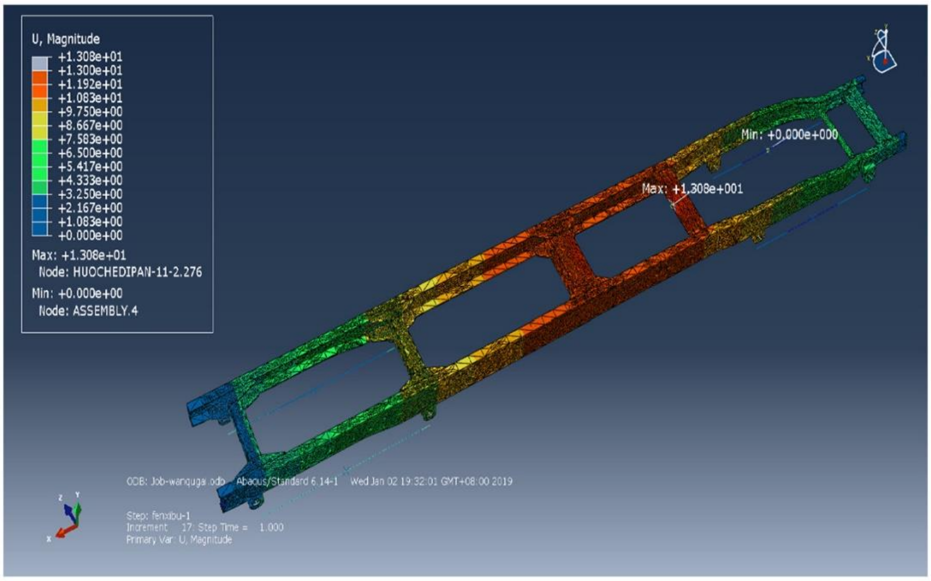
TASK 2: MULTIPLE CONSTRAINTS

In this report, I will be investigating and recommending suitable materials for vehicle frames.
A strong understanding of materials engineering and research is crucial in the design process to comprehend design constraints and material properties. In currently, our focus must be directed toward sustainability, safety and cost-effectiveness.

The material selection "cases" will be centred around trucks and passenger cars, with the aim of proposing realistic materials for their frame structures, as illustrated in Figure 1 below.
I will assume that the frame structure takes the form of a beam, and the force applied to the vehicle's frame is evenly distributed between the vehicle's axles.

Task 2.1 / Design requirements



Design requirements I defined according to task assignment and the textbook.
If we simplify the frame function, its role is to serve as the 'body' of the vehicle, withstanding the forces generated by the vehicle's weight and all dynamic forces, including impact situations. In a impact scenario, the car's bumper structures absorb most of the impact energy.

Deging Requirements for stiff beam	
Function	sufficiently rigid structure / beam for transport fleet
Constraints	Length L
	Section shape
	Bending load F
	Bendinf stiffness S
Objective	Material cost minimization
	Mass minimization m
Free Variab-les	Material selection
	Cross section area A

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Task 2.1 / Derivation

Formula for the mass

$$m = A * L * p$$

Minimal bending stiffness

$$S \geq S^*$$

Considering certain variables, we denote the Young's modulus of the material as E and the second moment of area as I. Additionally, we can utilize the constant value C provided in textbook. Thus, we can express the matter as follows

$$S = \frac{F}{\delta} = \frac{C*E*I}{L^3}$$

The moment of inertia I for a square-sectioned beam is

$$I = \frac{b^4}{12}\frac{A^2}{12}$$

Then we add the value of I to formula 3

$$\frac{C * E * A^2}{12 * L^3} \geq S^*$$

Ideal formula to minimizing the cost P

$$P = C_m * m$$

The bending stiffness S* is modified based on the length L**.**

$$m \geq \left(\frac{12*S*L^3}{C}\right)^{\frac{1}{2}} * L * (\frac{p^2}{E})^{\frac{1}{2}}$$

Material index 1 / minimizing the mass

$$M_1 = \frac{E^{1/2}}{p}$$

Material index 2 / minimizing the mass

$$M_2 = \frac{E^{1/2}}{C_m * p}$$

Penalty function Z is formulated as based on the textbook.
Please note that, “α” is alpha [€/kg], “M” is [kg/S] and “C” is [€/kS]

$$\boldsymbol{Z = C * \propto * M = \frac{p}{E^{\frac{1}{2}}} * (C_m + \propto)}$$

Passenger car

$$\boldsymbol{Z_1} = \frac{p}{E^{1/2}} * (C_m + \mathbf{5})$$

Truck

$$\boldsymbol{Z_2} = \frac{p}{E^{1/2}} * (C_m + \mathbf{15})$$

Application	Alpha [€/kg]
Passenger car	5
Truck	15
Commercial airplane	250
Fighter jet	750
Space shuttle	5000

Case 1 passenger car alpha 5

Now we will be able to create a bar chart of Z-values and observe different materials at Level 2. Please note that the result is scaled on the Y-axis from 0 to 10,000.

We can also list all the materials that meet the predefined material properties, as can be seen, the most suitable material for a passenger car is aluminium alloys.

Rank by: Stage 1: (Density / Young's modulus^(1 / 2) * (Price + 5))

Name	(Density / Young's modul...
Softwood: pine, along grain	843 - 1,18e3
Bamboo	944 - 1,3e3
Cement	1,44e3 - 1,76e3
Plywood	1,45e3 - 1,9e3
Wrought magnesium alloys	1,59e3 - 2,08e3
Slate	1,65e3 - 2,08e3
Brick	1,74e3 - 3,94e3
Marble	1,87e3 - 2,29e3
Glass ceramic	1,87e3 - 4,63e3
Soda-lime glass	1,88e3 - 1,97e3
Cast magnesium alloys	1,94e3 - 2,13e3
Limestone	1,96e3 - 2,52e3
Non age-hardening wrought Al-alloys	2,17e3 - 2,27e3
Cast Al-alloys	2,18e3 - 2,34e3
Hardwood: oak, along grain	2,22e3 - 3,18e3
Granite	2,24e3 - 4,31e3
Concrete	2,36e3 - 3,19e3
Paper and cardboard	2,43e3 - 4,36e3
Silicon	2,59e3 - 3,76e3
Sandstone	2,63e3 - 3,66e3
Age-hardening wrought Al-alloys	2,69e3 - 2,93e3
Cast iron, ductile (nodular)	2,79e3 - 2,88e3

Perhaps even a surprising material that emerges, apart from various aluminium alloys, is plywood. Plywood has in fact, been used in older cars but is not a contemporary material for the automotive industry, especially since its uniformity of quality cannot be guaranteed.

Case 2 Truck alpha 15

Now I create level 2 bar chart using the same principle as before, but with alpha set to 15. In other words, (Density / Young's modulus ^ (1/2) * (price + 15)).
These can also be listed and ranked according to the desired stage, as we can see.

Rank by: Stage 1: (Density / Young's modulus^(1 / 2) * (Price + 15))

Name	(Density / Young's modul...
Softwood: pine, along grain	2,28e3 - 3,16e3
Bamboo	2,37e3 - 3,24e3
Wrought magnesium alloys	3,83e3 - 5,01e3
Hardwood: oak, along grain	4,05e3 - 5,3e3
Plywood	4,06e3 - 5,3e3
Cement	4,25e3 - 5,2e3
Silicon	4,39e3 - 5,66e3
Slate	4,51e3 - 5,67e3
Glass ceramic	4,53e3 - 7,28e3
Cast magnesium alloys	4,54e3 - 4,95e3
Silicon carbide	4,55e3 - 5,57e3
Brick	4,61e3 - 1,03e4
Rigid Polymer Foam (LD)	4,71e3 - 1,11e4
Soda-lime glass	4,79e3 - 4,96e3
Marble	5,21e3 - 6,22e3
Non age-hardening wrought Al-alloys	5,25e3 - 5,49e3
Cast Al-alloys	5,27e3 - 5,63e3
Silica glass	5,44e3 - 6,52e3
Limestone	5,45e3 - 6,86e3
Aluminum/Silicon carbide composite	5,69e3 - 6,66e3

Many of these materials (cast magnesium alloys, wrought magnesium alloys, cast AL-alloys and Age-hardening wrought Al-alloys) could be suitable for the construction of a truck's frame; however, weight and cost are the most crucial factors. Price should be kept under control while simultaneously aiming to minimize the total weight. For instance, cast aluminum alloys may offer an economical option, while lightweight magnesium alloys could be a good choice for weight reduction, albeit at a higher cost. The choice depends on specific requirements and budget considerations.

Summary of Case 1 and 2

There is little difference between the case scenarios. To achieve better results and comparability. It would have been helpful to select the extreme values of Alpha, for example, a passenger car with Alpha 5 and a spacecraft with Alpha 5000.

Task 2.2 material property map

In this task, the objective is to find an alternative material for phone casings instead of using ABS plastics. However, the alternative material should still withstand external forces while being as lightweight as possible, containing minimal material, and cost-effective. The textbook provides valuable insights into this topic. I will start with the design requirements:

Deging Requirements for thin panel	
Function	Stiff thin panel and ability to absorb energy
Constraints	Length L
	Bendinf stiffness S
Objective	Material cost minimization
	Mass minimization m
Free Variables	Material selection

Task 2.2 Derivation

We can utilize Chapter 8.6 of the textbook for reference. When selecting the material for the phone casing, the aim is to minimize the mass and thickness of the component. As it is a volume product, cost should be kept low. In addition to these three demanding requirements, the casing must maintain sufficient bending stiffness to withstand external impacts. These specified requirements can be described using the following equations according to the textbook.

$$\frac{m_a}{m_{a,0}} = \frac{p}{E^{1/3}}(\frac{E_0}{p_o})^{1/3}$$
$$\frac{t}{t_0} = (\frac{E_0}{p_o})^{1/3}$$

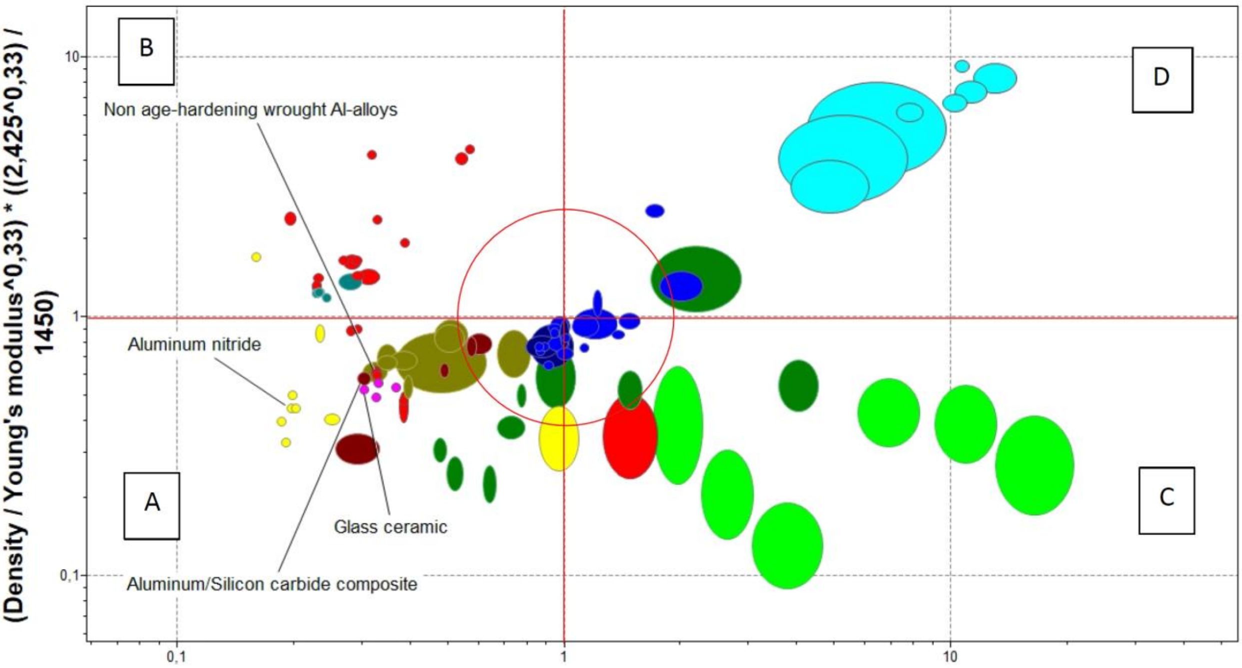
In the material selection, we can utilize the above equations to form as Z penalty function, which is defined as follows:

$$Z^* = \propto_t^* * (\frac{E_0}{E})^{\frac{1}{3}} + \propto_m^* * \frac{p}{E^{\frac{1}{3}}} * (\frac{E_0^{1/3}}{P_0})$$

Now, we will add ABS values into this penalty function, which is also used as our material selection function in Granta EduPack at level 2.

$$Z^* = \propto_t^* * (\frac{2.4e9}{E})^{\frac{1}{3}} + \propto_m^* * \frac{p}{E^{\frac{1}{3}}} * (\frac{2.4e9}{1045})$$

Task 2.2 Material selection map



Task 2.2. summary and result of alternative material for phone cover

The chart created with Granta EduPack at level 2 provides valuable insights for material selection in phone casing design. In upper figure, ABS is located at coordinates (1,1), "in the center of red circle”. ABS's performance has been compared to other contemporary casing materials such as aluminum, carbon fiber-reinforced polymers, and glass ceramics. The results indicate that aluminum and carbon fiber-reinforced polymers (CFRP) enable the manufacturing of thinner and lighter phones compared to ABS, with superior relative properties in terms of bending stiffness. However, these alternatives may come at a higher cost and manufacturing complexity. On the other hand, ABS is susceptible to material degradation over time, which is not as significant for aluminum and glass, potentially impacting long-term casing durability.

The chart also highlights that material selection depends on various factors, including reducing thickness and minimizing mass, and different materials may be preferable based on the weight given to these factors. The final choice hinges on specific requirements and budget considerations. It is crucial to note that the alternatives to ABS offer opportunities for lighter and thinner casings, but careful consideration of cost and performance trade-offs is essential.