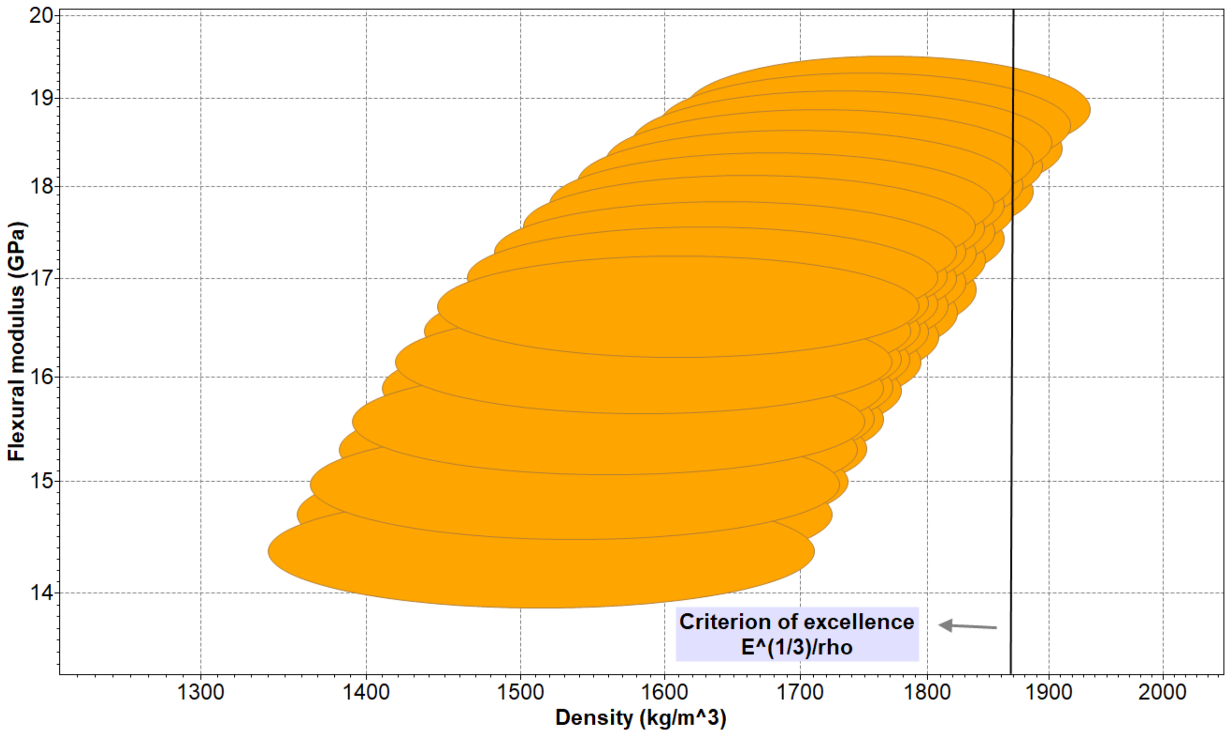
$P_{strength} = M_3 + \alpha M_4, \ \alpha = 0.189$

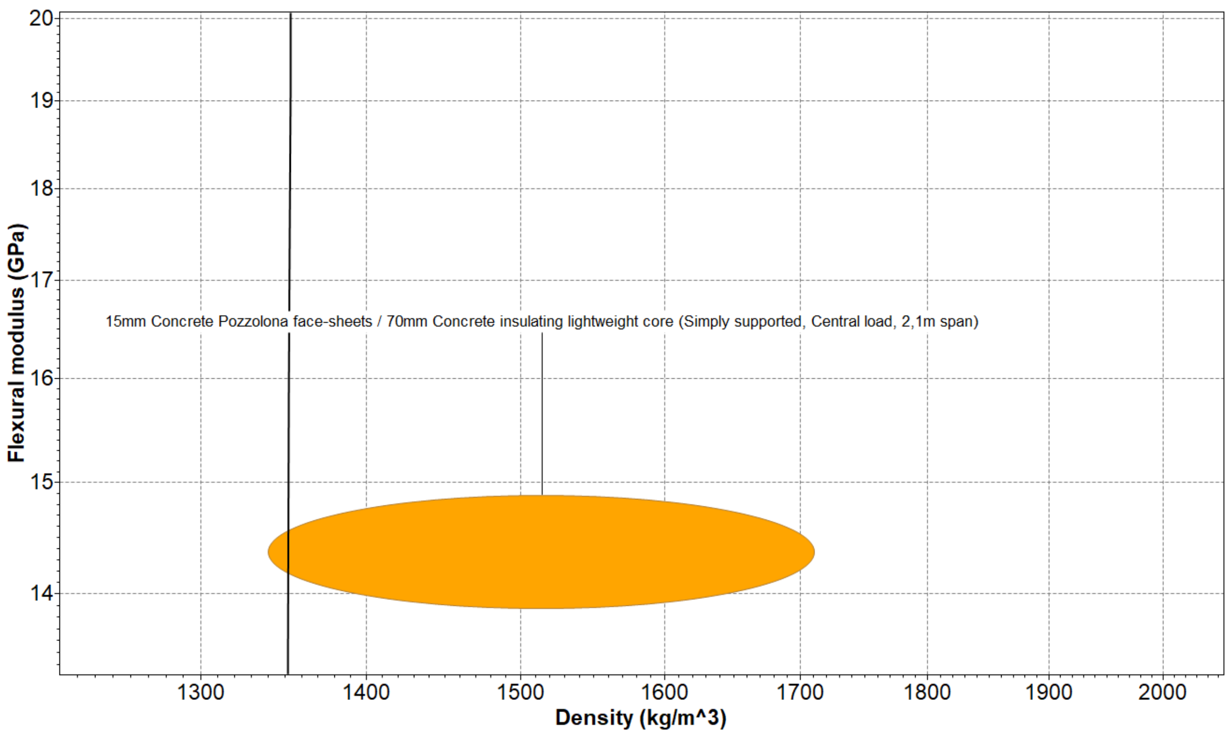


The two filtered materials are Insulating lightweight and Pozzolana cement concrete, respectively. Since insulating lightweight has better insulation, I will use it as the core ad the other one will be used as the face in the sandwich composite material design



There are many candidates for the composites. I proceed to plot the Flexural modulus vs Density diagram to choose the best material with constant stiffness





Finally, the chosen sandwich design is as follows:

- Total thickness = 100mm. Face thickness = 15mm, Core thickness = 15mm
- The face is pozzolana concrete and the core is lightweight insulating concrete

Task 4.2: Capacitive touchscreens work by sensing small electric charges from fingertips. Explain the material requirements for winter gloves intended to enable the use of a capacitive touch screen with these gloves. Design a hybrid material to achieve the desired combination of properties. Show your design and choice with diagrams and necessary explanations.

Hint: See *example 12.4: Extreme Combinations of Thermal and Electrical Conduction* as a guideline. If it is difficult to find electrical conductivity in GRANTA, you can also use 1/ electrical resistivity instead.

This exercise requires that the material made for the glove should be made from a hybrid material. Additionally, the glove should have low conductivity while higher electrical property. Like the textbook, I proceed to work with High electrical conductivity Copper and Low Thermal conductivity Polyethylene Fibers.

High conductivity copper, PE (Polyethylene)

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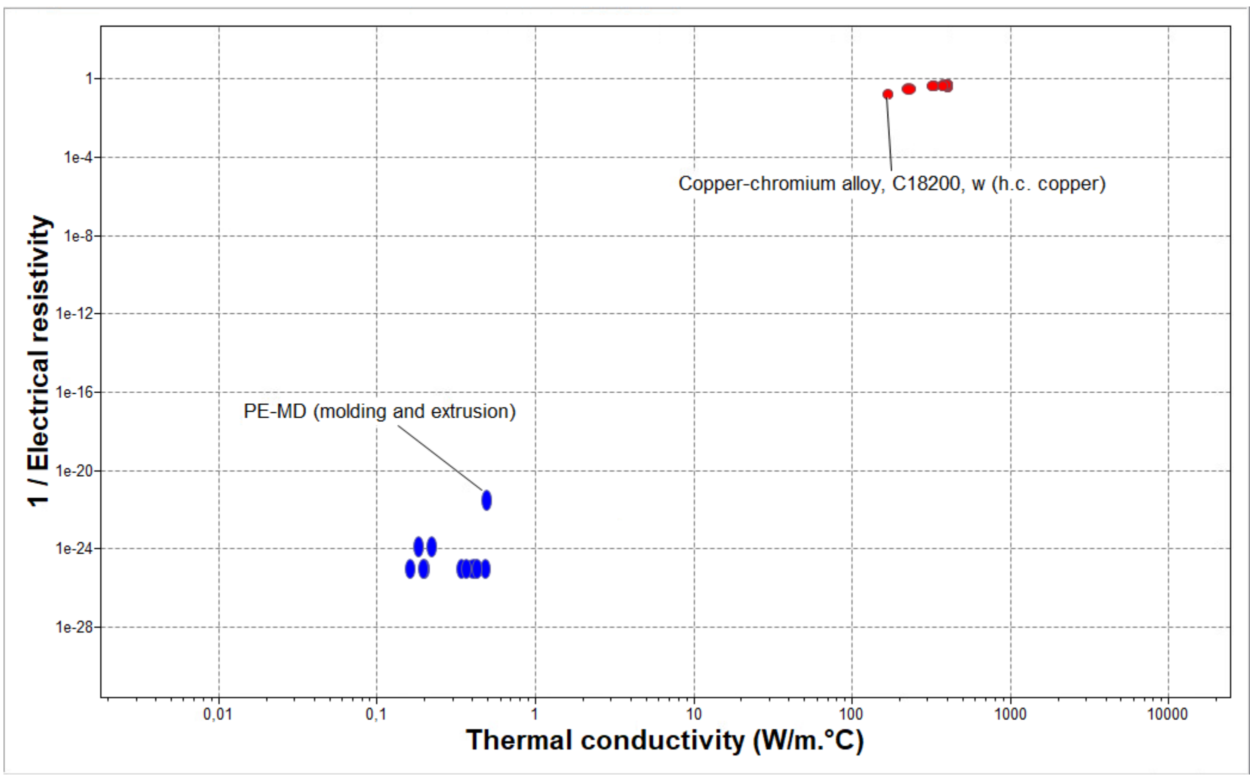
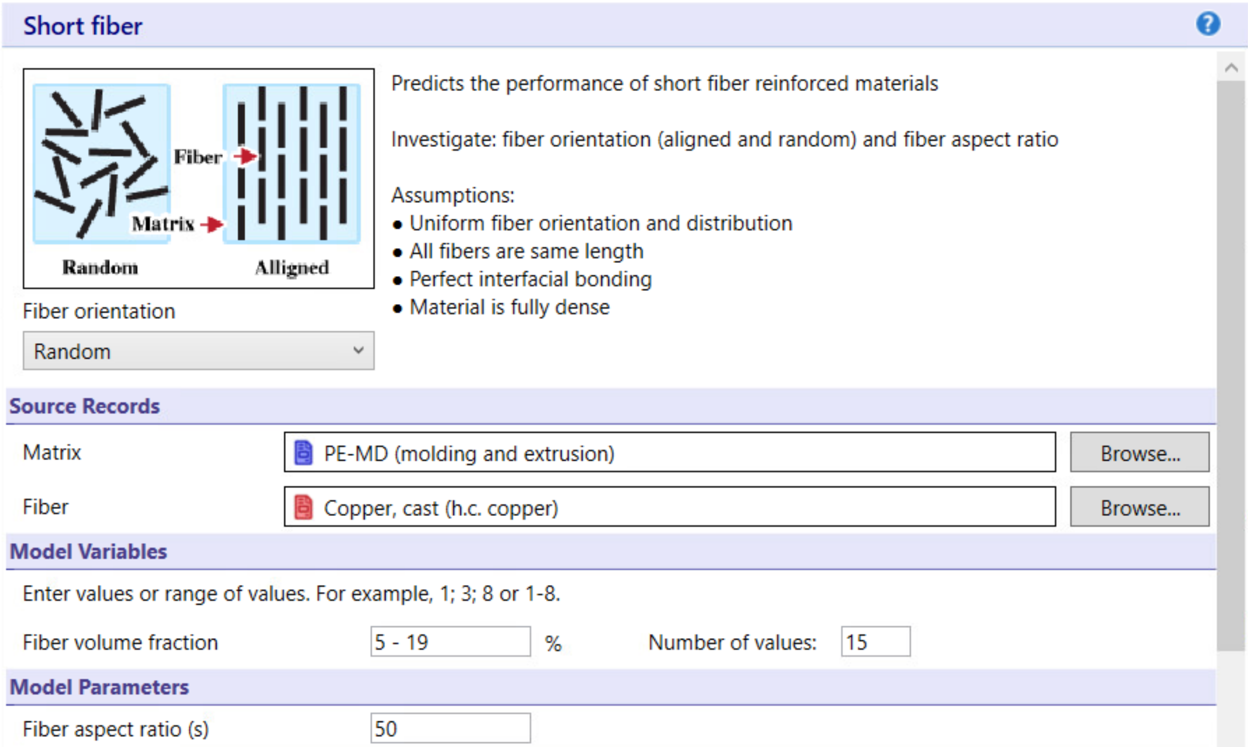
Link Record	Number Passed	
MaterialUniverse: \ Metals and alloys \ Non-ferrous \ Copper \ High conductivity	27	Show
MaterialUniverse: \ Polymers: plastics, elastomers \ Plastics \ Thermoplastics \ PE (Polyethylene)	11	Show



Then I create a hybrid material using Short Fiber composite type with the below settings



Finally, I obtained the hybrid PE matrix with copper fibers material for the glove. At 19% Copper short fiber composition, this material offers a much higher electrical conductivity, while also not compromising thermal conductivity so much.