UIT Arctic University

Descending commuter

The design progress and completion of a descending commuter

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Master’s thesis in Engineering Design … 06 2018

Abstract

The task is to produce a suitable option for those who go mountain hiking and wants the thrill to ride down the hills. The product should be lightweight and foldable, and easy to bring along for a bus ride or other types of public transportation.

The final product is a downhill scooter, where the neck is foldable. The deck of the scooter is a sandwich structure where the core is made of aluminum 5052 honeycomb structure. The face of the sandwich structure is made of an epoxy/carbon fiber composite, along with the handle and the handlebar. The wheel fork and the neck is made out of aluminum 6063 T6.

Dimensions such as thickness has been computed, and tested by Solidworks simulations.

The handlebar of the scooter has adjustable height, and the max bar height is set at 120 mm. The deck of the scooter has a length of 600 mm, and the total mass of the product is 2,449 kg.

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Introduction

The focus of the project is to design a type of a lightweight, foldable and carry-able commuter. A preliminary project was made to check the existing marked, from this and the customer objectives were reapplied as specifications for the design product. This yielded a start for the project where the design will be created for a descending commuter.
The thesis is the final part of the Master of Science and will provide 30 students points and a diploma in Engineering Design. The formal date for delivery of the thesis is 11th of June 2017.

Background

In Narvik, there are various mountains to conquer, and for many Norwegians it has become a pastime. Others even have a greater interest making different competitions reaching many peaks. While the trekking to defeat the mountaintop yields these individuals the most adrenaline, the descent however many feel like is a chore or bore. Imagine if there was a gravel road downwards and you had to walk the long journey while you feel the adrenaline slowly escapes your body. Many have expressed their thought regarding the possibility of hiking up on foot and cruising down on wheels.

Problem Description

Design a type of lightweight, foldable and carry-able commuter. The main idea behind this commuter is that people who like to hike can use whichever path/ trail they wish on the way to up the summit carrying the commuter on the back. When the hiker wish to travel back the hiker should be able to unfold the commuter and descend down in a safely manner. The commuter can be also used in the city in situations where one need a light and mobile commuter, which can fold easily and taken in a bus/ train/ taxi or into a shopping centre.

Method

The design itself will be a product of the method described by Nigel Cross in his text course book "Engineering Design Methods" that have been frequently used in courses during the master program. This method consists of eight steps and is a guide to assure that the designer do not lose sight of the original demand during the process. These steps are:

- 1: Identifying opportunities
- 2: Clarification of Objectives
- 3: Establish functions
- 4: Setting requirements
- 5: Determining characteristics
- 6: Generation of solutions
- 7: Evaluations of solutions
- 8: Adjustment of details

For the material selections of the design, the method presented by Michael F. Ashby in his book “Materials Selection in Mechanical Design” and the program CES EduPack 2017 is used to ensure that the selection is as precise as possible.
When the design and materials are chosen, analyses and various calculations will be performed on the object to make sure it will meet the demands and requirements set in the beginning of the project. If the design object do not pass this stage, it might be necessary to reconsider the design before prototyping it and performing numerical analysis.
System boundaries are set only around the commuter itself, and no surrounding factors or organisms will affect it.

The design process

The design process consists of eight steps from an idea or demand arises to a finished product. In order to design a product that is safe, reliable and satisfactory otherwise it is necessary to examine the demands for the design. This is perform regarding both physical conditions and what the international standards have to determine the specifications. Step one of the process is in the preliminary report.

Objectives

To clarify the objectives the information from the customer is crucial. Since the commuter will have to transport the hiker from the mountain, it will need to have strength and stiffness to be able to maintain appropriate structure and control to the user. The client should not have to struggle bringing the commuter on an otherwise harsh trek. The design will also have to be able to fold to minimize its volume in places such as the bus or a shopping centre. It will also have to on occasion be utilized in a city environment with concrete and gravel

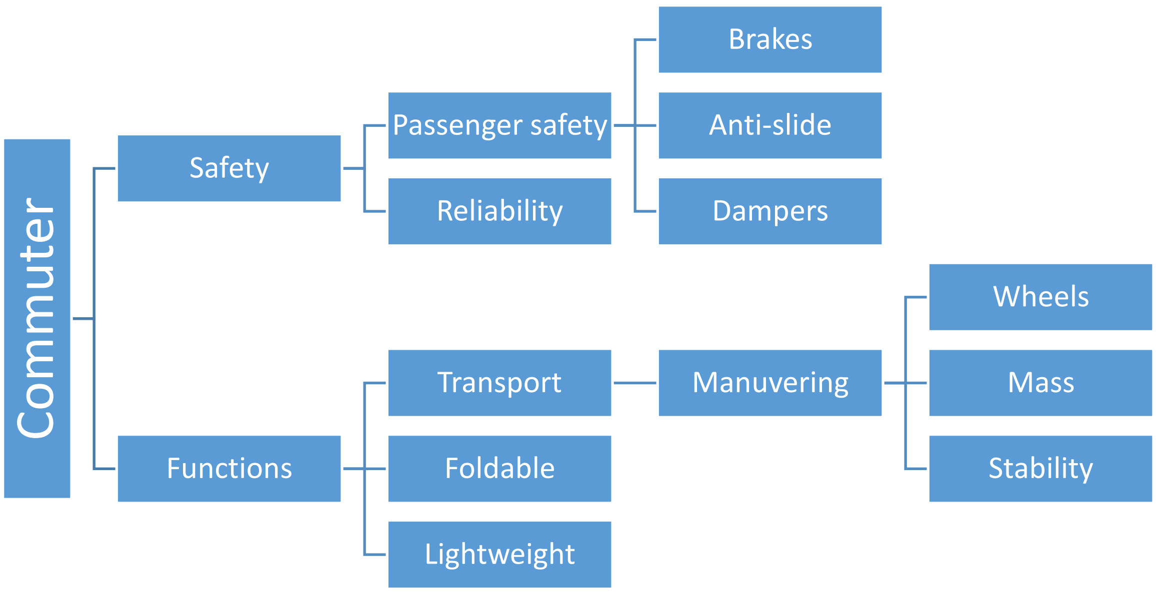


Figure 1: Nigel Cross`s objective tree. Created by Word SmartArt.

Functions

By using the theory based of “the black box” principal, you input in one side and extract outcome on the other side. The requirements will be about the commuter itself, no other variables will be accounted for.

What needs to function to make the commuter foldable, carry-able and able to transport, see table 1.

Table 1 Description of each of the functions, gathered from the "the black box"

Function	Description
Sustain loads	The ability of the commuter to hold the required weight without the structure failing.
Maneuverability	The ability of the commuter to steer and control.
Reliability	How reliable the commuter is with respect to its utilities and the function of these.
User safety	The ability of the commuter to keep the customer safe while utilizing it.
Comfort	How comfortable the commuter is to ride.
Foldability	The ability of the commuter to fold.
Stability	The ability of the commuter to hold balance while being in activity.

Physical requirements

The commuter is intended to be used as a downhill transportation from the mountain, but also be able to utilize within the city limits. Its intended use would be at the summer, but can be used at winter times as well. The material therefore needs to be able to endure the harsh arctic environment and the summer.
Climatic requirements
-Temperatures varying from -50°C to 40°C
- Ice, rain, sun, mud

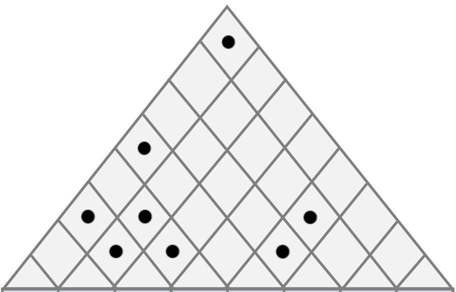
Since the commuter is supposed to be carried by the user it is important that the total mass of the design should be around 5 kg. Most people who venture atop mountains is within the assumption that the person is in relative good physical health.
The average weight of men of military age in Norway in 2010 were 76 kg [1]. In addition to the persons, they might carry some heavy backpacks that have to be transported as well. From this the commuter`s design should withstand a load of 100kg.
Additionally, the commuter would have to be steered and used to balance the person using it; this will apply a force to its handlebars. The load the handle bars will need to withstand is 50kg backwards and forwards, and a 10kg mass vertical on the handlebar.
The board is designed this way that the some of the dampening will be absorbed through the honeycomb structures of the board itself. The wheels will supply the rest of the dampening that is required to soothe the bumpy ride. From the standards, the board also need 200 cm^2 of anti-slide. This requires the board to be 10*60 cm in areal.[2]

Table 2 Shows the physical requirements the product must uphold

Requirement	Minimum	Maximum
Weight of commuter	-	5 kg
Load weight	-	100 kg
Length board	-	60 cm
With board	-	10 cm
Temperature	-50°C	40°C
Foldability	Yes	Yes

Determining Characteristics

To ascertain the importance of the engineering characteristics of the product it is necessary to get overview of the relations between the customers' demands and the specifications of the product. This is obtained by using the "Quality Function Deployment Analysis" (QFDA) (Cross, 2008). The method results in a "House of Quality" (HOQ) where the specifications are rated after the relevance to the demands for the product, and the characteristics are determined.
In Figure 2, HOQ is presented and shows the strength of the handlebar and the stiffness of structure are the most important characteristics of the commuter. In the mid table the objectives (blue) are related to the engineering characteristics and rated from 1-3 on the relationship between them, where 3 is the strongest relationship. The objectives are weighted (orange column) based on the importance where 0 is worst and 10 is most important. In the summation, the rank and the weight are multiplied and summed up.
On the top of the table the engineering characteristics (red) are compared to each other, and marked with a black dot if they are related.



	Weight	Total Mass	Strength handlebar	Dampening handlebar	Stiffness of structure	Size of board	Stiffness of board	Strength board	Dampening board
Sustain loads	9		2	3	2	1	2	3	2
Maneuverability	6	2	1	1	2	1	2		1
Reliability	7		3		1		1	1	
User safety	5		2	1		2		2	1
Comfort	3			3		1	1	2	3
Easy to operate	4	3			1	2	1		
Foldability	8	1	2		2	2	1		
Stability	6	3		1	3	2	1	1	3
Unit		kg	Pa	Pa	mm/g	mm	mm/g	Pa	Pa
Sum		50	**71**	**53**	**75**	**64**	**58**	**56**	**56**

Figure 2: House of Quality, Quality Function Deployment, made in Word

Alternatives

To generate different design alternatives a morphological chart is made. A morphological chart is a chart where the options for each part of the design are created, and several designs are made from the different options. The created design will eventually be evaluated to find the most optimal design.

One of the key attributes of the design will be its foldability, and the design determines how it is folded. In the available options the neck will be taken advantage of as the foldable part, due to its placement.

The options are made by researching the known products on the market and mixing them up with some innovative solutions.

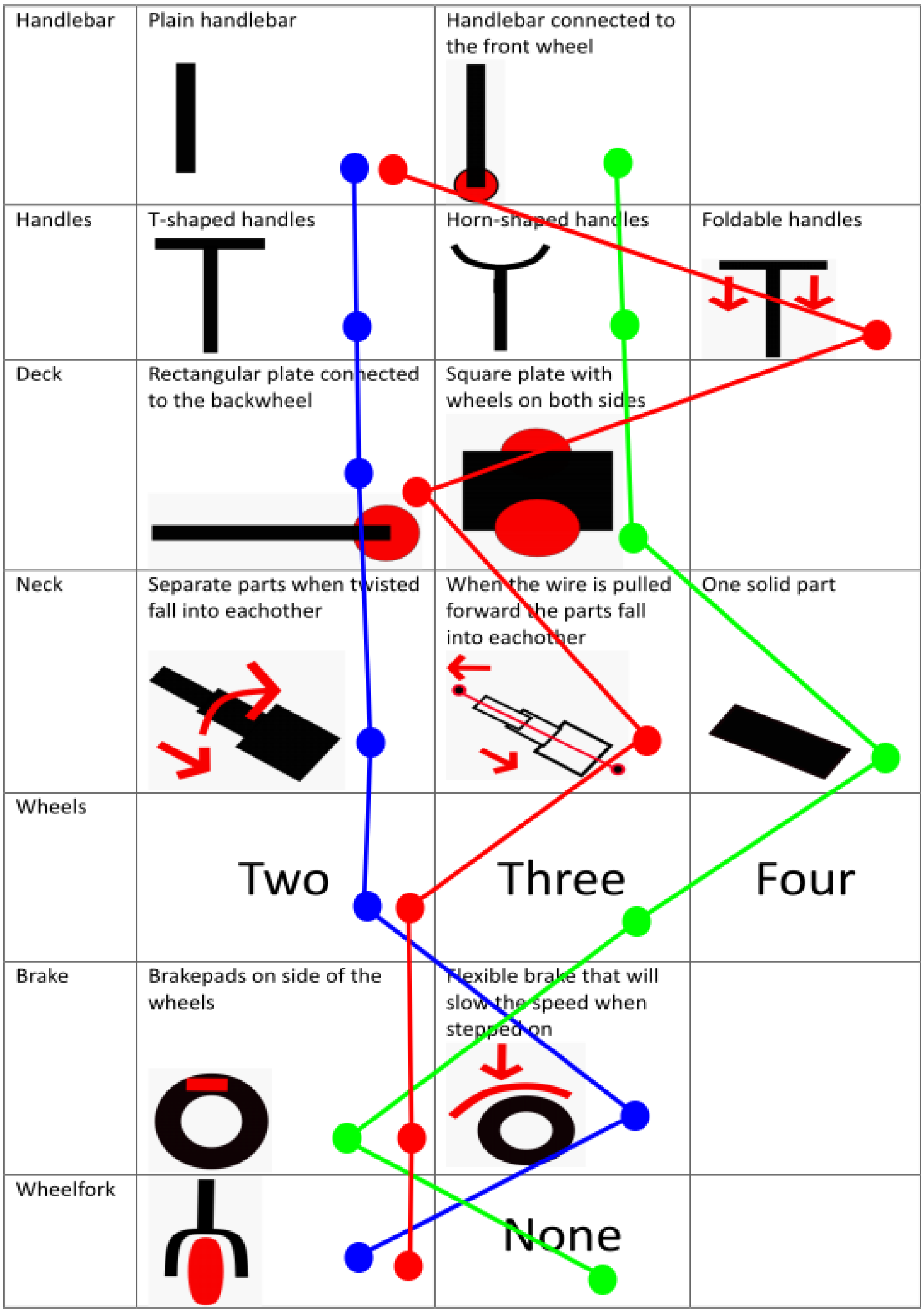


Figure 3: Morphological chart, created with Inkscape

Evaluation

The evaluation of alternatives is done by the weighted objectives method, see table 3. This is made by rating each of the alternatives with respect to function and calculating by the functions importance. Each functions importance rank is divided by the sum of all the functions ranked in the Quality Function Deployment, see figure 2.

The alternatives are ranked from 1 to 5:

1. Inadequate
2. Weak
3. Satisfactory
4. Good
5. Excellent

These numbers represent how well they fulfilled each of the functions. The alternatives rank are calculated with respect to the functions importance and the alternative with the highest sum is the most optimal design, see table 3.

Table 3 ranking the different alternatives of concepts to each respectable function

Functions	Red	Blue	Green	Importance
Sustain loads	4	4	2	0,1875
Maneuverability	3	3	4	0,125
Reliability	3	4	2	0,1458
User safety	3	3	4	0,1042
Comfort	3	3	4	0,0625
Easy to operate	3	4	3	0,0833
Foldability	3	4	1	0,1667
Stability	2	3	3	0,125
Total Sum	3.0625	3.5833	2.6250	1,00

The blue alternative ends up with the highest scoring of the three.

Details

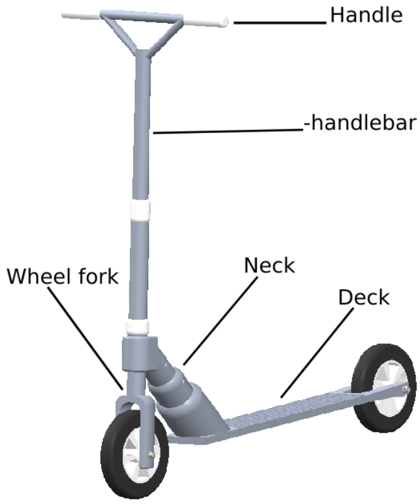


Figure 4: Showcases the different part of the design the project will focus on. Made with InkScape

Handles
The handles are the widest point of the design, which is why the length of the handles is to be considered. The greater length of the handles the more comfortable the scooter is for the user.

Figure xx shows that minimizing the size of the scooter is of more importance than the comfort. It is decided to set the handles at 400 mm in total length. This is a compromise between size and comfort, because the user will not have difficulties to turn and the length is not especially large.

The outer handle diameter of the handles are set at 22 mm because it will fit most grip handles on the market. This gives the customer variability to change his/her commuter to their preferences. This can be bought at most online sites like amazon & eBay.[3]

Handlebar
The handlebar height is possible to adjust to each customer by themselves. This gives the product more viability to be used by a wide verity of people, being short or tall. The outer diameter on the handlebar was designed to be 32 mm, this was done because it is the most used by other types of kick scooters, so the customer does not need to buy costume items that make the commuter more available.

Handlebar is height adjustable, due to a twisting cap on the bar, which tightens and loosen the wheel fork on to the handlebar

Wheel fork
The inner diameter is 32 mm so the handlebar fits within the wheel fork. Indre diameter satt til 32mm så handlebarn passer inni

Wheel
The wheel diameter

The wheel is optimized for having big wheels to enhance the dampening and the comfort of the customer. Diameter of the wheel is 205mm and its width is 33mm. [4]

Board
The board has the dimensions of 600 mm length and 100 mm width. The width is to give the customer a better ability to steer the commuter and more manuverability, though this would decrees the comfort of the commuter. The structure of the board is that of a honeycomb, this was created to alleviate as much mass as possible and increase the stiffness as per the request of the objectives.

The neck is connected to the board/deck and is foldable. The fold happens with help of a pattern in the neck parts.

Material selection
The engineering program CES Edu Pack is used to make the material selection. This is done by using level 1, level 2, and level 3 of the CES Edu Pack in chronological order. Each level becomes more and more detailed which is crucial to make the most appropriate material choice.

The material indices M_1 and M_2 will be put into yield strength – density and Young's modulus – density charts in all levels.

The material selection for the handlebar and the deck will be done separately.

Neck

The neck is looked upon as a rod with pressure points on each end, see figure 4.

Figure 5: Tie rod illustration, made with Inkscape

The material indices must be found with the help of the mass $m = AL\rho$ and the yield $\frac{F}{A} \leq \sigma_f$.

Where $\rho = \frac{m}{V} = \frac{m}{\pi r^2 L}$, and r^2 is found with:

$$r^2 = \frac{m}{\rho \pi L}$$

$$r^2 = \frac{F}{\pi \sigma_f}$$

$$\frac{m}{\rho \pi L} = \frac{F}{\pi \sigma_f}$$

The material indices is found with regards to the mass m.

$$m = FL\left(\frac{\rho}{\sigma_f}\right)$$

Thus the material indice $M_1 = \frac{\sigma_f}{\rho}$.

[5]

Material indice M_2 is found with the help of the mass and the max deflection $\delta = \frac{FL}{AE}$. Where r^2 is found and the material indices is found with the mass.

$$r^2 = \frac{FL}{\pi E \delta} = \frac{m}{\pi L \rho}$$

$$m = FL^2\left(\frac{\rho}{E}\right)$$

Thus the material indice $M_2 = \frac{E}{\rho}$.

[5]

Level 1

A yield strength – density chart is used to make the first eliminations of the process. An arbitrary line made by M_1 is placed on the chart to eliminate most materials, but still leave some options left.

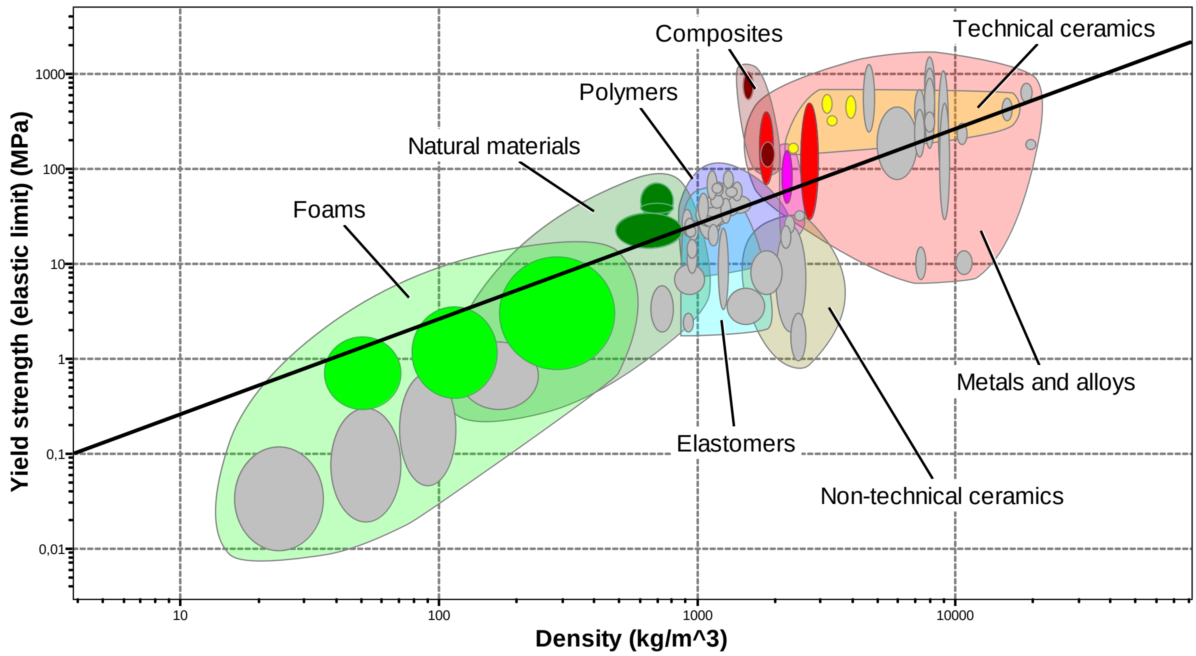


Figure 6: Illustrates the materaials within the requirement with respect to Yield strenght and Densisty, made by CES EDUPack

M_2 is set on the Young's modulus – density chart to eliminate further options.

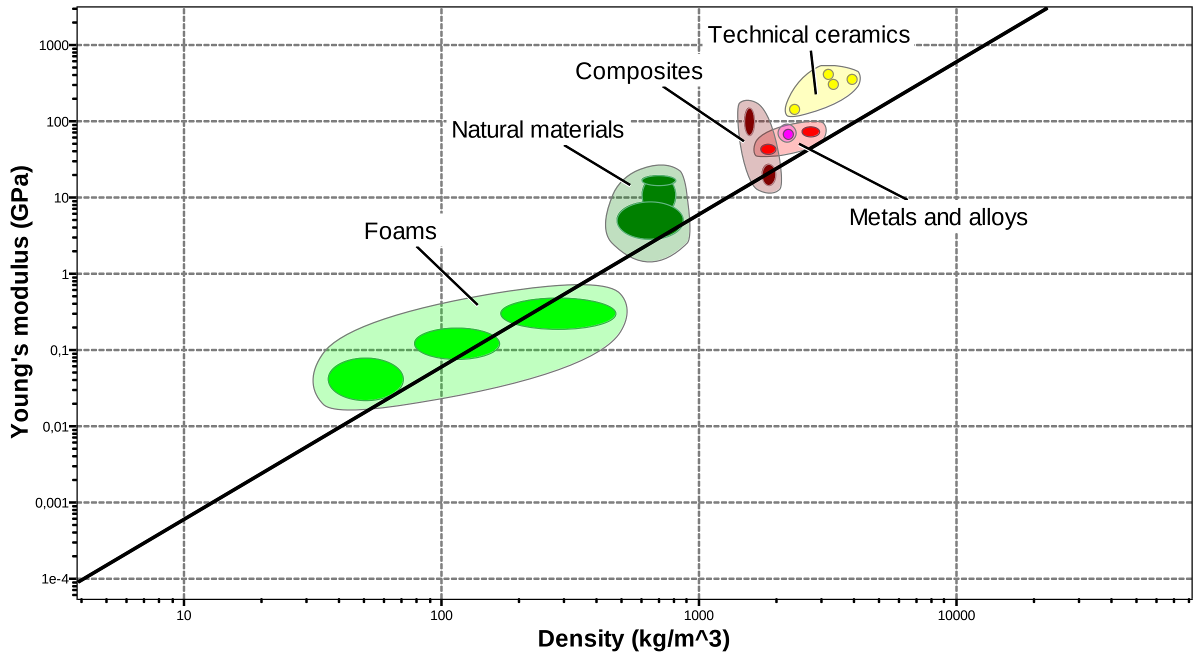


Figure 7. Illustrates the young modulus vs density to further eliminate materials. Made with CES EduPack

Finally the materials are sorted by price, to find the most cost effective materials, as there are quite a few options left. The price limit is set at 100 NOK/kg.

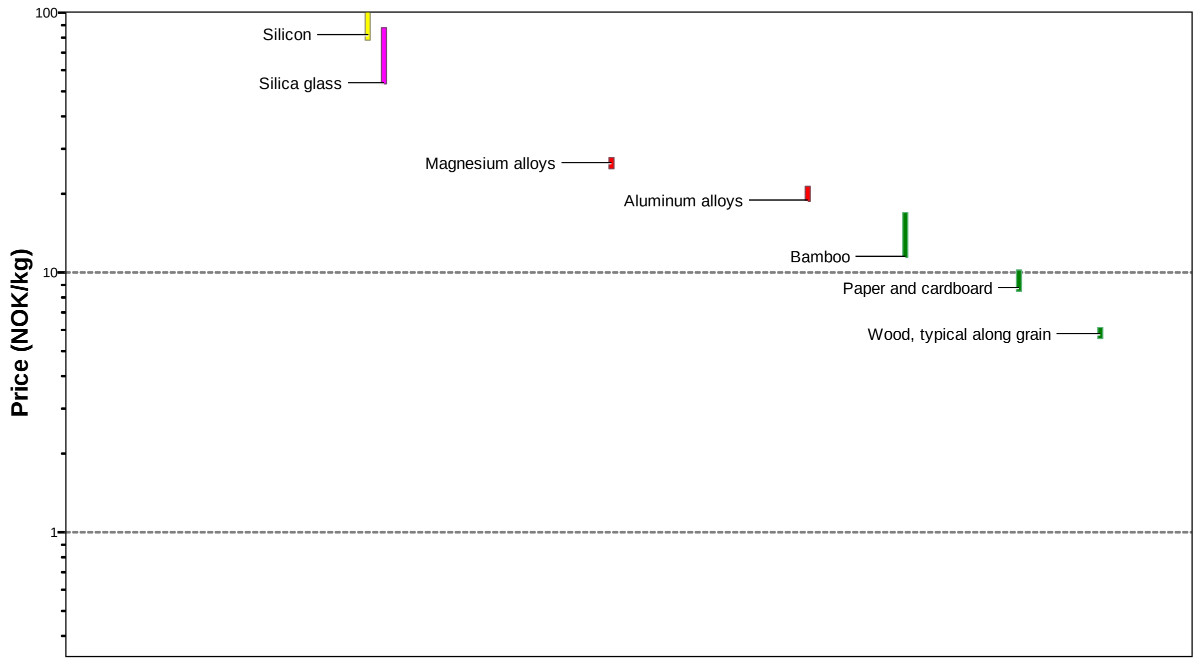


Figure 8: To further eliminate materials the cost of each material is weighted. Made in CES EduPack

To finalise level 1 there are two realistic material options left, magnesium alloys and aluminium alloys. Magnesium alloys are more lightweight than aluminium, while aluminium is the most cost effective option of the two.

Level 2

For level 2 only «magnesium and alloys» and «aluminium and alloys» are left, and the differences between them are evaluated.

The yield strength – density chart eliminates further materials within both material options, with the help of material indice M_1.

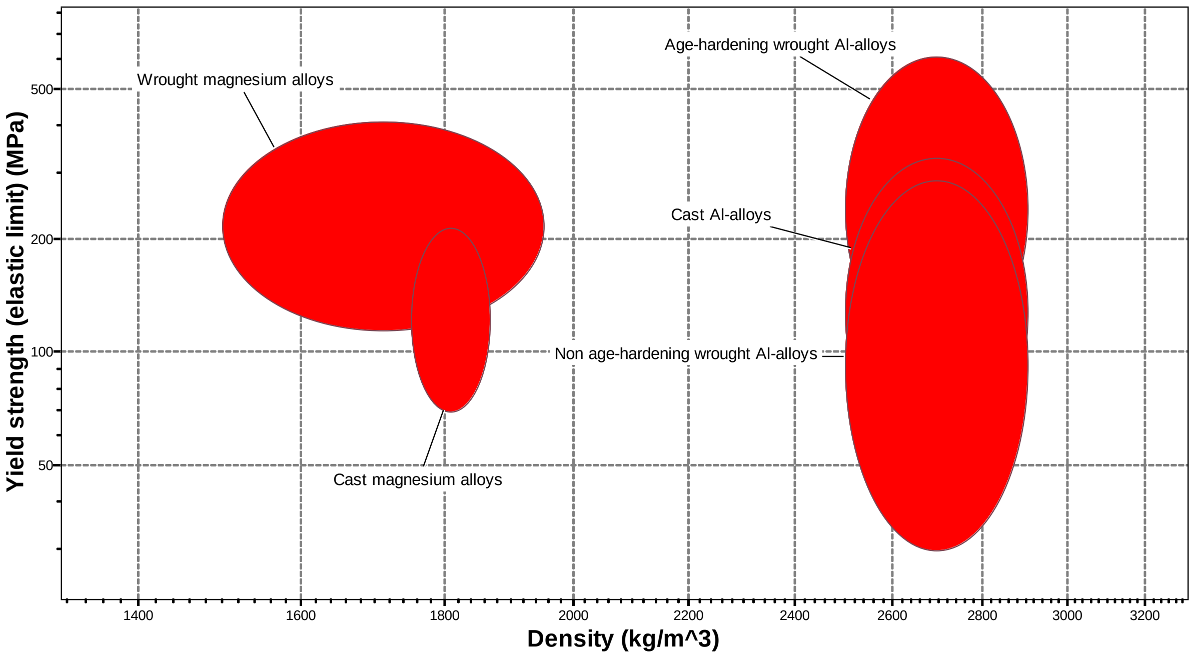


Figure 9: Level two of material selection, only remaining are magnesium and aluminium alloys, made with CES EduPack

The yield strength – density chart shows that magnesium alloys has the same elastic limit as the aluminium alloys, but magnesium alloys are more lightweight.

Next step is to insert M_2 into the Young's modulus – density chart, to eliminate options further.

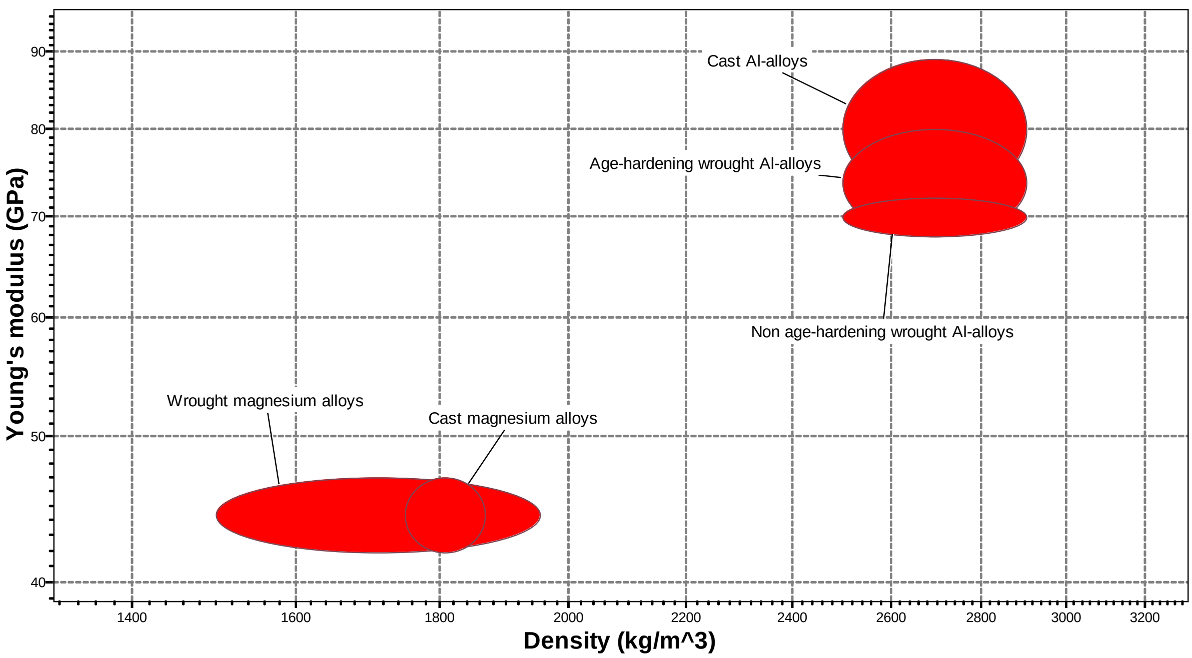


Figure 10: Continuing to look at the two materials using Young's modulus vs density, made with CES EduPack

The Young's modulus – density chart shows that magnesium alloys handles compressive forces worse than aluminium alloys, which is known through the lower E-module of the magnesium alloys.

The magnesium and aluminium alloys are evaluated to find the most appropriate material. The aluminium alloys has greater strength in total, greater density and is more cost effective. To put the lack of strength of the magnesium materials into consideration, the wall thickness would have to be thicker than for the aluminium alloys, therefore the gain in mass would be minimal.

It is decided to continue the elimination process with the aluminium alloys and look at the cost of the different alloys.

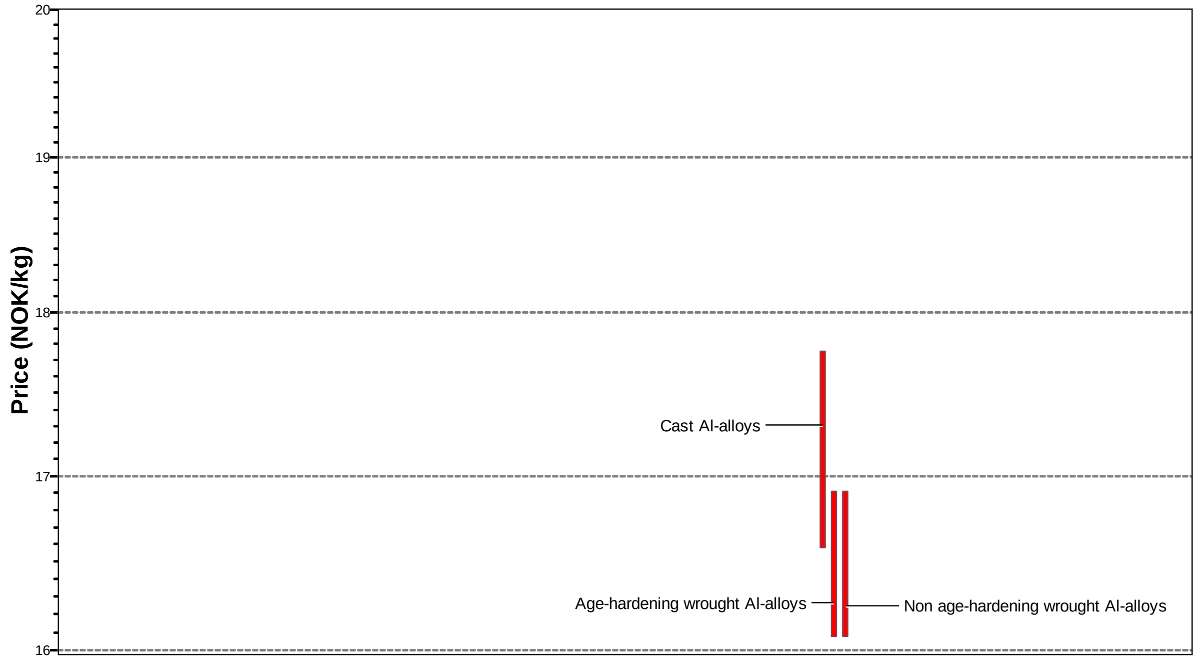


Figure 11: A final check to see what divides the two materials between each other. Made with CES EduPack

The price chart shows that cast Al-alloys is the least cost-effective, while Non age-hardening Al-alloys has the lowest yield strength and Young's modulus. The non age-hardening Al-alloys will therefore demand a greater wall thickness than the other two options. The cast Al-alloys has the greater Young's modulus, while the age-hardening Al-alloys has the greater tensile strength, thus the non age-hardening Al-alloys are eliminated.

The cast Al-alloys and the age-hardening Al-alloys are put into level 3 for further evaluation.

Level 3

Start level 3 with the same procedure as in level 1 and level 2. M_1 is put into the yield strength – density chart to eliminate options.

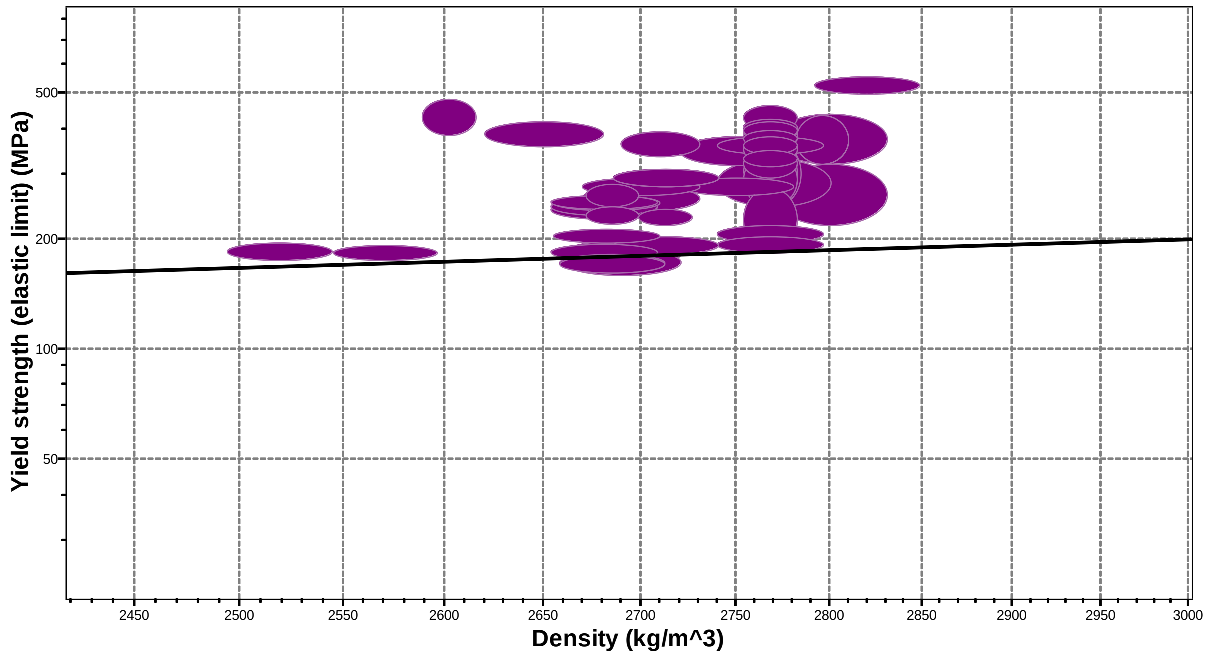


Figure 12: At the level three step where the materals can be seperated, made by CES EduPack

Step 2 is to put M_2 into the Young's modulus – density chart and eliminate further options.

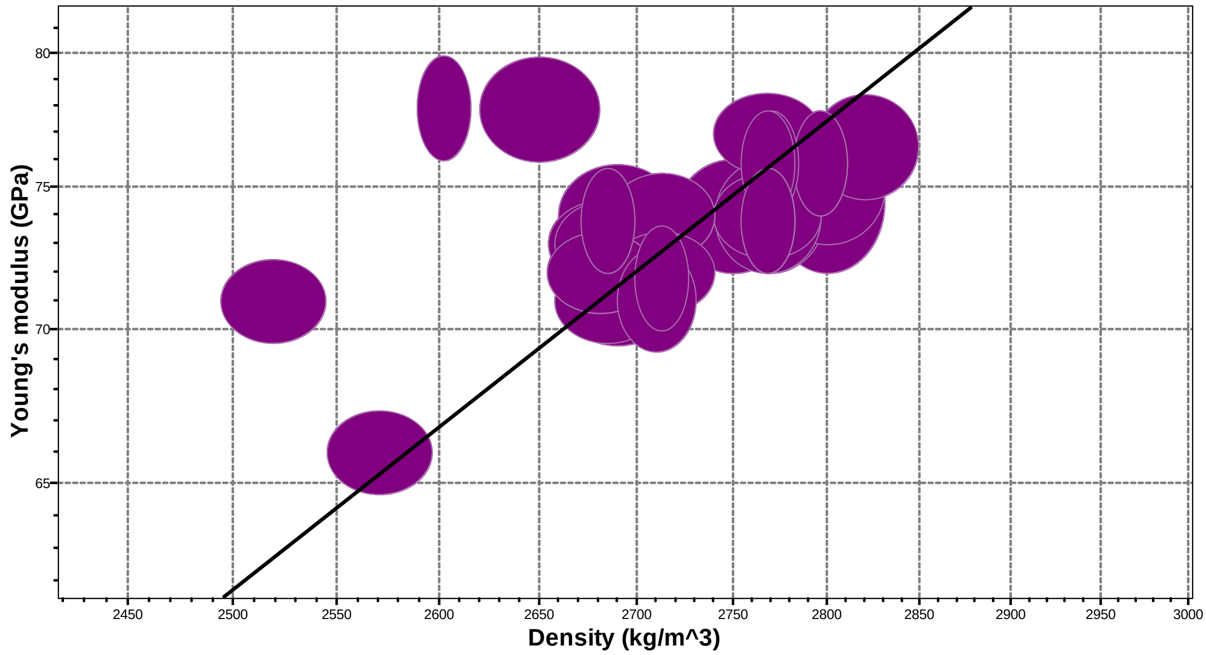


Figure 13: Utilizing the material indices to further eliminate the unwanted materials. made with CES EduPack

After the first rounds of elimination there are still more than 50 options left.

Next is to consider the production methods. Much of the design consist of solid and hollow rods, it is desirable to extrude these kind of designs for mass production. It is profitable to heat treat the material, unlike cold extrusion, due to the energy usage.

To eliminate options «metal hot forming» is set as a criteria for the material. Metal hot forming is a process that heat the metal and put it under pressure to form the metal into the desired design. This method is energy effective as there is relatively low pressure needed to alter the metal. Metal hot forming includes processes such as extrusion, molding, forging, and more.

[6]

With «metal hot forming» as a criteria the material indices M_1 and M_2 with the yield strength – density chart and the Young's modulus – density chart are considered yet again.

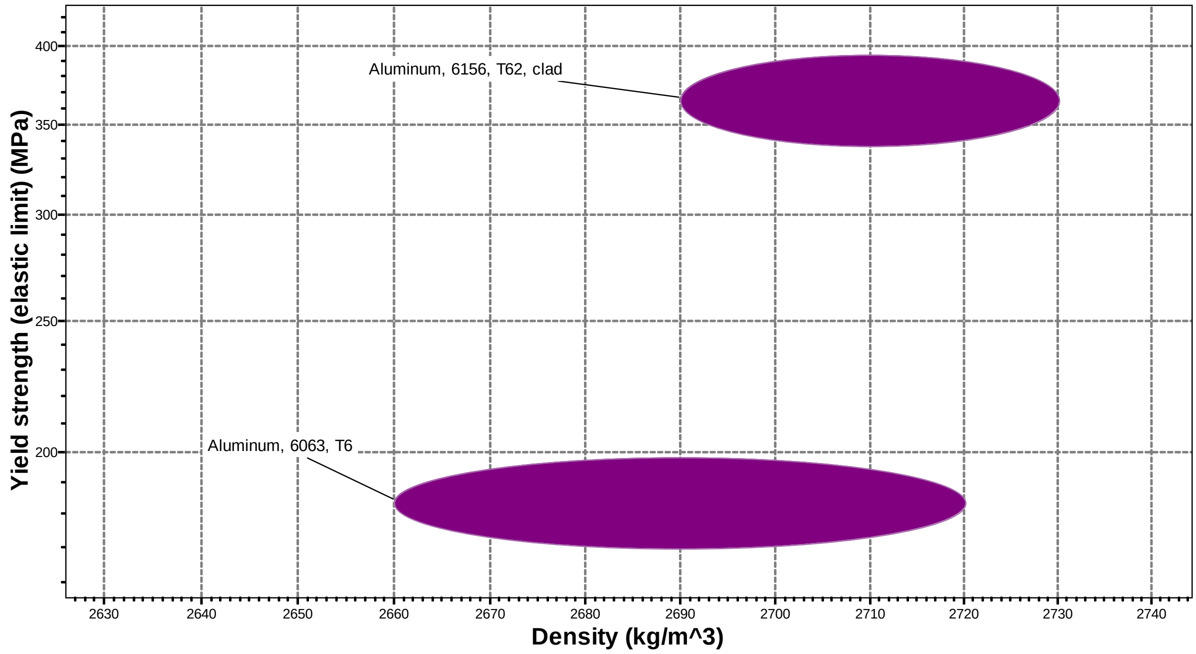


Figure 14: Two final materials within the parameters of Yield strength and Density, made with CES EduPack

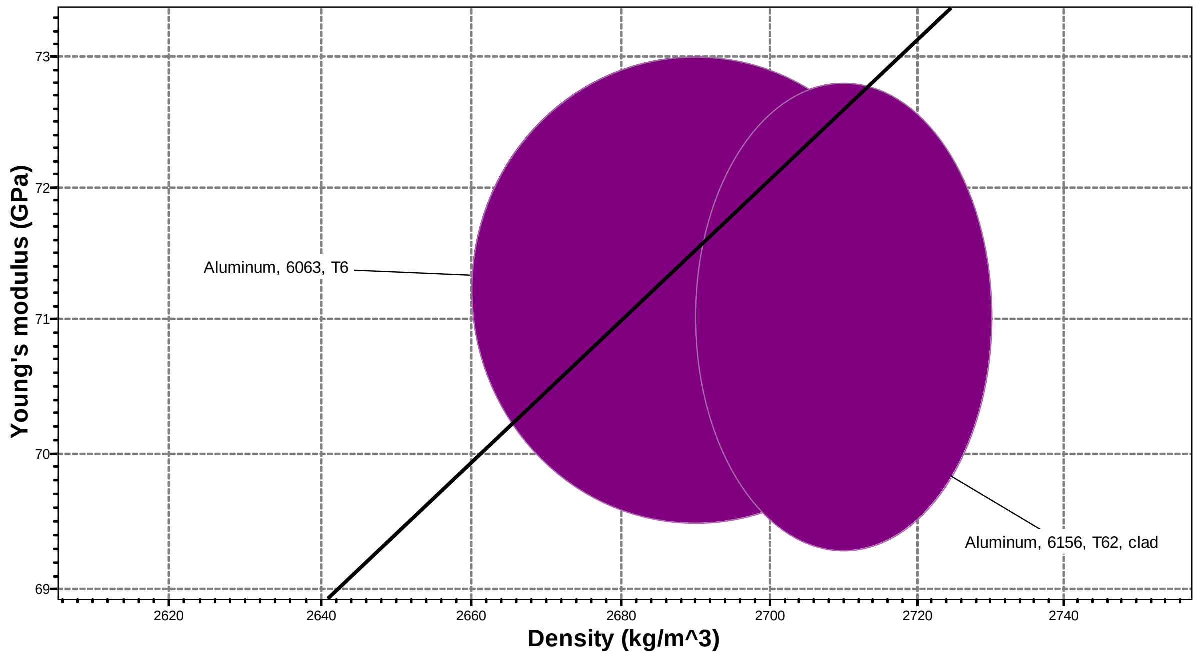


Figure 15: Final two materials, made by CES EduPack

There are only two aluminium alloys left that fit the demands: 6063 T6 and 6156 T62 clad.

To finalise the elimination process price has to be considered.

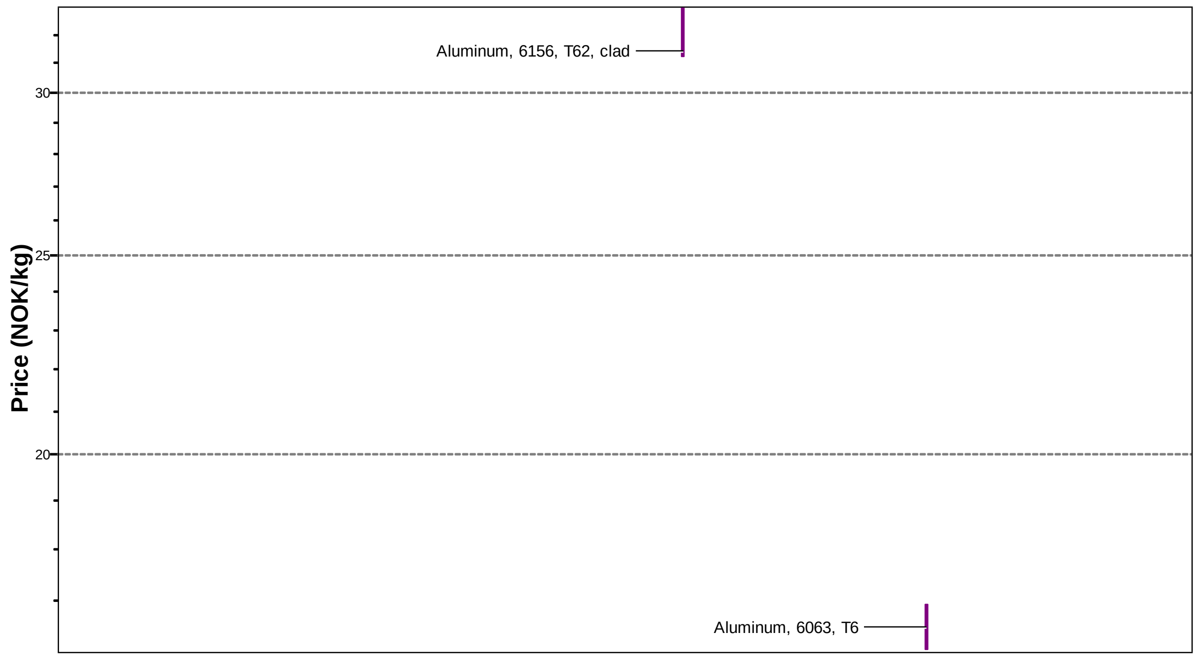


Figure 16: Once you look at the price there is no reason to go with the more expencive and weaker material. Made with CES EDUPack

Table 4 Highlights the differences between two of the remaining materials.

Materiale	Tetthet [kg/m3]	Emod [GPa]	Yield [Mpa]	Pris [NOK/kg]	Typical uses
6063 T6	2,66e3-2,72e3	69,5-73	170-198	16,1-16,9	Pipes, railing, hardware, architectual uses, structural frames, pylons, towers, bridges, decoration, furniture, door & window frames
6156 T62, clad	2,69e3-2,73e3	69,3-72,8	338-394	31,2-33	Aircraft components such as fuselage panels

There are some differences to the two remaining materials. 6152 T62 clad is especially developed for the aircraft industry, and it proves to be a lot stronger and less cost effective than needed for a downhill scooter.

The material of choice is Al-alloy 6063 T6, and will be used for the neck.

Deck

The deck is a honeycomb structure and the material selection process will be divided into face and core. The deck is simplified into a plate with a midpoint load, see figure 16.

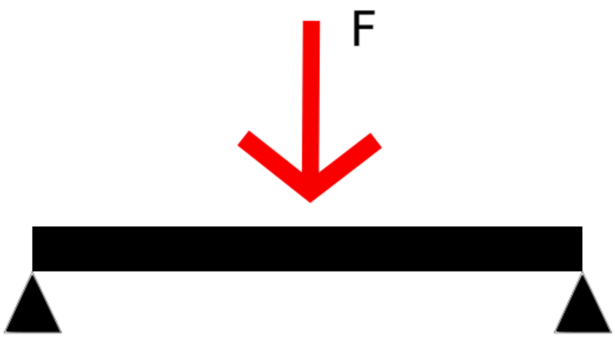


Figure 17: A simple plate with a point load, made with InkScape

The material indices M_1 is found from the mass, where $m = \rho twL$, and the max deflection, $\delta = \frac{FL^3}{48EI}$. F equals stiffness S and the second moment of inertia $I = \frac{wt^3}{12}$, which gives the stiffness $S = \frac{48E}{L^3}\frac{wt^3}{12}$. Next step is to find the thickness t.

$$t = \frac{m}{\rho wL} = \left(\frac{SL^3}{4w}\right)^{\frac{1}{3}}$$

Finally it is needed to find the mass m to get M_1.

$$m = \left(\frac{SL^3}{4w}\right)^{\left(\frac{1}{3}\right)} wL\left(\frac{\rho}{E^{\frac{1}{3}}}\right)$$

Thus $M_1 = \frac{E^{\frac{1}{3}}}{\rho}$.

[5]

$M_2 = \frac{\sigma_f^{\frac{1}{2}}}{\rho}$ is found in Michael Ashbys "Materials selection in Mechanical Design", Appendix B, table B 2.

To find the optimal material the same procedure as with the handlebar is used where M_1 and M_2 are set arbitrary into the Young's modulus – density chart and the yield strength – density chart.

Level 1

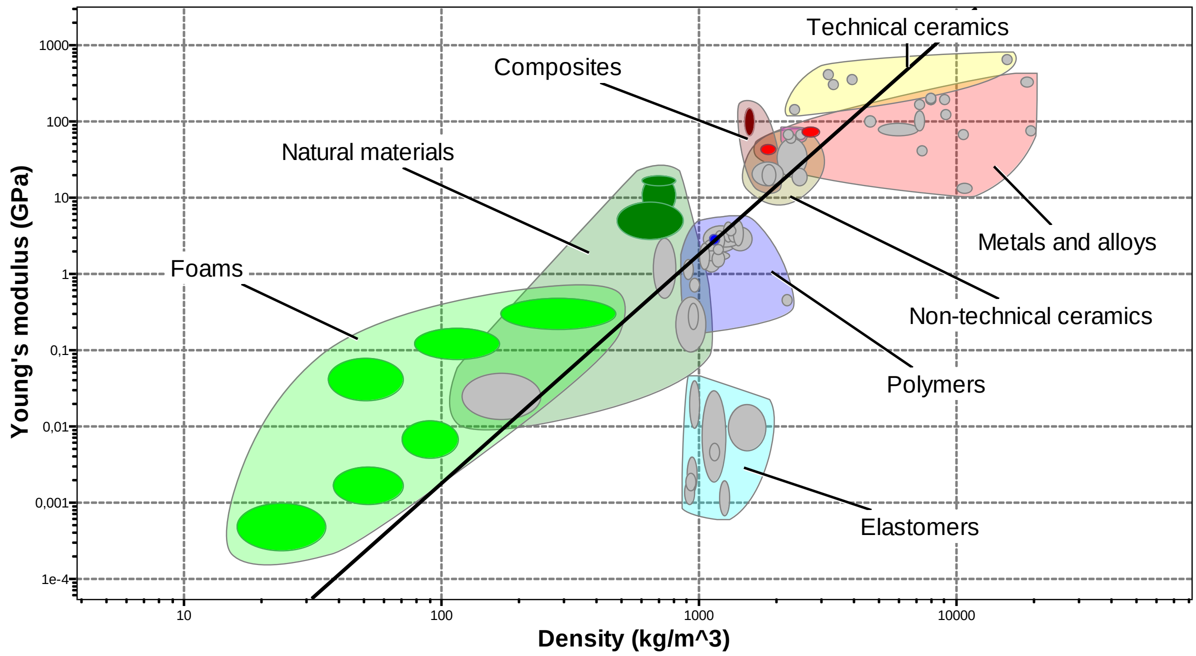


Figure 18: The different material indices are applied to filter out the unwanted materials. Made with CES Edupack

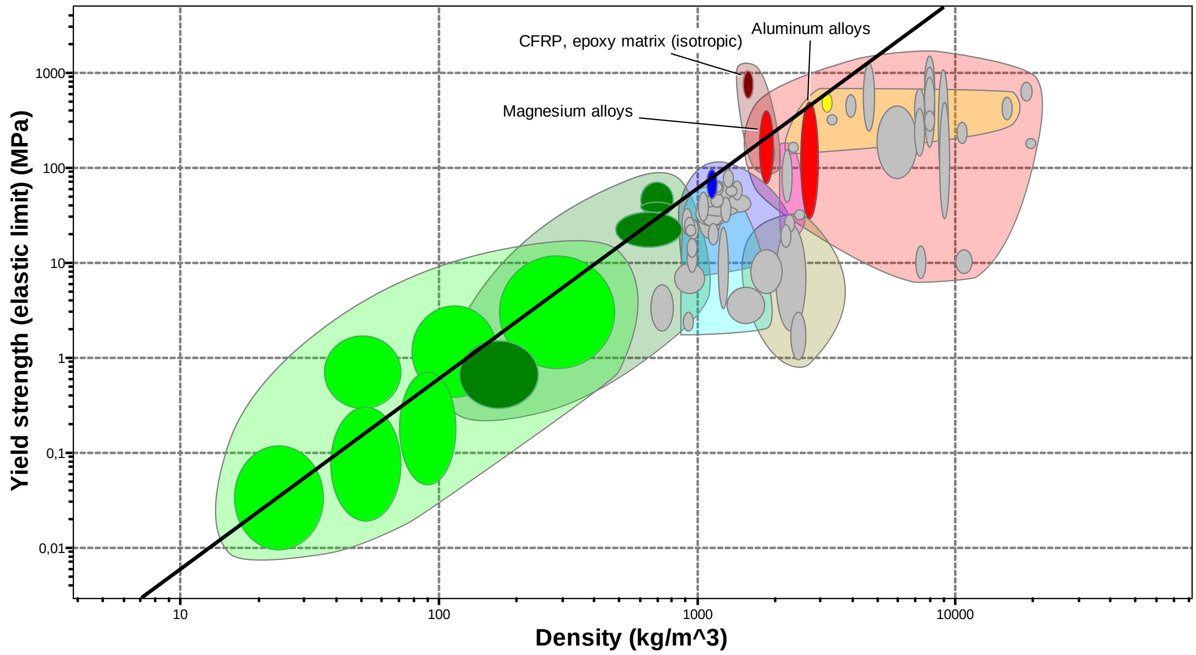


Figure 19: Same indices only this time looking at yield strength vs density, made with CES EduPack

From the first step of the process the Young's modulus – density chart and the yield strength – density chart shows that there are three realistic materials left: Magnesium alloys, CFRP and aluminium alloys.

Level 2

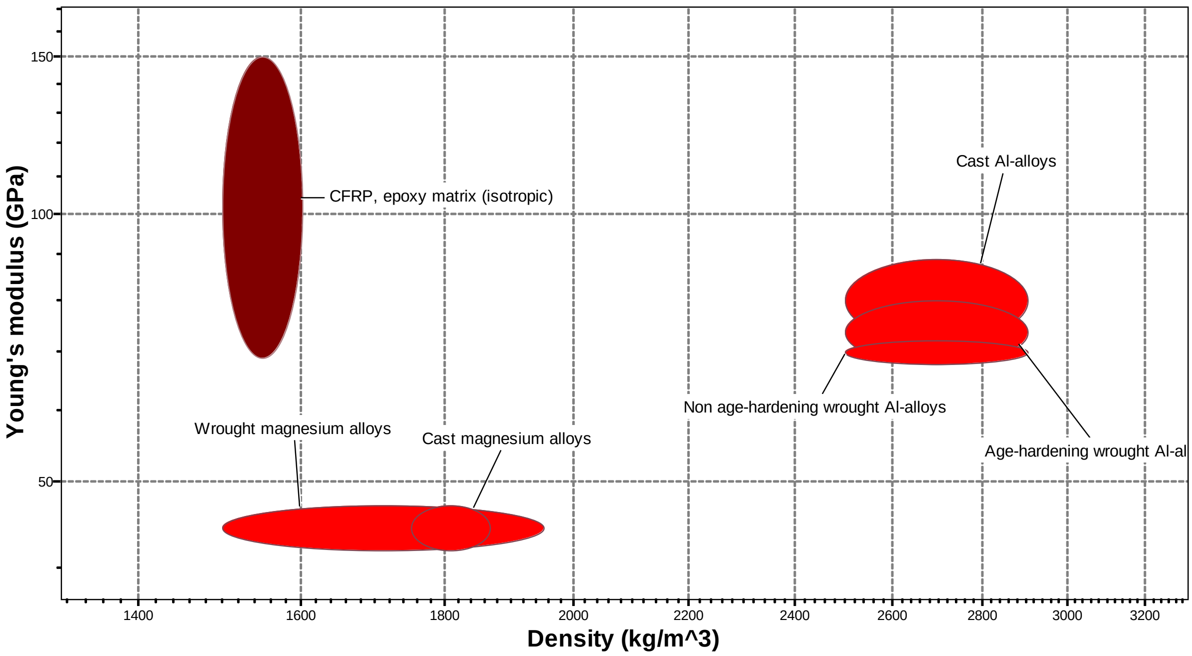


Figure 20: Level 2 dramatecly decreased the number of materials, made with CES Edupack

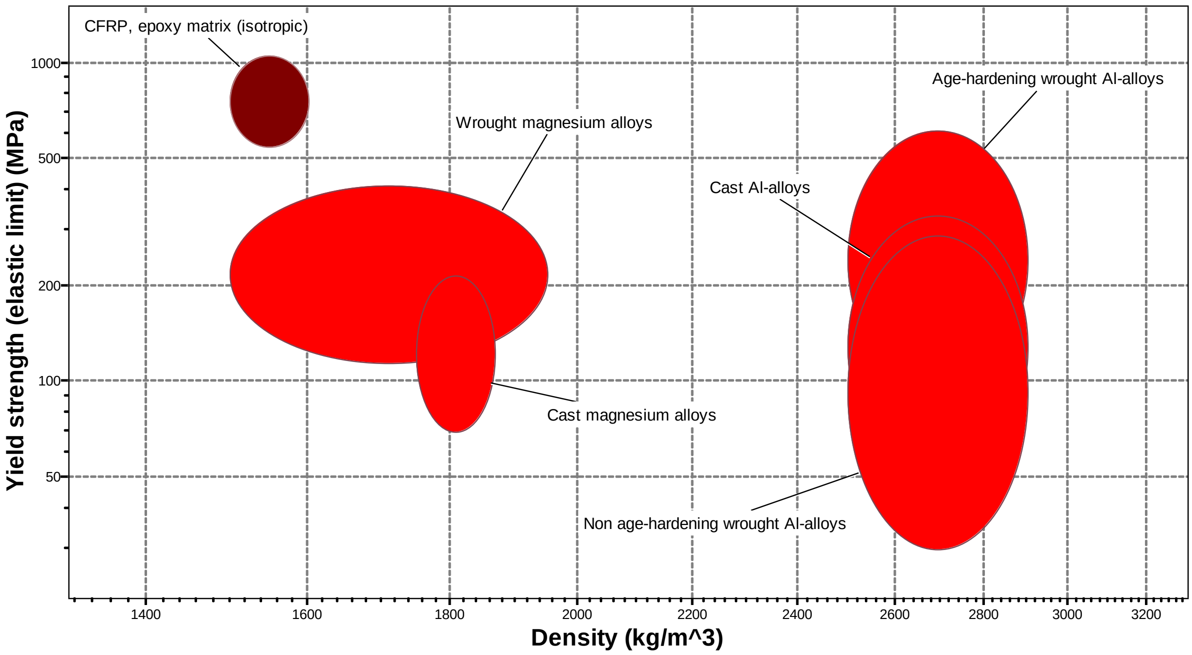


Figure 21: Materails are checked for yield strenght vs density. Made with CES Edupack

The charts show that CFRPs are stronger and more lightweight than both magnesium and aluminium alloys. The stiffness and strength of CFRP makes it an optimal choice for the face of the deck.

Aluminum is the chosen material for the core due to the available manufacturing methods for honeycomb structures.

Level 3

For level 3 the core and the face selections are done separately because different types of materials were chosen for them.

Core

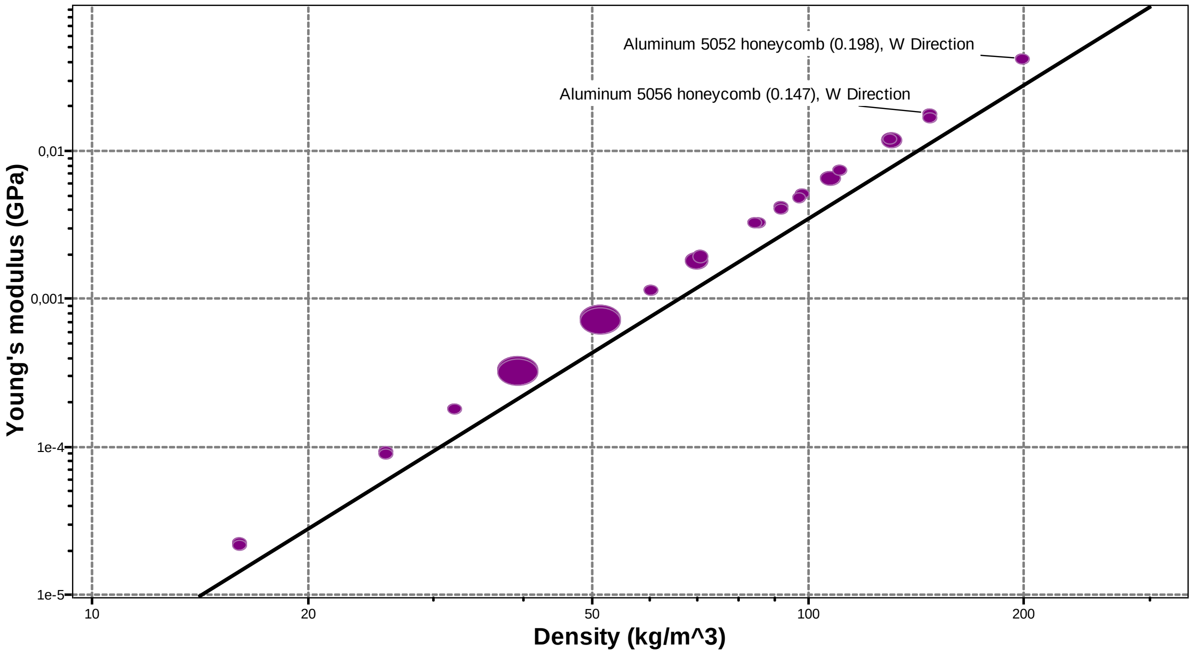


Figure 22: Yong`s modulus vs Density, made in CES Edupack

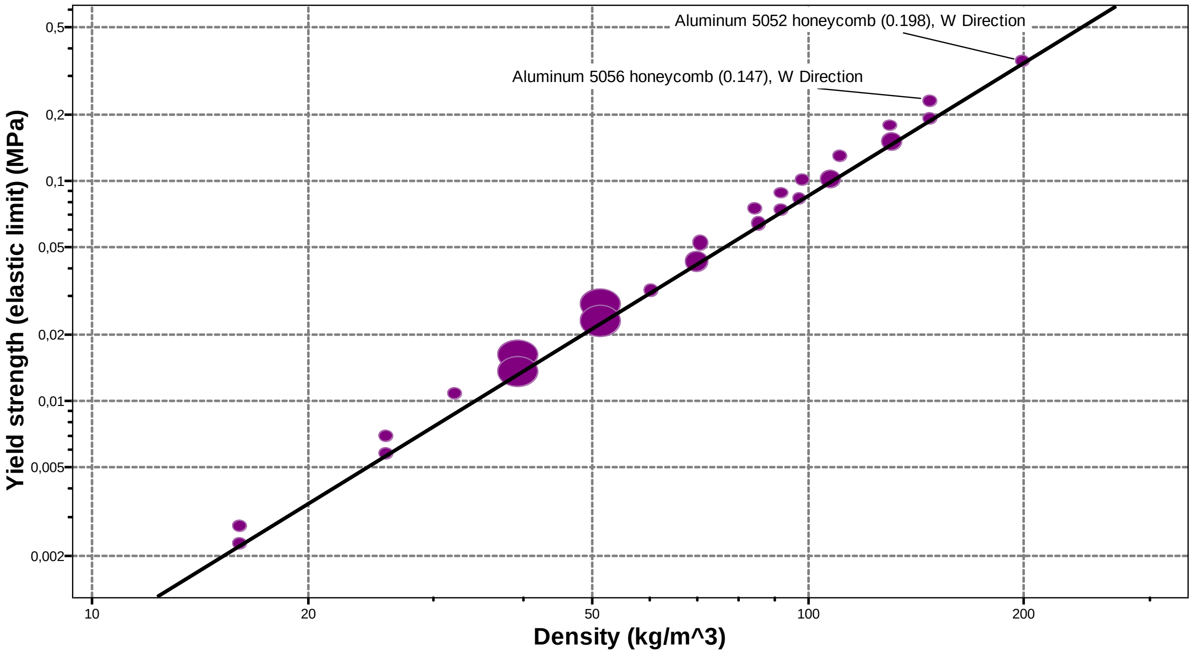


Figure 23: Yield strength vs density level 2, made with CES edupack

The charts show that Aluminium 5052 is the preferred material for the core due to its strength compared to the other options. Aluminium 5052 is a honeycomb structure with hexagonal cells and W-direction. When honeycomb structures are in W-direction it is perpendicular to where the cells have twice the wall thickness, also called the ribbon.

Corex is a producer of aluminium 5052 honeycomb structures and their most regular cell size are 12,7 mm x 9,5 mm x 6,4 mm. These dimensions will be used as base for further computations.

[7]

Face

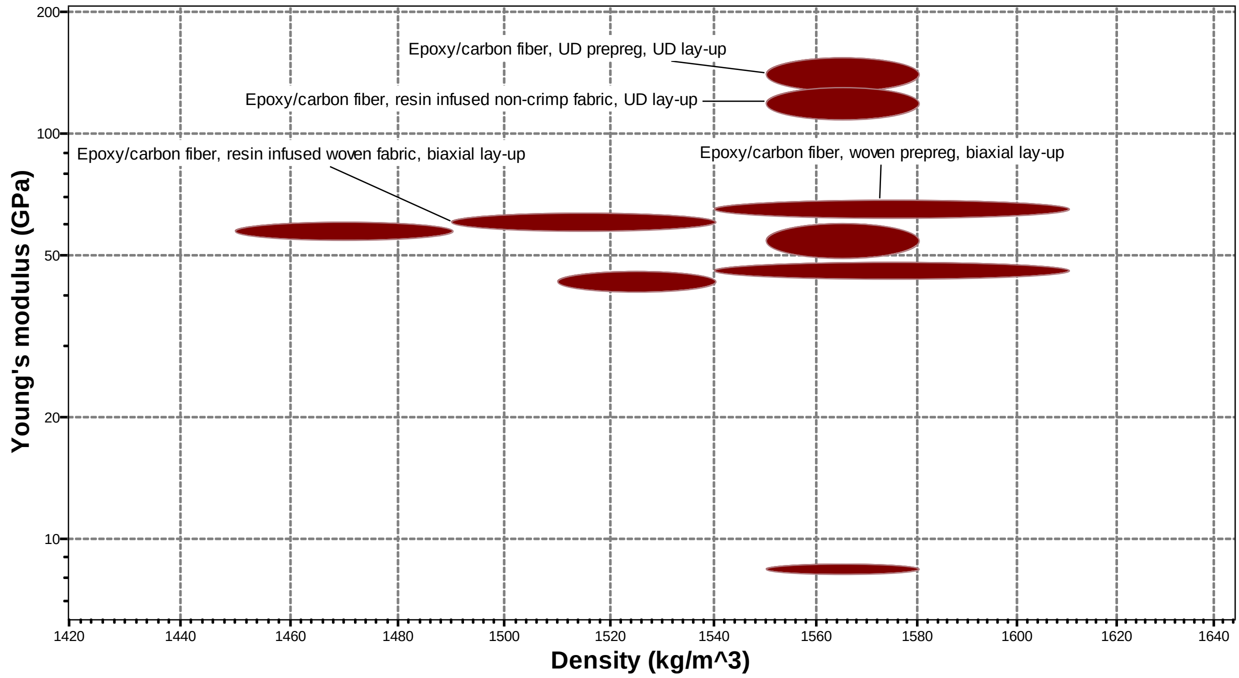


Figure 24: Young`s modulus vs density, made with CES edupack.

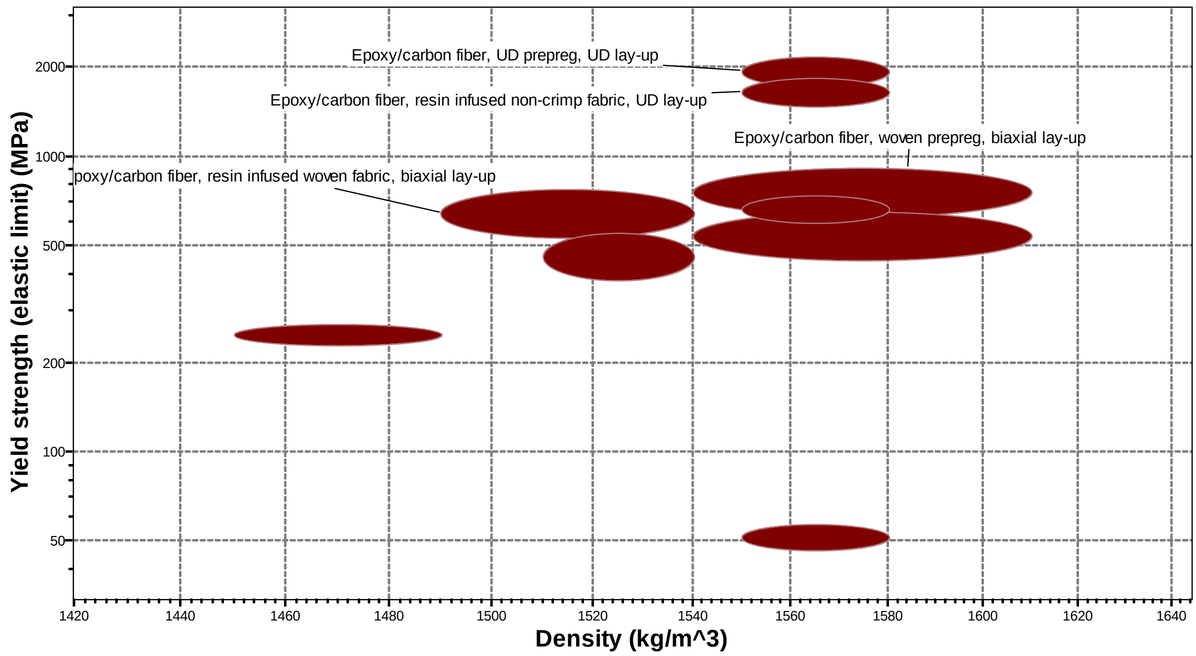


Figure 25: Yield strength vs Density

For the face the carbon fibre reinforced polymer material Epoxy/carbon fibre with unidirectional prepreg and lay-up is the material of choice. Its unidirectional lay-up makes it possible to customize the material strength to where the design is most exposed. The material is the most strength in the direction the carbon fibres are layed up, and unidirectional carbon fibres can be layed up in several direction, layer by layer, to fit the need of the usage. This way the material can be customized to handle specific forces and force directions, thus decrease the volume and mass.

The handlebar and handles will be made by epoxy/carbon fiber. An iteration has been made after the scooter design exceeded the max weight, see Appendix 4. The wheel fork and neck will hold the original material due to the production and good machinability properties of the aluminium 6063 T6.

Dimensioning

To optimize the scooter, with regards to design thickness and mass, the dimensions has to be computed. The computations will consider the material properties and the set dimensions, such as length and width, to find the optimal thickness.

The computations will find the critical compression forces and the elastic limit of the materials to set the thickness. Where the compression is found with Eulers buckling, $P_{cr} = \frac{\pi^2 EI}{L^2}$, and the elastic limit is found with the yield $A \geq \frac{F}{\sigma_f}$.
[8]

Handlebar

From the requirements a load of 50kg has to be applied to the handlebar backwards and forwards, and a mass of 10kg downwards on the handlebar, see figure 26.

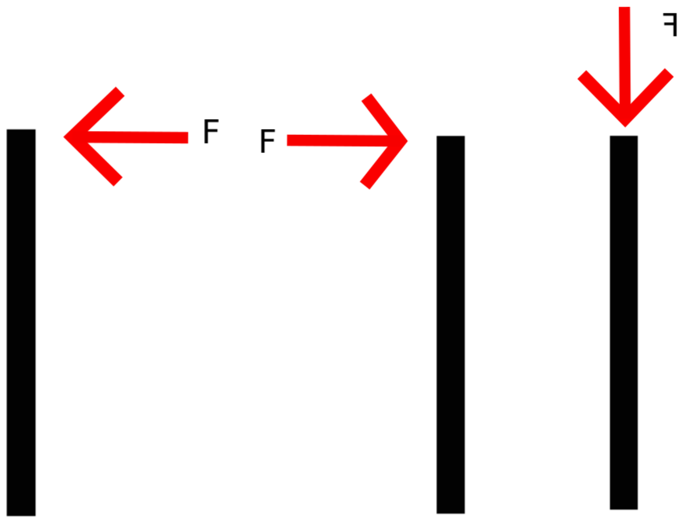


Figure 26: Showcases the different forces the handlebar should withstand, created by InkScape

Case 1 where 50kg is applied forward from the handlebar it is needed to find the force F.

$$F_x = 50kg * 9{,}81\frac{m}{s^2}$$

$$F = \frac{F_x}{cos\alpha} = \frac{50kg * \frac{9{,}81m}{s^2}}{cos83} = 4024{,}8N$$

Case 2 where a force of 50kg is applied backwards from the handlebar it is needed to find F.

$$F = \frac{F_x}{cos\alpha} = \frac{50kg * \frac{9{,}81m}{s^2}}{cos97} = -4024{,}8N$$

Case 3 has a load of 10 downwards onto the handlebar and the same procedure is used to find F.

$$F = \frac{F_y}{sin\alpha} = \frac{10kg * \frac{9{,}81m}{s^2}}{sin83} = 98{,}84N$$

From the calculations it is known that case 1 and case 3 has forces in the same direction, while case 1 and case 2 has the same amount of force onto the handlebar. Thus case 3 is neglected.

The yield and the Eulers buckling is needed to determine the inner and outer diameter of the handlebar. Yield is found through the equation $A \geq \frac{F}{\sigma_f}$, where σ_f is 170 MPa.

$$\frac{F}{\sigma_f} = \frac{4025{,}8N}{1740MPa} = 2{,}3\ mm^2$$

$$A = \pi\left(r_o^2 - r_i^2\right) = 2{,}3mm^2$$

$$r_i^2 = r_o^2 - \frac{2{,}3mm^2}{\pi}$$

$$r_i = 16mm - \sqrt{\frac{2{,}3\ mm^2}{\pi}} = 14{,}7\ mm$$

Eulers buckling is found through the formula $F_{cr} = \frac{\pi^2 EI}{L^2}$, where E is 129 GPa and L is 700mm.

$$I = \frac{F_{cr}L^2}{\pi^2 E} = \frac{4025 * 700^2}{\pi^2 * 129 * 10^3} = 1550{,}65mm^4$$

Where $I = \frac{\pi}{4}\left(r_0^4 - r_i^4\right)$ and r_o is 16mm.

$$\frac{\pi}{4}\left(r_0^4 - r_i^4\right) = 2875{,}26mm^4$$

$$r_i = 16mm - \left(\frac{4}{\pi} * 1550{,}65\ mm^4\right)^{\frac{1}{4}} = 9{,}33mm$$

From the calculations the inner radius (r_i) for Eulers buckling is lower than the inner radius to sustain the yield the handlebar is exposed to, thus the inner radius from the Eulers buckling is chosen.

A safety margin of 10% is given, this makes $r_i = 8{,}4mm$.

Mass of handlebar $m = \pi L\left(r_o^2 - r_i^2\right)\rho$

$$m = \pi 700(16^2 - 8{,}4^2)1{,}565 = 0{,}638\ kg.$$

Wheel fork

The wheel fork has to sustain an energy of $135\ J$ at a velocity of $4{,}5$ m/s onto the frontwheel. To find the force acting on the wheelfork it is needed to find the mass of the object.

$$\frac{1}{2}mv^2 = kg * \frac{m^2}{s^2} = J$$

$$\frac{1}{2}mv^2 = 135\ J$$

$$m = \frac{2 * 135\ J}{\left(4{,}5\frac{m}{s}\right)^2} = 13{,}33kg$$

$$F = ma = 13{,}33kg * 9{,}81\frac{m}{s^2} = 130{,}8N$$

The wheelfork is given a length of 600mm to provide support to the handlebar and to offer the user the ability to adjust the bar into several different heights, and the inner diameter is set to 32mm to fit the outer diameter of the handlebar.

To find the yield and Eulers buckling of the wheelfork the same method as in the dimensioning of the handlebar is used.

$$\frac{F}{\sigma_f} = \frac{130{,}8N}{1740\ MPa} = 0{,}075\ mm^2$$

$$A = \pi\left(r_o^2 - r_i^2\right) = \pi r_o^2 - \pi 16^2$$

Where $A = \frac{F}{\sigma_f}$, thus:

$$r_o = \sqrt{\frac{A}{\pi}} + 16 = \sqrt{\frac{0{,}075}{\pi}} + 16 = 16{,}15mm$$

Eulers buckling:

$$I = \frac{F_{cr}L^2}{\pi E} = \frac{130{,}8 * 600^2}{\pi * 129 * 10^3} = 116{,}2\ mm^4$$

$$\frac{\pi}{4}\left(r_o^4 - r_i^4\right) = 116{,}2mm^4$$

$$r_o^4 = \frac{4 * 116{,}2}{\pi} + r_i^4$$

$$r_o = \left(\frac{275{,}6}{\pi}\right)^{\frac{1}{4}} + 16 = 19{,}49\ mm$$

The outer radius to sustain the Eulers buckling is greater than the yield, hence the outer radius for the Eulers buckling is chosen.

A safety margin of 10% is given, this makes $r_o = 21{,}43mm$.

Mass of wheelfork $m = \pi L\left(r_o^2 - r_i^2\right)\rho$

$$m = \pi 600(21^2 - 16^2)2{,}69 = 0{,}938\ kg.$$

Neck

The neck is made out of three parts, but for the calculations the neck is simplified into one part. The neck will be the connection between the deck and the wheel fork, and will be connected 200mm from the bottom of the fork wheel, while the deck will be positioned 200mm in x-direction from the bottom of the wheel fork, see figure 27.

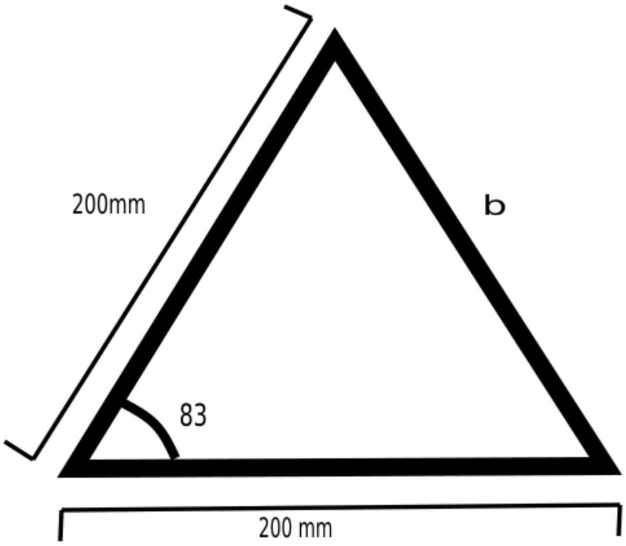


Figure 27: Visualises the position of the neck and the different angles. Made with InkScape

The length and the angle of the neck will be computed by using the given angles and lengths between the fork wheel and the deck. To find the dimensions of the neck the triangle has to be divided in to two triangles to simplify the calculations, see figure 28.

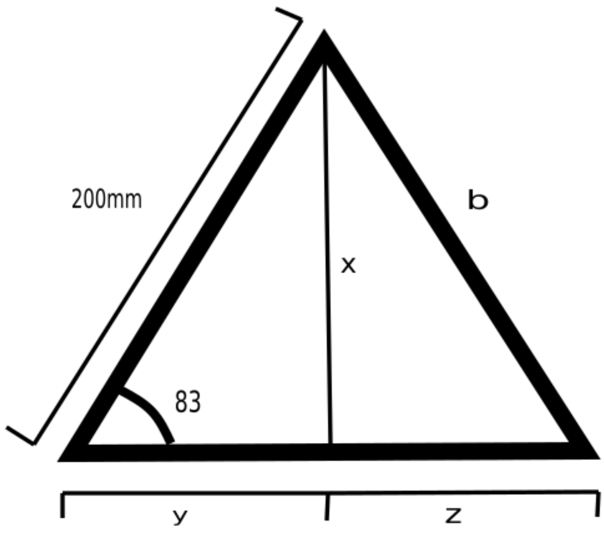


Figure 28: Dividing up the triangles to simplify the calculations, made with InkScape

The length of the neck is found through:

$$x = 20sin83 = 19{,}85$$

$$y = 20cos83 = 2{,}44$$

$$z = 20 - y = 17{,}56$$

$$b = \sqrt{x^2 + z^2} = \sqrt{19{,}85^2 + 17{,}56^2} = 26{,}5cm = 265mm$$

The angle of the neck is calculated:

$$cos\alpha = \frac{z}{b} = \frac{17{,}56}{26{,}5} \rightarrow \alpha = 48{,}5°$$

The connection between the neck and the wheel fork is looked upon as the most exposed part of the neck, therefore the force upon the neck from the forces on the wheel fork has to be calculated. The force is found through the sinus equation $\frac{sin\beta}{F} = \frac{sin\alpha}{F_s}$, which gives:

$$F_s = \frac{Fsin48{,}5}{sin83} = \frac{4025sin48{,}5}{sin83} = 3037{,}19N$$

When the length, angle and the force upon the neck is computed the thickness can be calculated. This is done by finding the yield and Euler's buckling of the system. The outer radius is set to 30mm, due to the outer diameter of the wheel fork, to make a smooth connection point.

The yield:

$$\frac{F_s}{\sigma_f} = \frac{3037{,}19N}{170MPa} = 17{,}87mm^2 = \pi\left(r_o^2 - r_i^2\right)$$

$$r_i = r_o - \sqrt{\frac{17{,}87}{\pi}} = 30 - \sqrt{\frac{17{,}87}{\pi}} = 27{,}62mm$$

Euler's buckling:

$$I = \frac{3037{,}19 * 265^2}{\pi^2 * 69{,}5 * 10^3} = 310{,}94mm^4$$

$$r_i = r_o - \left(\frac{4}{\pi} * 310{,}94\right)^{\frac{1}{4}} = 30mm - \left(\frac{4}{\pi} * 310{,}94\right)^{\frac{1}{4}} = 25{,}54mm$$

Due to the needed inner radius to sustain the yield is greater than the inner radius for Euler's buckling, the inner radius for the Euler's buckling is chosen.

A safety margin of 10% makes $r_i = 23mm$

Handle

The handles must be able to sustain a mass of 10kg to the endpoint of the handle, see figure 29.

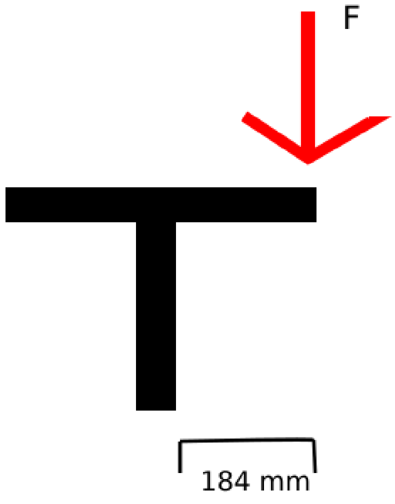


Figure 29: Handle illustreded with an load on the side. Made with Inkscape

Force $F = 10kg * 9{,}81 = 98{,}1\ N$.

The endpoint of the handle is 184 mm from the handlebar and the max allowed deflection is 4 mm. Where max deflection is $v = \frac{Px^2}{6EI}(3L - x)$.

$$4\ mm \geq 98{,}1\ N * \frac{(184\ mm)^2}{6 * 129 * 10^3\ MPa * I}(3 * 184\ mm - 184\ mm)$$

$$I \leq \frac{98{,}1\ N * (184\ mm)^2}{6 * 129 * 10^3 * 4\ mm}(3 * 184\ mm - 184\ mm)$$

$$I \leq 394{,}7767\ mm^4$$

The outer diameter is set to 22 mm, and the inner diameter is found through $I = \frac{\pi}{4}(r_o^4 - r_i^4)$.

$$r_i = r_o - \left(\frac{4I}{\pi}\right)^{\frac{1}{4}} = 11\ mm - \left(\frac{4 * 394{,}7767}{\pi}\right)^{\frac{1}{4}} = 6{,}265\ mm$$

The 10% security margin gives $r_i = 5{,}64\ mm$.

The mass of the handle $m = \pi L\left(r_o^2 - r_i^2\right)\rho$

$$m = \pi * 400mm(11^2 - 5{,}65^2) * 1{,}565 = 0{,}175\ kg.$$

Deck

The carbon fibre composite of the face of the deck is an anisotropic material, and according to a study by science direct “bending of straight bars made of anisotropic materials” it is possible to calculate the deflection of a bar with anisotropic material as a bar of isotropic material. The result will not be perfect, but it will be acceptable.

According to the requirements the deck has to support a load of 100 kg, this is computed by looking at the system as a simply supported beam in three point bending, where max midpoint deflection is L/100, see figure ccc.

In this case the task is to minimize the mass, thus the thickness of both the core and the face has to be optimized.

Table 5 Optimization of the face and core of the deck

	Face	Core	Unit
E-module	129000	40,3	MPa
Density	0,00158	0,000202	g/mm^3
Shear mod (G)	3740	426	MPa

All the needed properties are found in table 5, where the material properties are found in CES Edu Pack. The mass of beam per unit is given as $W(d) = \left(\frac{4\rho_f L^2}{B_1 E_f b}\left[\frac{Cd^2}{L} - \frac{d}{B_2 b G_c}\right]^{-1} + \rho_c d\right) L$. Where B_1 is 48, B_2 is 4, max deflection is 6 mm and the flexibility $C = \frac{6\ mm}{1000\ N}$ 0,006 mm/N.

Ref: modern materials compendia II, example 17.1.2

$$W(d) = \left(3{,}72 * 10^{-6}\left[\frac{1022{,}4d^2}{600} - \frac{d}{170400}\right]^{-1} + 2{,}02 * 10^{-4}d\right)600$$

$$W(d) = \frac{228199{,}68}{1022{,}4d^2 - 600d} + 0{,}1212d$$

To find the mass of beam per unit $W(d)$ has to be derivated and set $W'(d) = 0$.

$$W'(d) = -\frac{466{,}6 * 10^6 d - 136{,}92 * 10^6}{d^2(1022{,}4d - 600)^2} + 0{,}1212$$

$$W'(d) = 136{,}92 * 10^6 - 466{,}6 * 10^6 d + (1022{,}4d - 600)^2 0{,}1212d^2$$

Clean up the equation and find all solutions.

$$136{,}92 * 10^6 - 466{,}6 * 10^6 d + 43{,}63 * 10^3 d^2 - 14{,}87 * 10^3 d^3 + 12{,}67 * 10^4 d^4 = 0$$

$$d_1 = 15{,}37552923\ d_2 = 0{,}2934511811\ \ d_3 = -7{,}7758 + 13{,}3809i\ d_4 = -7{,}7758 - 13{,}3809i$$

To find the most realistic solutions d_1 and d_2 are put into equation $W(d)$ and gives:

$$W(d_1) = 2{,}83308723$$

$$W(d_2) = -2560{,}54861$$

The mass cannot be negative, thus d_1 is the real solutions and the deck thickness is set to 15,5 mm.

Further it is needed to find the thickness of the face and core separately when it is known that the thickness is set to 15,5 mm. Face thickness is found through the equation:

$$t_f = \frac{2L^2}{B_1 E_f b}\left[\frac{Cd^2}{L} - \frac{d}{B_2 b G_c}\right]^{-1}.$$

This gives:

$$t_f = \frac{2 * 600^2}{48 * 129000 * 100}\left[\frac{0{,}006 * 15{,}5^2}{600} - \frac{15{,}5}{4 * 100 * 426}\right]^{-1}$$

$$t_f = 0,5030378 \approx 0,5\ mm$$

From this the core thickness can be found by:

$$t_c = 15,5 - 0,5 * 2 = 14,5\ mm$$

Mass $m = t_c L w \rho_c + 2 t_f L w \rho_f = 14,5 * 600 * 100 * 0,198 + 2 * 0,5 * 600 * 100 * 1,565$

$$m = (0,172 + 0,094) kg = 0,266 kg$$

Production and attachment

The handlebar, the handles, the neck and wheel fork has a cylindrical shape with the same radius throughout the whole design. This makes extrusion a suitable production method for these parts. Extrusion is a method where the aluminium is heated and forced through a die shape due to pressure, and the end result are the cylindrical aluminium parts with the same profile through it all. The length of the different parts has to be cut manually. [9]

Neck

The patterns of the neck are not possible to create with extrusion. The extruded parts of the neck will be machined afterwards. The neck will be welded onto the cap that connects the neck to the handlebar and the deck.

Wheel fork

The bottom part of the wheel fork will be produced with die casting. The chosen production method is vacuum die casting, where the molted aluminium is forced into the casting die due to the pressure differences caused by the vacuum. The wheel fork parts will be welded into one piece.

[10]

Board

The core of the deck is a honeycomb structure. Corex is a manufacturer of aluminium honeycomb structures, and their process consist of passing an aluminium foil through a printer to add adhesives and put into a heated press for the adhesives to settle in. The aluminium is cut into the needed size before its expanded.

[11]

The face will be produced by pultrusion. Pultrusion is a process where the material is pulled through a heated die. This is similar to extrusion, where the cross-section is constant, but the length has to be cut manually afterwards.

[12]

To attach the core to the face of the deck a heated press is used. An adhesive is put between the face and the core, and a heated press is placed on top of the structure to bond the face and core together.

Solidworks

Simulations were done in solidworks to confirm the calculated dimensions of the design. The deflection and the von Mises stress were evaluated by the static test, and the results would indicate if the design needed some alterations.

When analysing the handlebar and the handles titanium was used as material because it has similar E-module to Epoxy/carbon fiber.

There are more detailed information of the static test studies in appendix X.

Handles

The handles were tested by setting a fixed geometry on the middle of the handles, while a force of 9,81 N in negative y-direction was applied to the ends of the handles.

Figure 30 shows that the yield strength of the material was greater than the von Mises stress of $1{,}78 * 10^6\ N/m^2$.

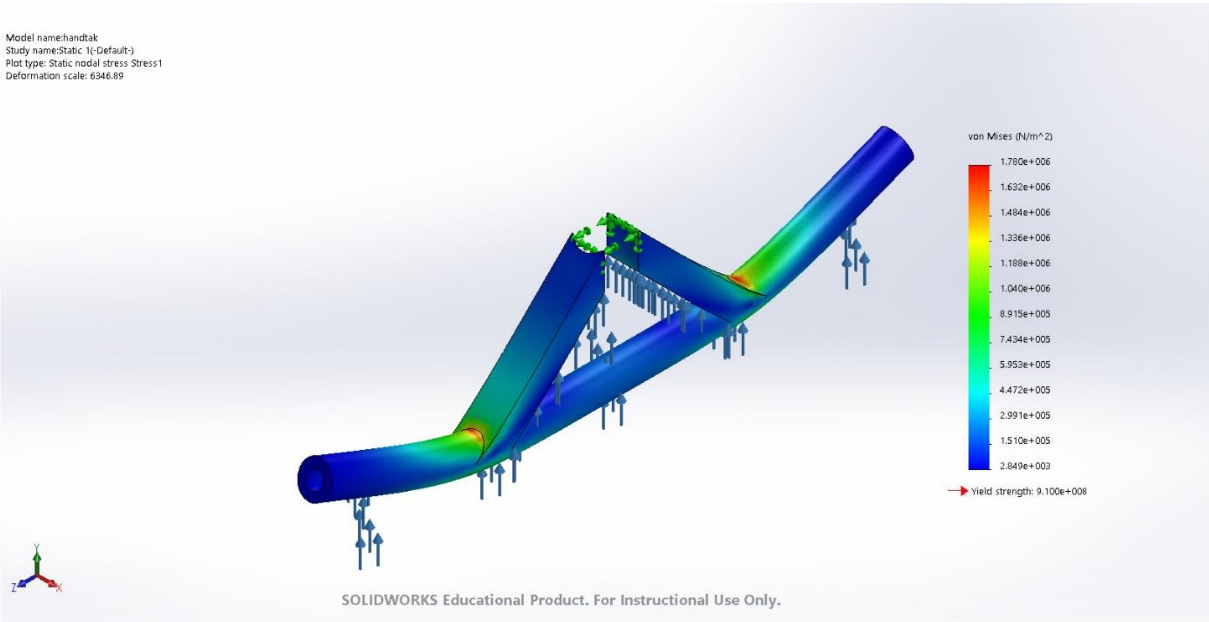


Figure 30: yield strenght of the handles, made by Solidworks

Figure 31 shows that the handles has a deflection of $6{,}35 * 10^{-3}\ mm$, which must be considered insignificant.

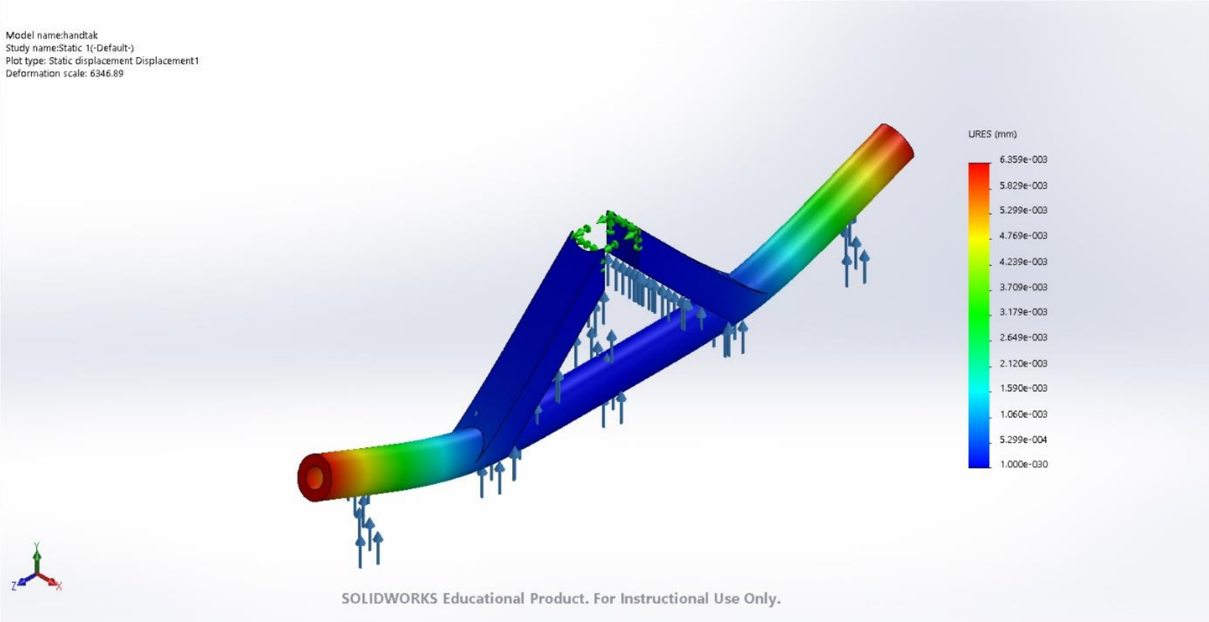


Figure 31: Deflection of the handles, made by Solidworks

Handlebar

The handlebar was tested by applying a fixed geometry on one end of the bar, and applying a force of 490,5 N on the other end.

Figure 32 shows that the handlebar had a yield strength greater than the von Mises stress of $2{,}637 * 10^8\ N/m^2$.

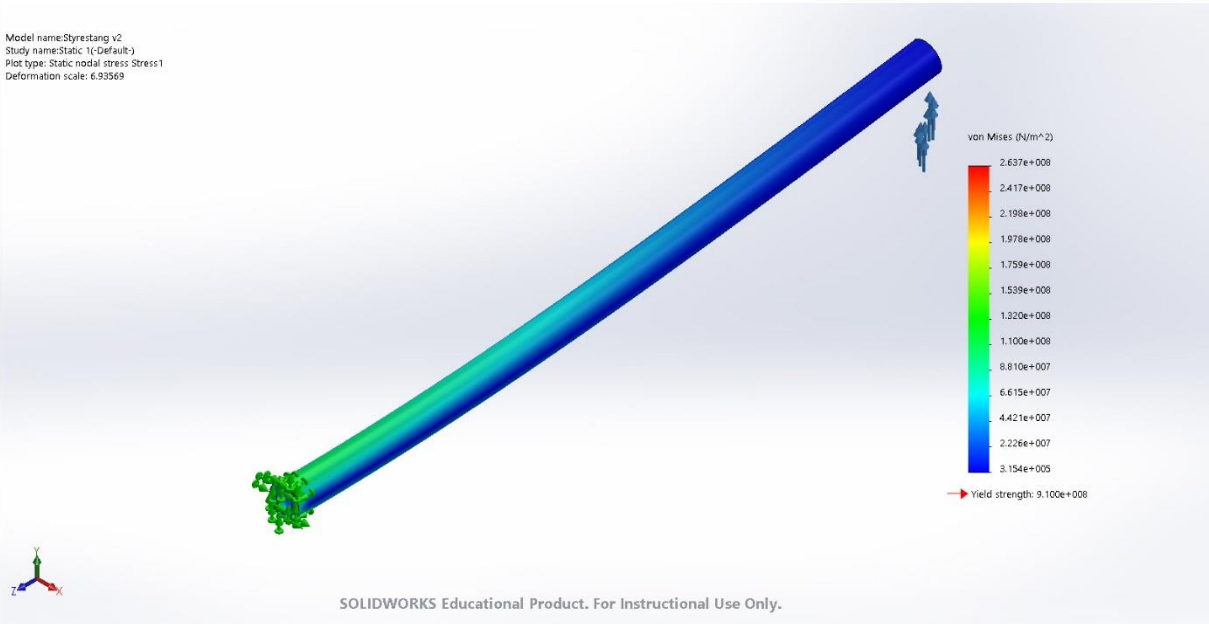


Figure 32: Shows the yeild strength of the von mieses stress, made by solidworks

The displacement of the handlebar was 10 mm, see figure 33.

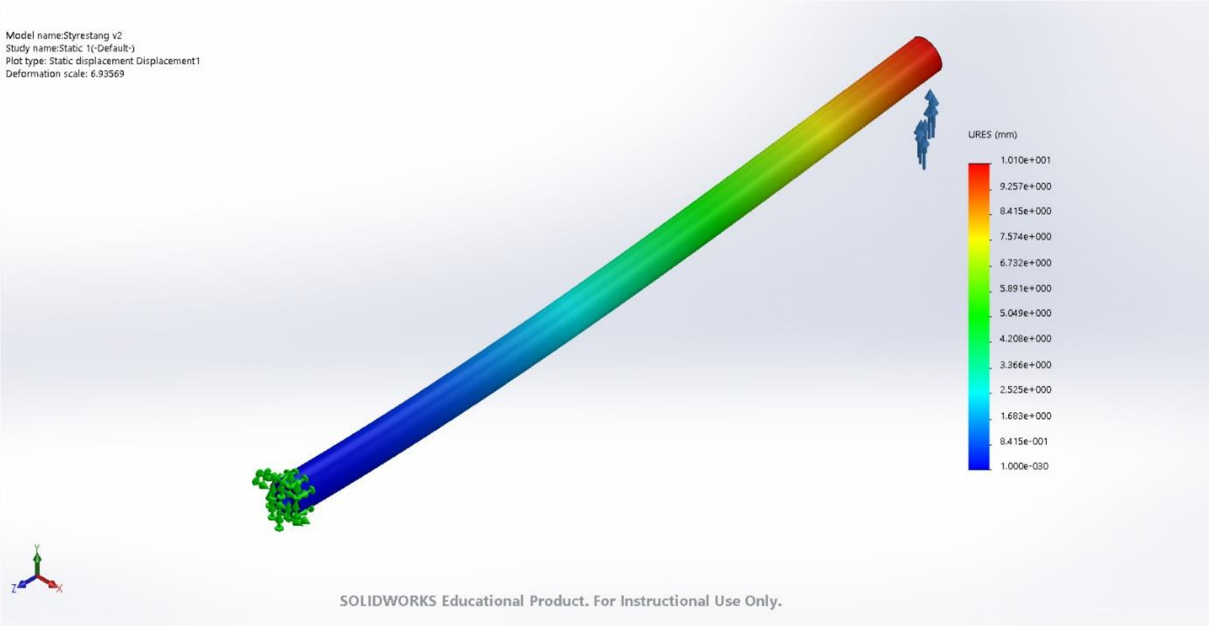


Figure 33: The displacement, made with solidworks

Wheel fork

The wheel fork was tested by setting fixed geometry on the top of the design, where the wheel fork is connected to the handlebar. A force of 130,8 N was applied to the bottom part of the design, where the front wheel are positioned.

The results show that the yield strength of the material is greater than the von Mises stress of $2{,}99 * 10^7\ N/m^2$.

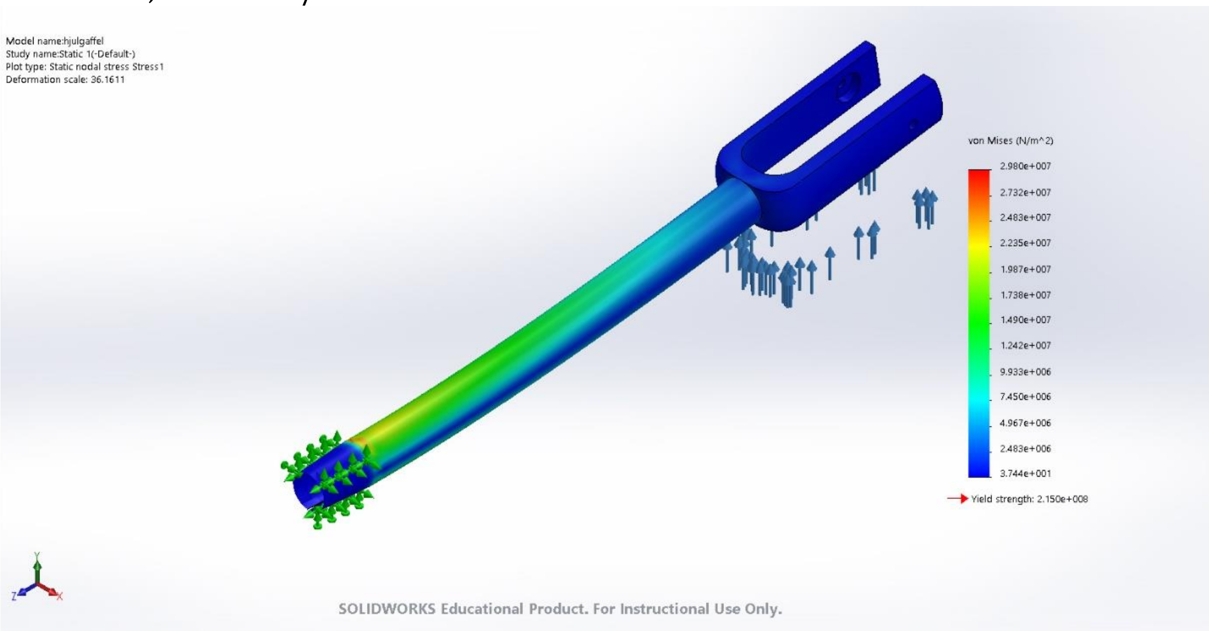


Figure 34:Yield strenght is greater than the von mieses stress. Made with solidworks

The design had a deflection of 1,7 mm, see figure 35.

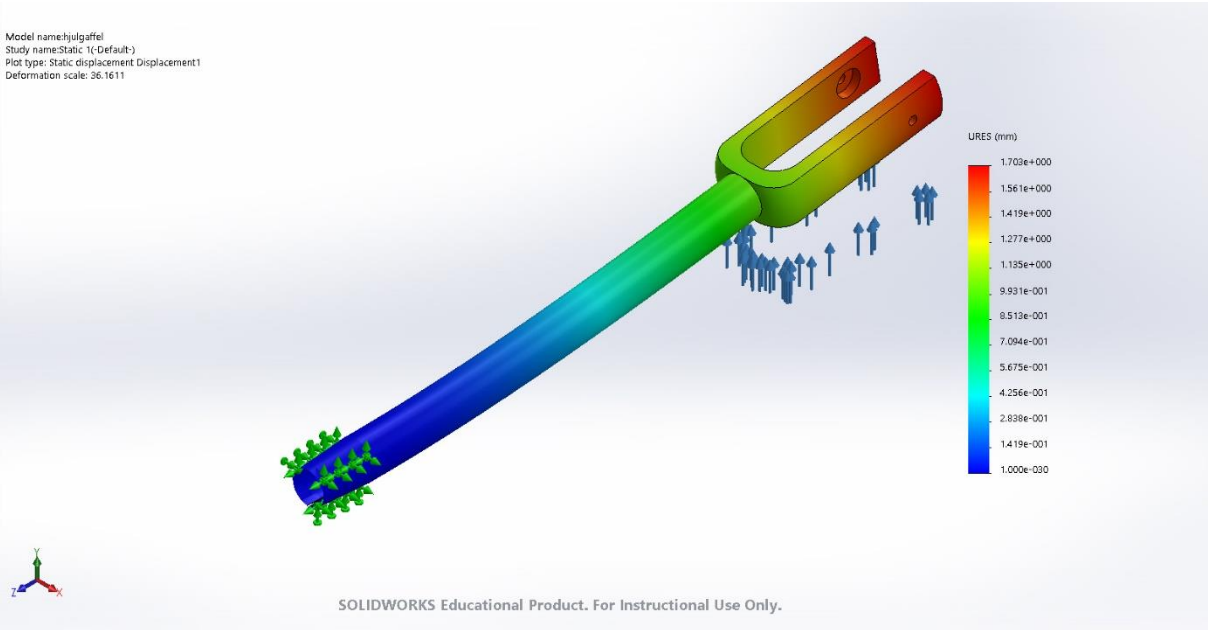


Figure 35: Displays the deflection of the fork. made by SolidWorks

Deck

The deck was tested by implementing a fixed geometry on both sides of the deck, while applying a midpoint force of 1000 N in negative y-direction. The design could only have one material in the simulation, hence the aluminium 5052 honeycomb core material was applied to both the face and core.

The results show that the yield strength of the material is greater than the von Mises stress of $6,3 * 10^7\ N/m^2$.

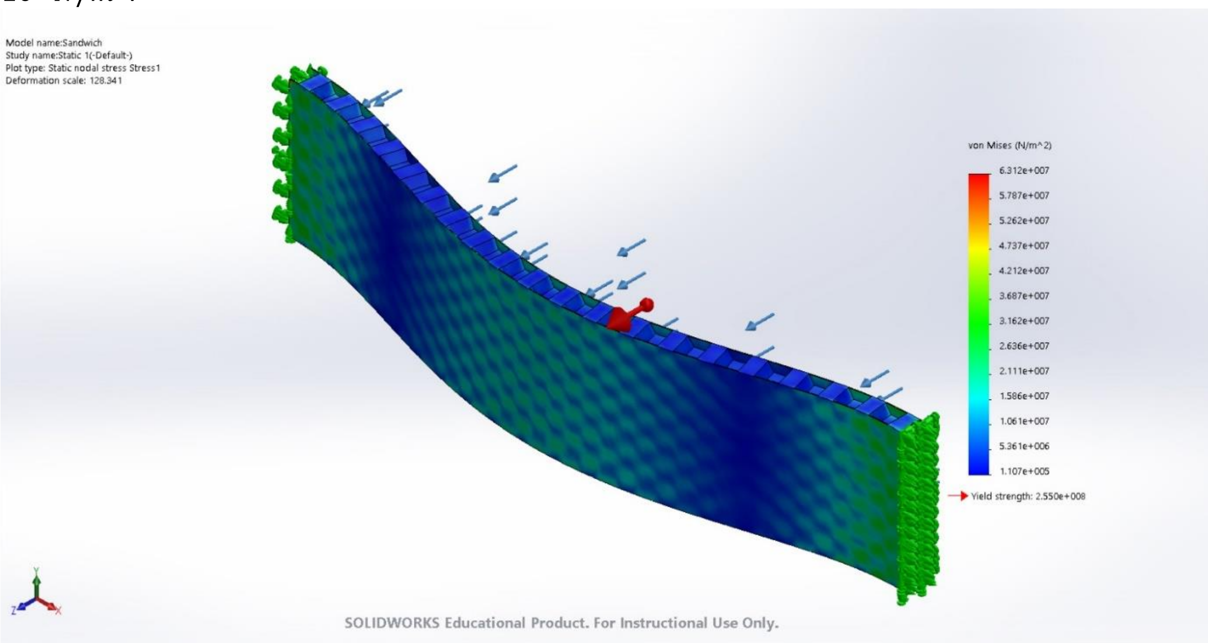


Figure 36: Shows that the Yield strenght is highter than the von Mieses stress, made by solidWorks

The displacement of the deck was 0,3 mm.

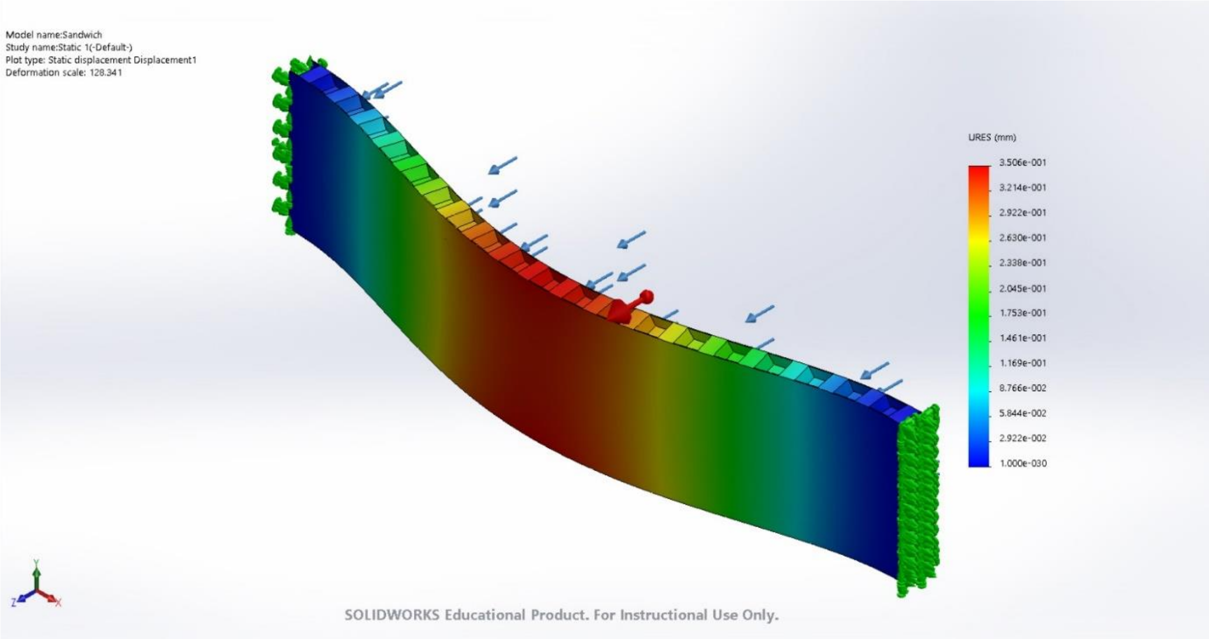


Figure 37: Illustrates the displacment of the deck, Made by SolidWorks

Final design

The final product is a foldable scooter with adjustable handlebar height up to 120 mm, a deck of length 600 mm and width of 100 mm. The deck is a sandwich structure made of epoxy/carbon fibre face material and a aluminium 5052 honeycomb core. The neck, made of aluminium 6063 T6, consists of three parts and is foldable. The total mass of the scooter is 2,449 kg.

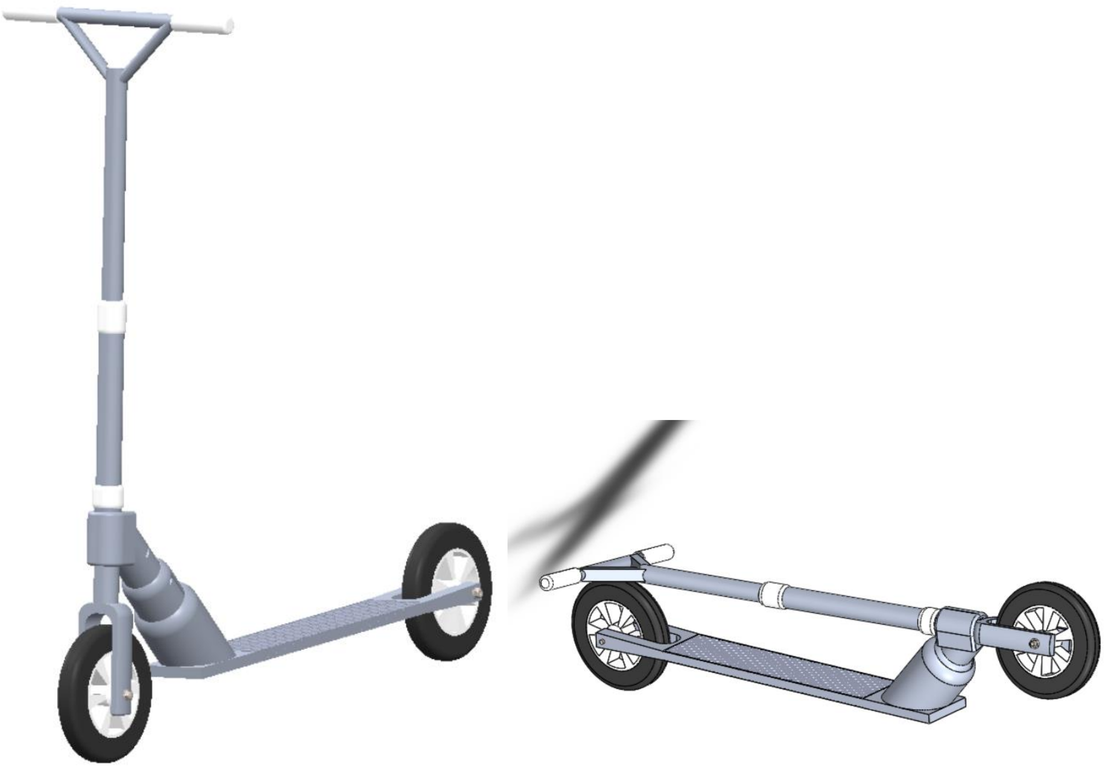


Figure 38: Final design of the decending commuter, made in Solidworks

Table 6: Final measurements of the finalized design

Parts	Material	Mass [kg]
Handle	Epoxy/carbon fiber	0,175
Handlebar	Epoxy/carbon fiber	0,638
Wheel fork	Aluminium 6063 T6	0,938
Neck	Aluminium 6063 T6	0,432
Deck core	Aluminium 5052 honeycomb (0,198)	0,172
Deck face	Epoxy/carbon fiber	0,0939/2

Design restrictions

The design has been subjected to analysis, though there are components and specification that have not been researched, this may affect the construct under severe conditions. These analysis were carried out using computer software and a close resemblance to how the system would react in practical terms, based on theory and computation. The results cannot conclude the conduct of the system with absolute resolution and therefore cannot be a guarantee for the design.

Appendices

Appendix 1- Design of decending commuter
Appendix 2 – Preliminary Project
Appendix 3 – Hour budget and S-curve
Appendix 4 - Iteration
Appendix 5 – 2d – drawings
Appendix 6 – Solidworks simulations

Software

SolidWorks is a 3D CAD software and is used to produce 3D models, technical drawings and illustrations.

CES EduPack is a teaching resource that is a huge database of materials and production method.

InkScape is an open source vector graphics editor that allows the making of 2D drawings in scalable vector graphics.

List of figures

List of tables

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