# Task 4

**Task 4.1**

Let's find materials for a greenhouse door. The design requirements are shown in Table 1.

Table 1. Design requirements for greenhouse door.

| | |
|---|---|
| Function | Insulating heat loss |
| Constraints | Sufficient stiffness S<br>Strength<br>Low weight<br>Low price<br>Small width w<br>Light structure<br>Outer sheets must resist weather |
| Objective | Maximize thermal insulation through thickness h |
| Free variables | Cross-section A<br>Material(s)<br>Material relative thickness<br>Availability |

Typically sandwich panels have a relatively soft core compared to the stiff outer sheets that it is in the middle of. The core should be light but also stiff and strong enough, whilst isolating whereas the outer sheets protect it and must withstand bending. As the different parts of the sandwich panel have different uses and means, they can be researched and examined separately and, in the end, combined for an optimal solution.

As we know the formula for mass is:

$$m = Al\rho = whl\rho \qquad (1)$$

The material should also be sufficiently stiff so we can define stiffness S, where e F is the total load and $\delta$ is the bending deflection:

$$S = \frac{F}{\delta} \qquad (2)$$

The deflections relation to the force F is, where $C_1$ is a constant:

$$\delta = \frac{FL^3}{C_1 EI} \qquad (3)$$

Knowing this the formula for stiffness S can be led to:

$$S = \frac{F}{\frac{Fl^3}{C_1EI}} = F * \frac{C_1EI}{Fl^3} = \frac{FC_1EI}{Fl^3} = \frac{C_1EI}{l^3} \tag{4}$$

For a rectangular area the second moment of area, I, is:

$$I = \frac{wh^3}{12} \tag{5}$$

Bending stiffness S can be continued and led to:

$$S = \frac{C_1E*\frac{wh^3}{12}}{l^3} = \frac{C_1Ewh^3}{12} * \frac{1}{l^3} = \frac{C_1Ewh^3}{12l^3} \tag{6}$$

From the bending stiffness led in equation 6, lets determine height h:

$$S = \frac{C_1Ewh^3}{12l^3} \rightarrow h^3 = S * \frac{12l^3}{C_1Ew} \rightarrow h = \sqrt[3]{\frac{12Sl^3}{C_1Ew}} \tag{7}$$

As the goal was to minimize the mass of the panel, knowing height h we can insert it into the mass m of the beam:

$$m = AL\rho = whl\rho = w\sqrt[3]{\frac{12Sl^3}{C_1Ew}} * l\rho = w\sqrt[3]{\frac{12S}{C_1w}} * l\left(\frac{1}{E}\right)^{\frac{1}{3}} l\rho = \left(\frac{12S}{C_1w}\right)^{\frac{1}{3}} * wl^2\left(\frac{1}{E}\right)^{\frac{1}{3}}\rho$$

$$= \left(\frac{12S}{C_1w}\right)^{\frac{1}{3}} * wl^2 * \frac{\rho}{E^{\frac{1}{3}}} = (12S/C_1w)^{\frac{1}{3}} * wl^2 * (\rho/E^{\frac{1}{3}}) \tag{8}$$

The equation was divided into three different parts where specified and constant variables are grouped together (on the left and in the middle) and undefined variables are separate (on the right). The mass will be the smallest when the variables $(\rho/E^{\frac{1}{3}})$ (that have not been defined) are minimized. Thus, to minimize the mass, we must maximize $(\frac{E^{\frac{1}{3}}}{\rho})$. This means that we can graph E, Young's modulus and $\rho$, density and plot materials families there (see figure 1).

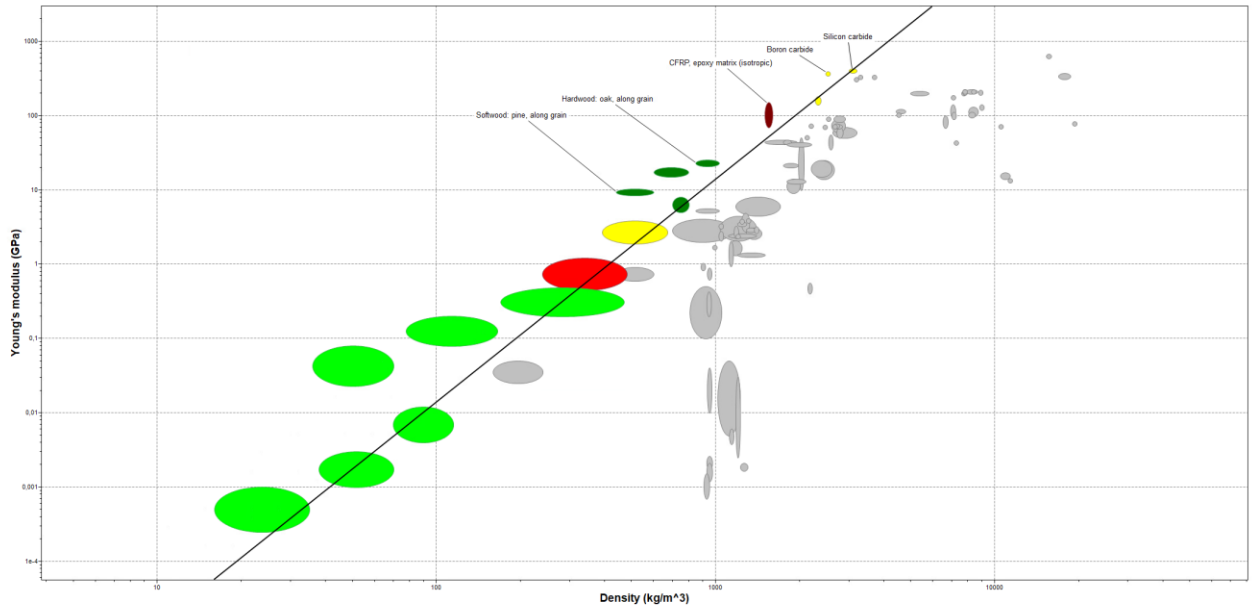


Figure 1. Materials in relation to Youngs modulus and density with plotted material selection line ($\frac{E^{\frac{1}{3}}}{\rho}$).

Similarly, we want to maximize the strength of the material in relation to density. This can be done with formula 9, which is found in the course material:

$$M_1 = \frac{\sigma_y^{\frac{1}{2}}}{\rho} \tag{9}$$

Figure 2 presents the strength of the material with the materials families plotted.

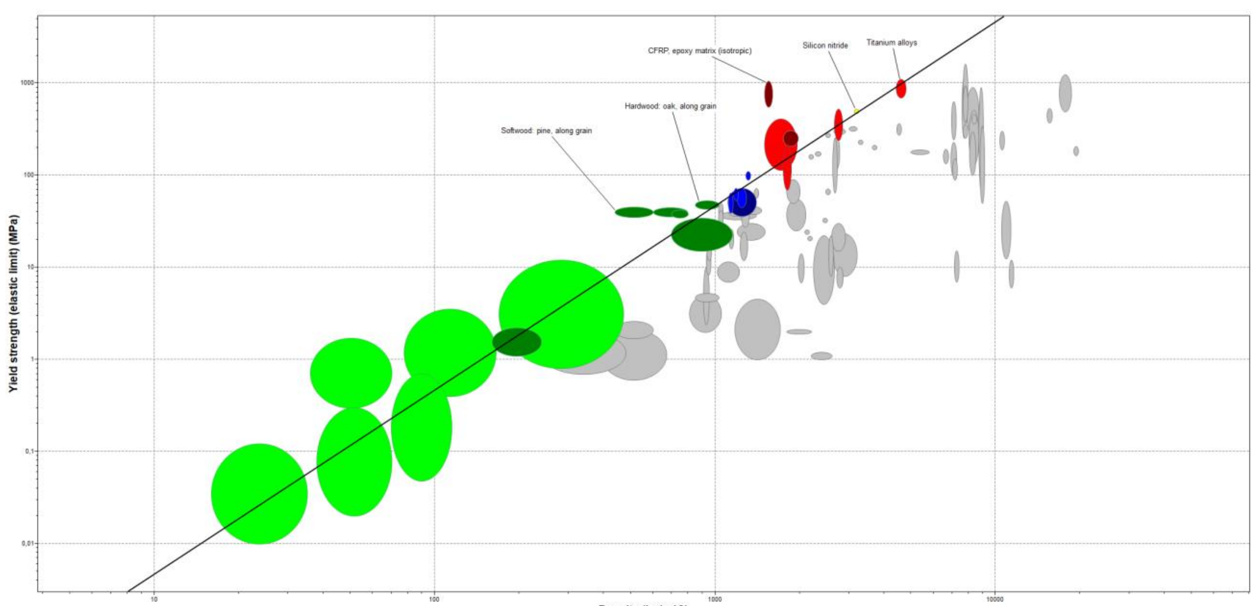

Figure 2. Materials in relation to Yield strength and density with plotted material selection line $(\frac{\sigma_y^{\frac{1}{2}}}{\rho})$.

We also want to consider the cost c of the materials in relation to both strength and stiffness. We should define it using the minimized mass, because the cost is the mass times cost of the material. Cost with stiffness:

$$c = \frac{c_m \rho}{E^{\frac{1}{3}}} \tag{10}$$

And cost with strength:

$$c = \frac{c_m \rho}{\sigma_y^{\frac{1}{2}}} \tag{11}$$

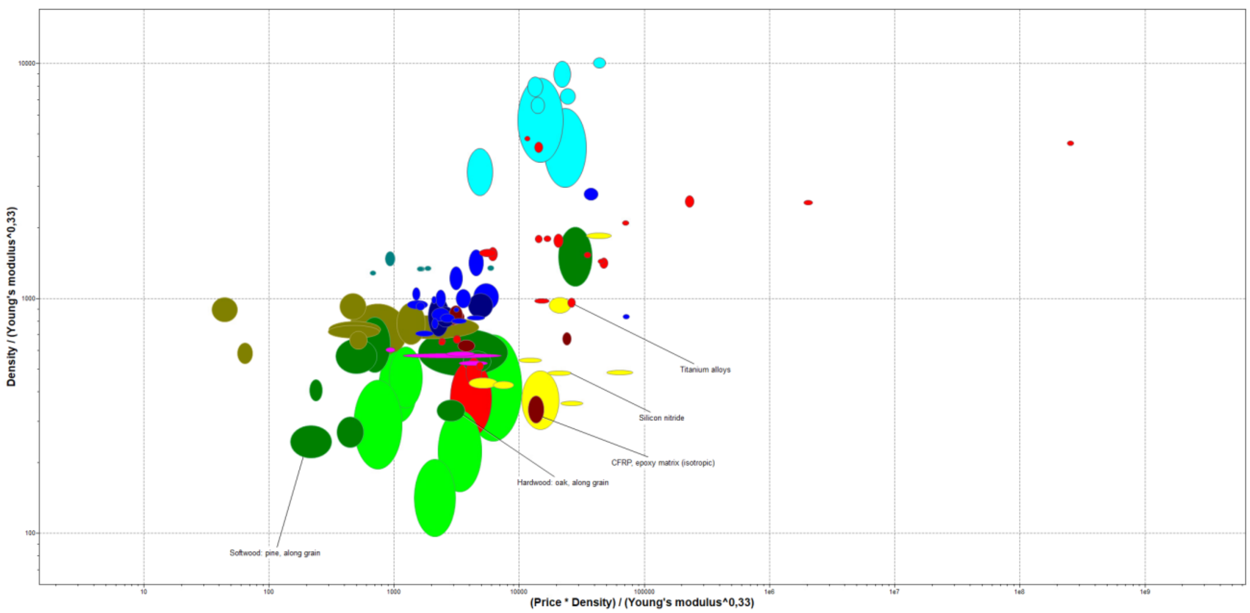


Figure 3. Material map with price taken to account for stiffness.

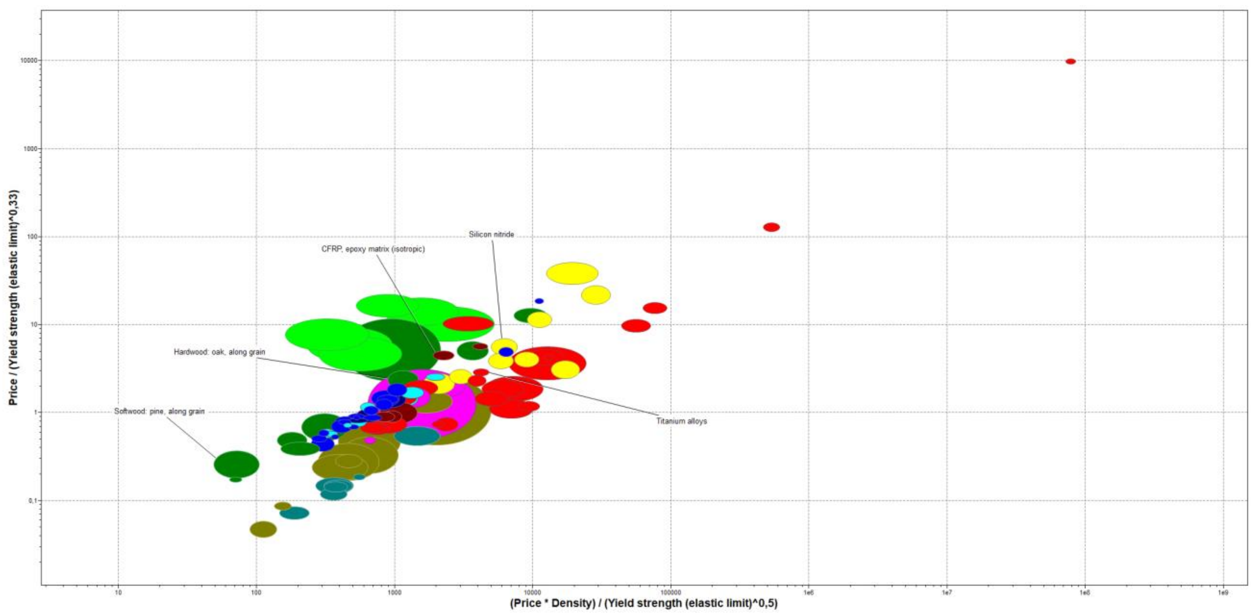


Figure 4. Material map with price taken to account for strength.

Based on the material maps done with GRANTA there are three main materials that are the best suited for the greenhouse door outer sheets. The materials for outer sheets must withstand weather conditions, thus for example wood unprocessed is not a great fit. The most optimal fits for the outer sheet materials are:

- CFRP
- Titanium
- Silicon nitride

Having options for the outer sheets of the greenhouse door, the core material must be found. Firstly, as mentioned the material must be a light thermal insulator. See light thermal insulator materials in figure 5.

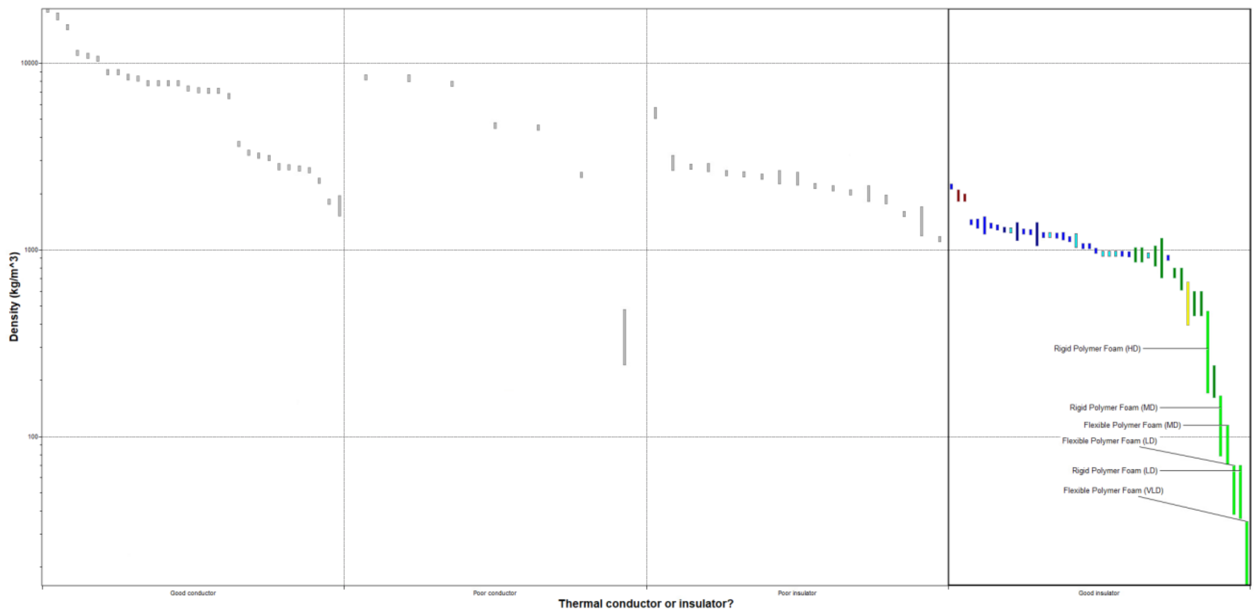


Figure 5. Light materials with good insulating properties.

Furthermore, the core should also be affordable. See cost of thermally insulating materials in figure 6.

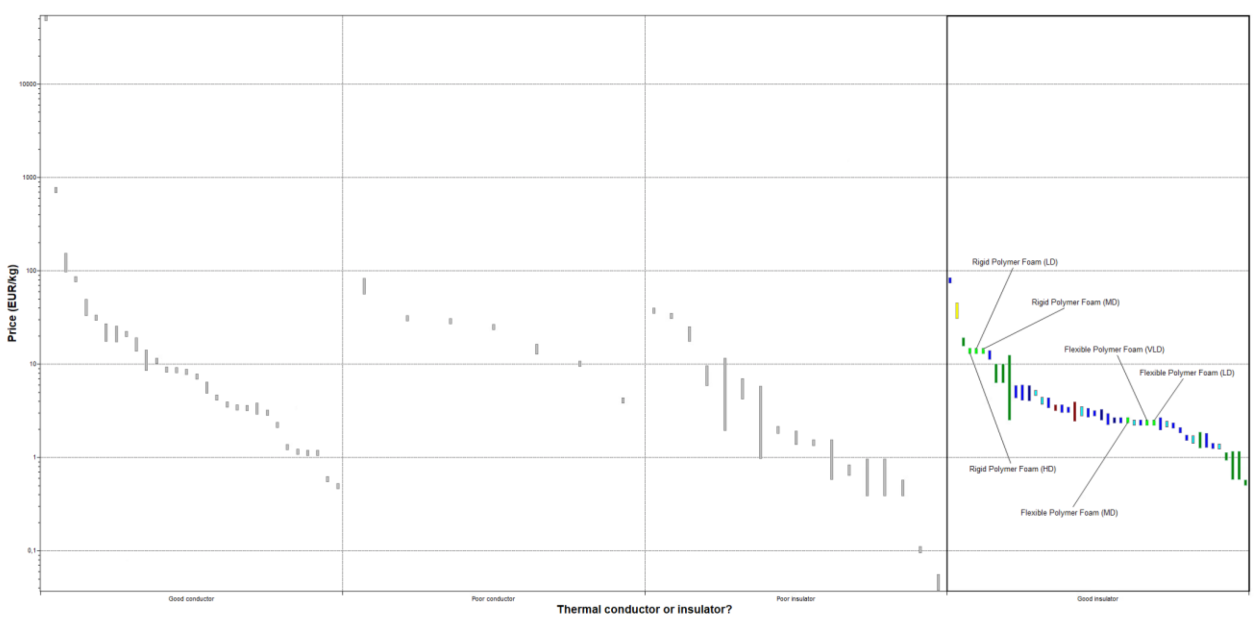


Figure 6. Cost of materials with thermal insulation.

In conclusion, affordable light thermally insulating materials mainly consist of polymer foams.

When combining the knowledge of the outer sheets and core different sandwich combinations can be compared. We can create a hybrid solution. Out of CFRP and flexible polymer foam. CFRP is over all a better solution from silicon nitride and titanium for the greenhouse door as it is lighter and cheaper.

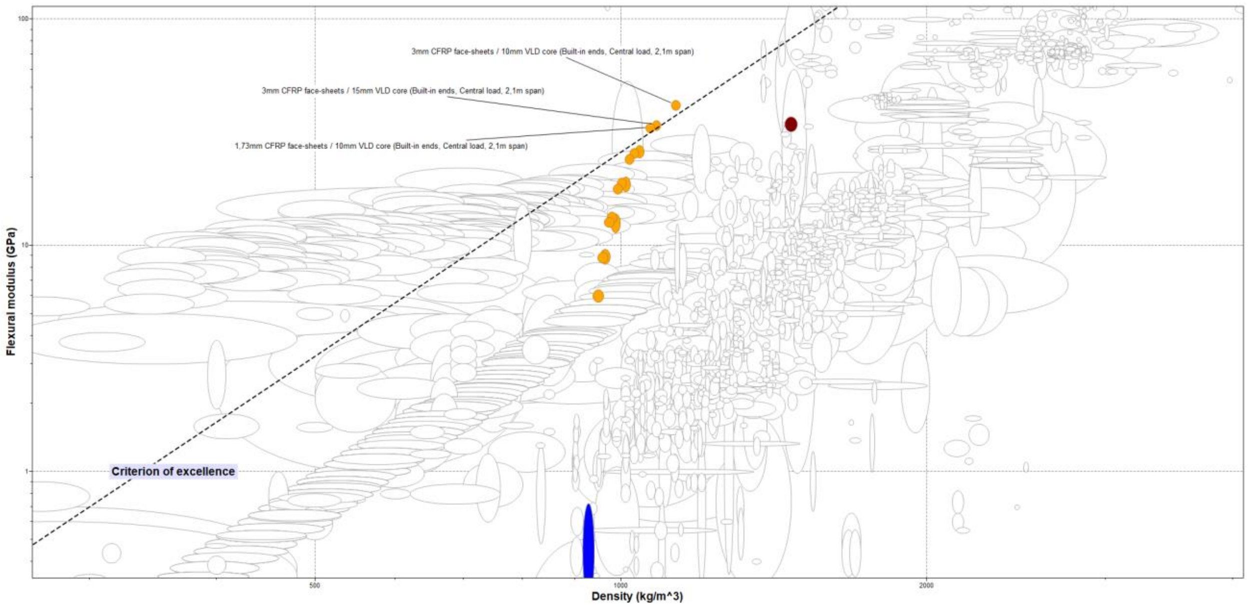


Figure 7. Hybrid solution utilizing sandwich combination.

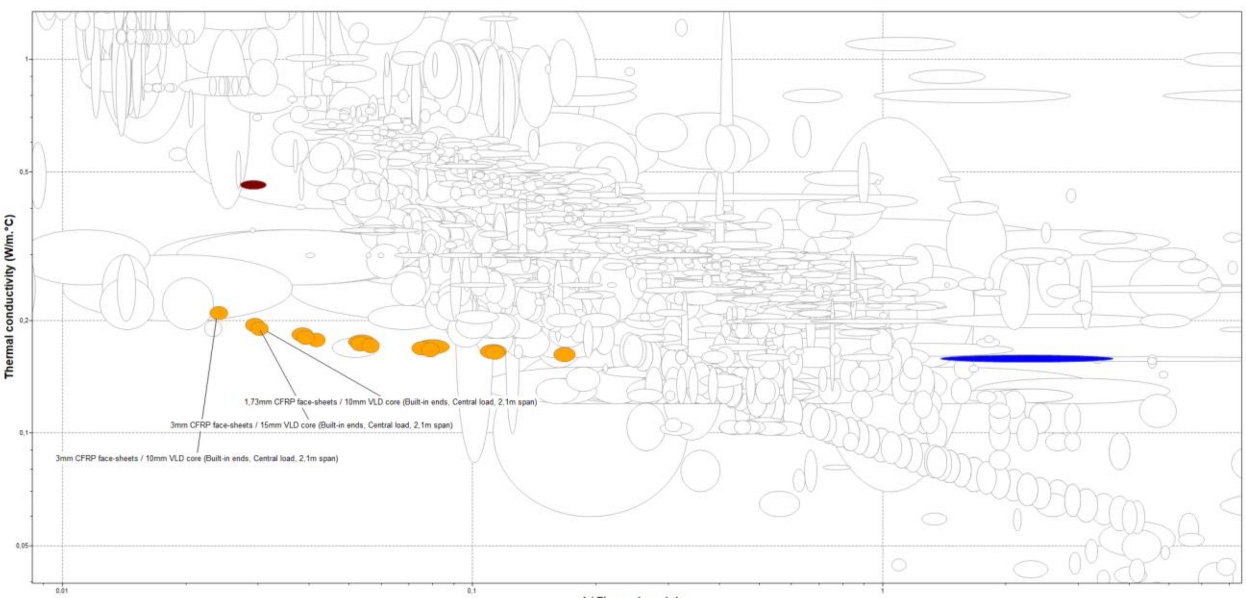


Figure 8. Hybrid solution utilizing sandwich combination.

When creating a sandwich from the materials we are able to fulfill the requirements better, compared to using a single material. We are able to consider cost, stiffness, weight, strength, insulating and weather durability all without having to give up on some of the requirements. From the material maps we can conclude that a sandwich combination with the outer sheets made out of CFRP and core from VLD (flexible polymer foam) we can create a greenhouse door that fulfills our needs. A combination I would go with would be 1,73 mm outer sheets and 10 mm core to minimize the mass. Although I chose these materials for the greenhouse door, there are other materials on the material maps, especially for the core that could be just as optimal.

**Task 4.2**

Let's create a hybrid material for gloves that work on touchscreen. The design requirements are shown in Table 2.

Table 2. Design requirements for greenhouse door.

| | |
|---|---|
| Function | Insulating heat loss |
| Constraints | Flexible<br>Low weight<br>Low price<br>Conductive |
| Objective | Maximize thermal insulation along with conductivity |
| Free variables | Material(s)<br>Material relative thickness |

We need a material that is very flexible but extremely light, thus see figure 9.

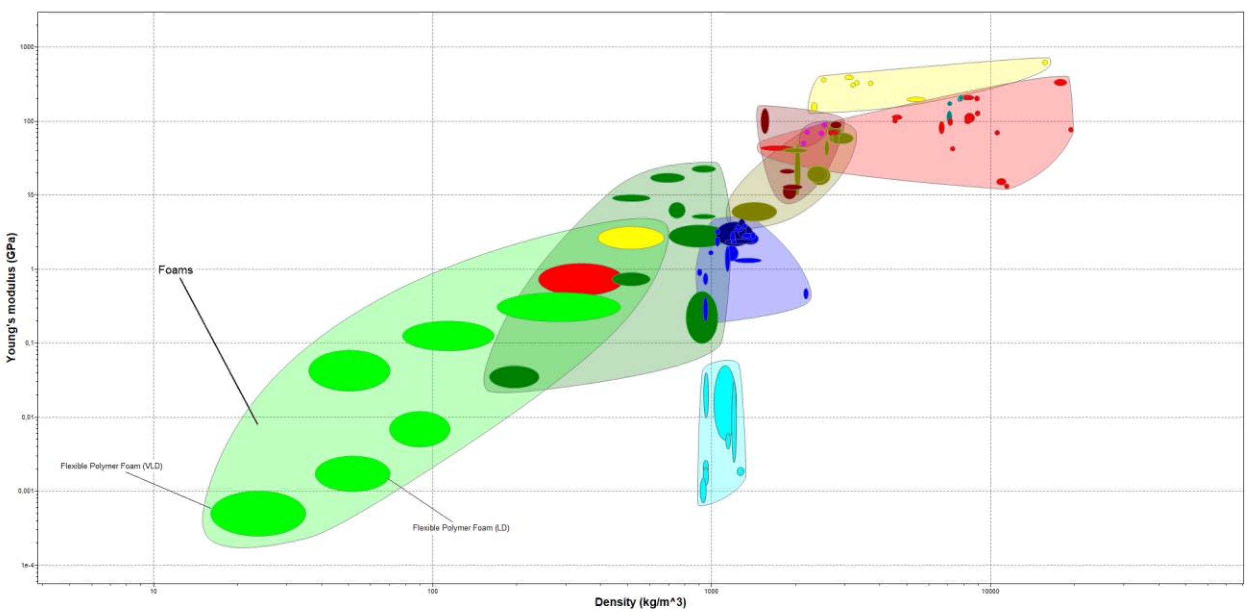


Figure 9. Flexible light material.

The material must also be insulating; thus we can refer to figure 5 that kind of material. For these aspects (flexibility, weight, insulator) foams, and especially VLD seems good. If this material could be mixed with a very good conductor, the gloves could be used for the touch screens. Light and conductive materials can be seen below in figure 10.

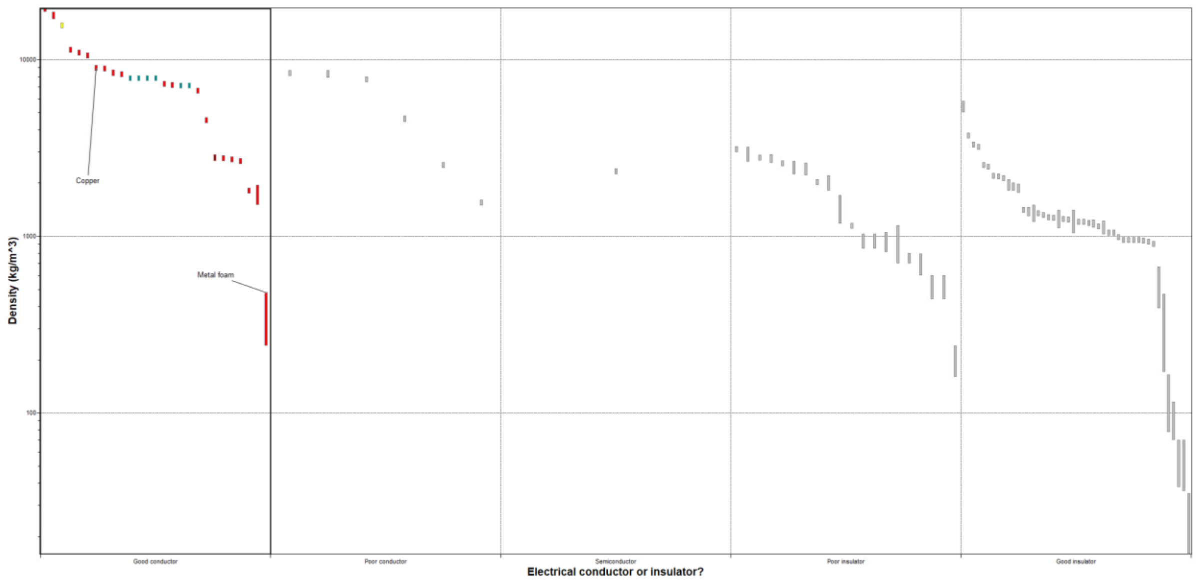


Figure 10. Conductive materials.

Although, copper is not as light as metal foam not that large amounts of it have to be used for the gloves. Thus, small amounts on crucial areas could be utilized.

NOTE: I believe that from this point on especially I did not do the assignment correctly. I created a synthesizer -> composites -> short fiber in GRANTA and mapped it below in figure 11. I was not sure how to advance or move forward from this point. Also, I understand that here the point is to make a composite material, however I wonder if one were to weave conductive material to crucial areas in gloves would that be a more simple solution to conductive gloves. Crucial areas would be fingertips. If the material like copper, or for example silicone rubber could be safely woven into for example wool, would it be a more cost efficient and ecological solution rather than creating a new composite.

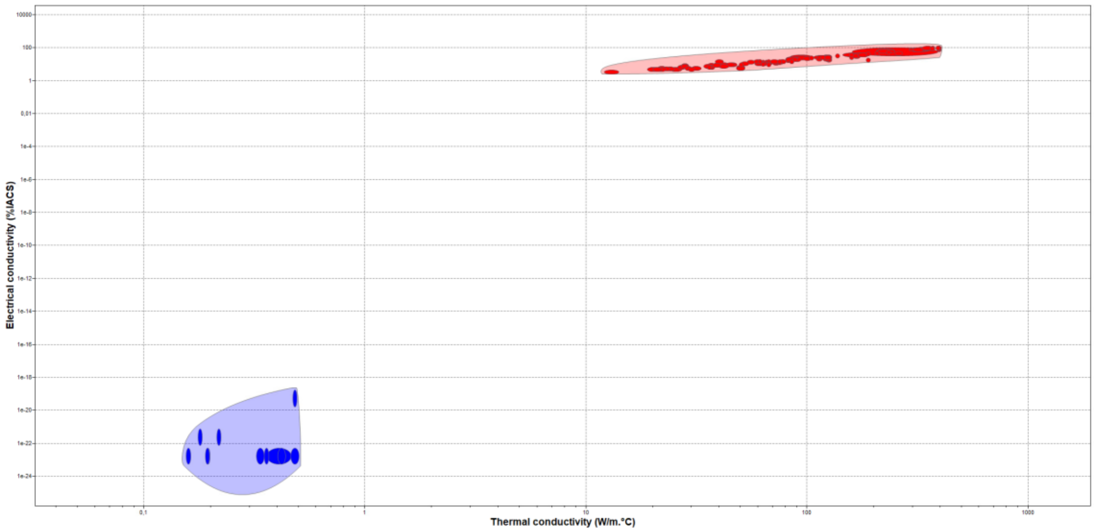


Figure 11. Composite short fiber figure.