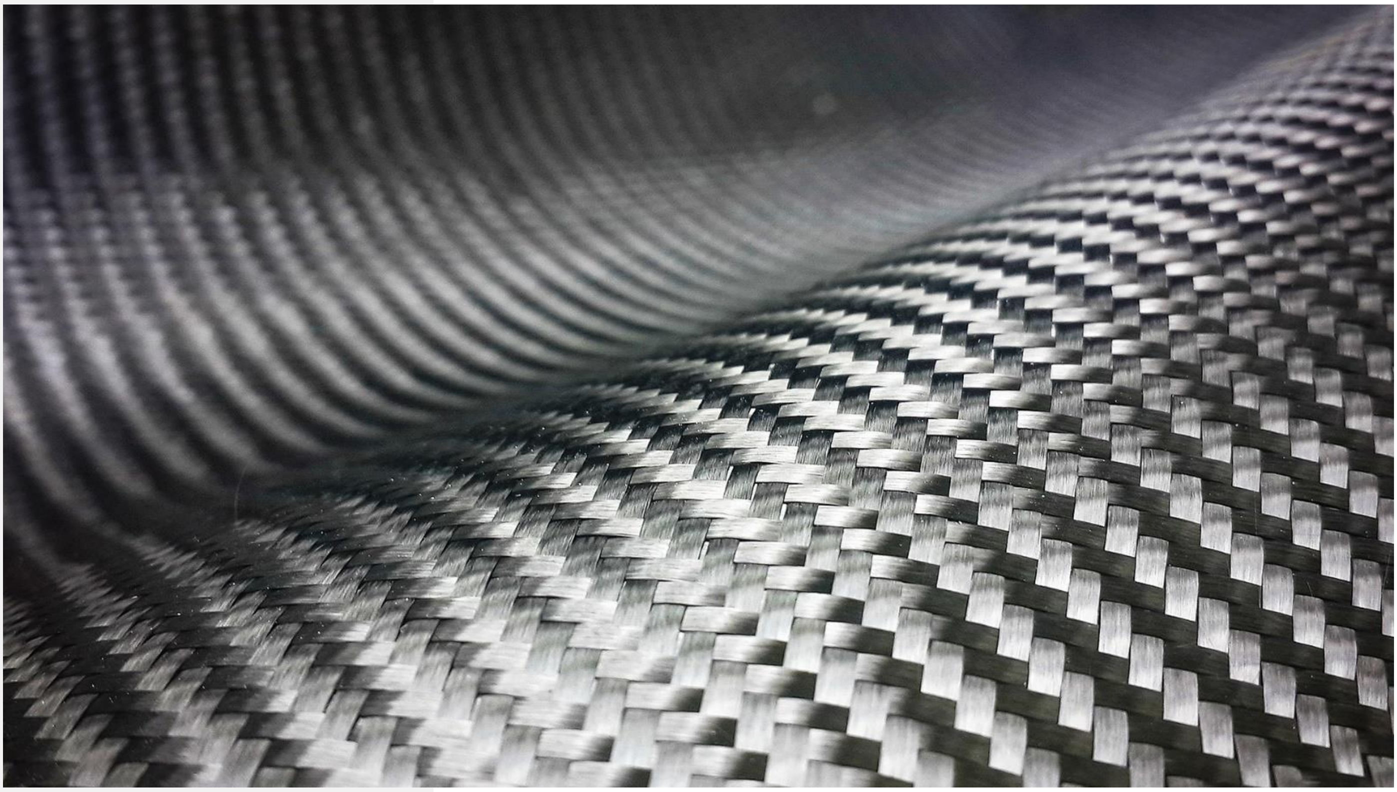
Lightweight design & Composite construction

2022-2025



Portfolio

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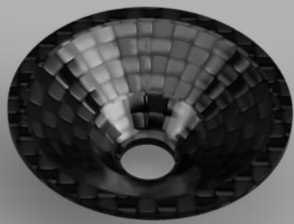
01

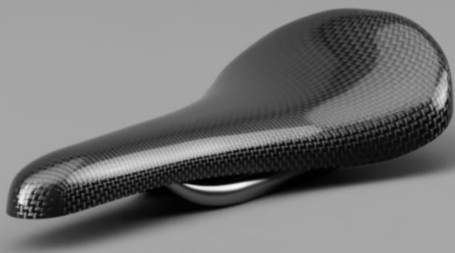
2022



Top Cap

02

2022-2024



Sattel

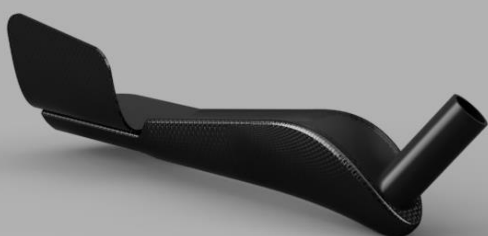
03

2024 -now

Bottle Cage

04

2025 - now



Aero Bars

Even before I started my master's degree in civil engineering, I developed a great enthusiasm for fiber composites by combining my hobbies of 3D printing and road cycling. The possibility of using lightweight yet high-strength materials to create creative and individual solutions has fascinated me ever since.

In order to further deepen my interest on a professional level, I therefore attended courses at the Chair of Carbon Composites and the Chair of Lightweight Design and Product Development at the Technical University of Munich alongside my main course of study. There, I was not only able to understand important basics, but also develop my manual skills in various internships. Working with composite materials showed me how much potential there is in the combination of theory and practice, and reinforced my desire to turn my own ideas into reality on both a small and large scale.

This portfolio shows a selection of my previous projects, from my first experiments (01 Top Cap) to my current developments (03 Bottle Cage, 04 Aero Bars). It is intended to convey my passion, my learning progress and my enthusiasm for innovative lightweight solutions and at the same time provide an insight into my experiences to date.

Extracurricular subjects	**Content of lecture**	**Workload**	**Grade**
Manufacturing technologies for composite components	Conceptualization, design and construction of sports equipment (surfboard, saddle, field hockey stick)	4-Ects (120 hours)	1,0
Analysis and design of composite structures	Classical laminate theory Fracture criteria (Tsai-Wu, Puck, Hashin) Sandwich structures Adhesive & screw connections	5-Ects (150 hours)	1.0
Lightweight construction & design	Plate theory, truss structures, Structural optimization	5-Ects (150 hours)	2.3
Manufacturing processes for composite components	VARI, V-RTM, RTM, braiding Matrix processing, fabric types and handling	5-Ects (150 hours)	2.0
Practical course on composite construction	Optimization of a 50cm long beam for a 3-point bending test; Maximum weight 250g; Design load 400 kg	4-Ects (120 hours)	1.7
Introduction to materials and manufacturing technologies of carbon composites	Fundamentals of material properties, weave types, matrix systems & processing technologies	5-Ects (150 hours)	1.7
Material Modeling	Structural mechanics fundamentals for composites & honeycomb structures and foams	3-Ects (90 hours)	2.3

01 Top Cap

As the top cap of a bicycle is only used to preload the bearings in the headset and does not have to fulfill any high structural requirements, it was an ideal entry-level project in the field of composite materials.

The first version was produced using the “wet layup” process, but proved to be impractical due to small radii and weak vacuum generation. Compression molding was therefore used in the next iteration. With the help of a PVA-based release agent, it was possible to achieve a significantly better surface quality as well as greater dimensional accuracy.

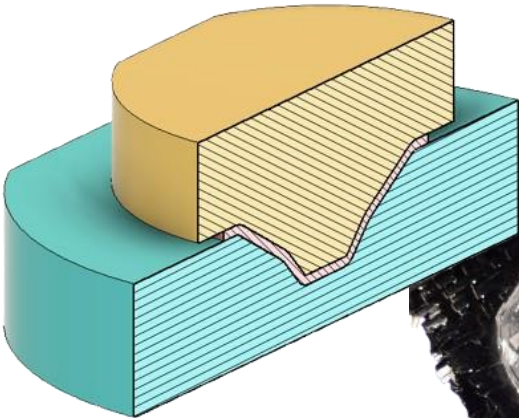
By testing various laminate structures, a lay-up consisting of eight individual layers of body fabric (45 / 0 / -45 / 0)s was developed, which reliably transfers the forces of up to 5 Nm applied by the stem screw.

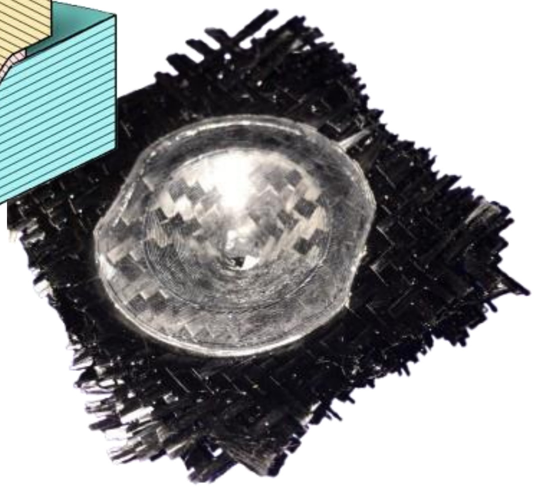
A drilling template and a grinding device were designed and used for the final machining process, enabling reproducible results and precise reworking.

Compared to a similar aluminum Ahead cap, a weight saving of around 9 g was achieved.

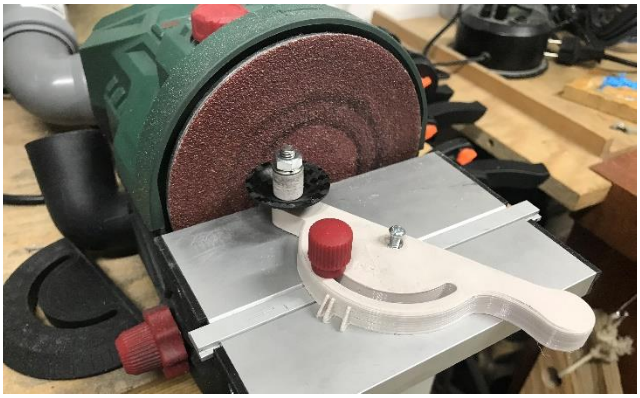
Weight	1,88 g
Lay-up	(45 / 0 / -45 / 0)$_s$
Cost	~ 40 €
Weight reduction	9 g / 79 %
Labour	~15 h

Wet-Layup





Compression Molding



Custom tooling for percice and repetable finish

Selection of different iterations (1st left; 5th bottom right)

02 Saddle

The aim of this project was to optimize my existing road bike to a total weight of less than 5 kg. The greatest potential for savings lay in the previous combination of saddle (Fizik Antares) and seat post (Thomson Elite) at 254 g.

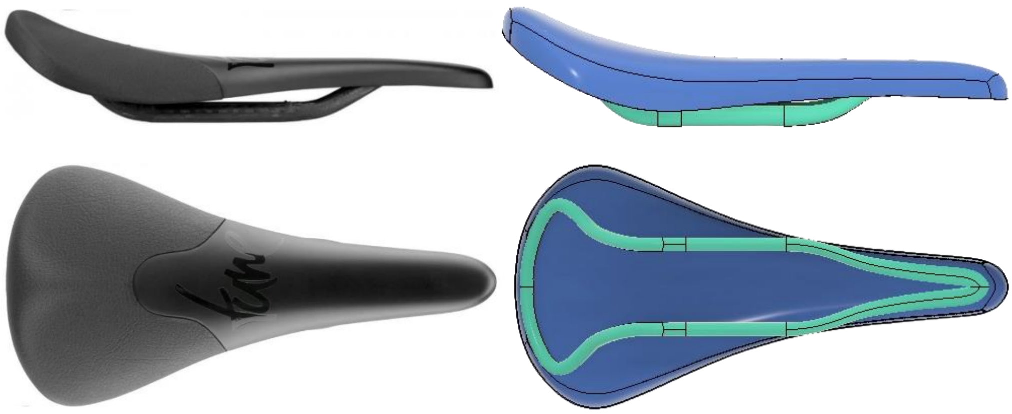
The Tune Komm-Vor saddle, which is specified by the manufacturer as weighing only 90 g, served as a reference for me in terms of optimum weight. Based on views and plan views from the Internet, this was modeled in detail in a CAD program using free-form surfaces.

As the saddle was designed as a tailor-made solution for my requirements, the idea of firmly connecting the saddle shell to the seat post emerged early on. Although this meant that it was no longer possible to adjust the angle and distance to the handlebars individually, this was not critical for my already familiar riding position. This led to the concept of an integrated saddle and seat post unit.

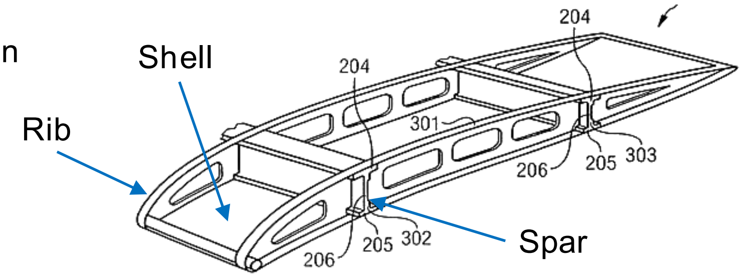
The design was based on the structure of an airplane wing: an inner structure consisting of spars and ribs is enclosed by a load-bearing shell. A web underneath the saddle shell can be used in a similar way to simultaneously connect to the saddle support and transfer the loads from the saddle shell. To do this, the support itself is slotted and the seatpost is then glued in place.

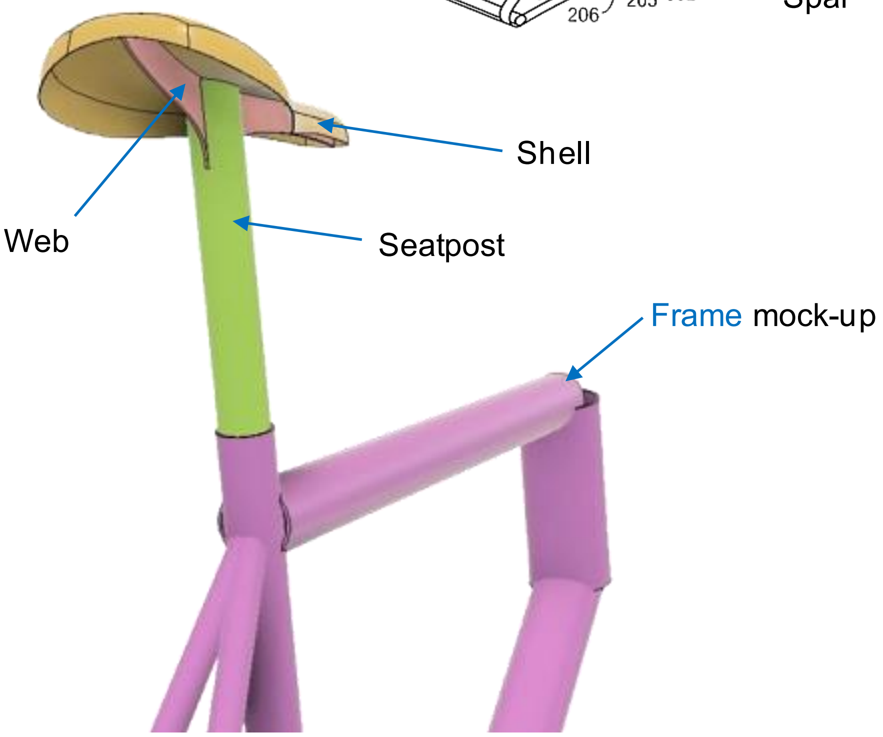
Tune Komm-Vor

CAD-Model



Wing Crosssection





In order to guarantee accurate assembly, the current position of the rider was first adapted to an original Tune saddle and measured using a laser system. The distances relative to the frame and the geometry table of the frame were used to determine the absolute dimensions for the CAD drawing.

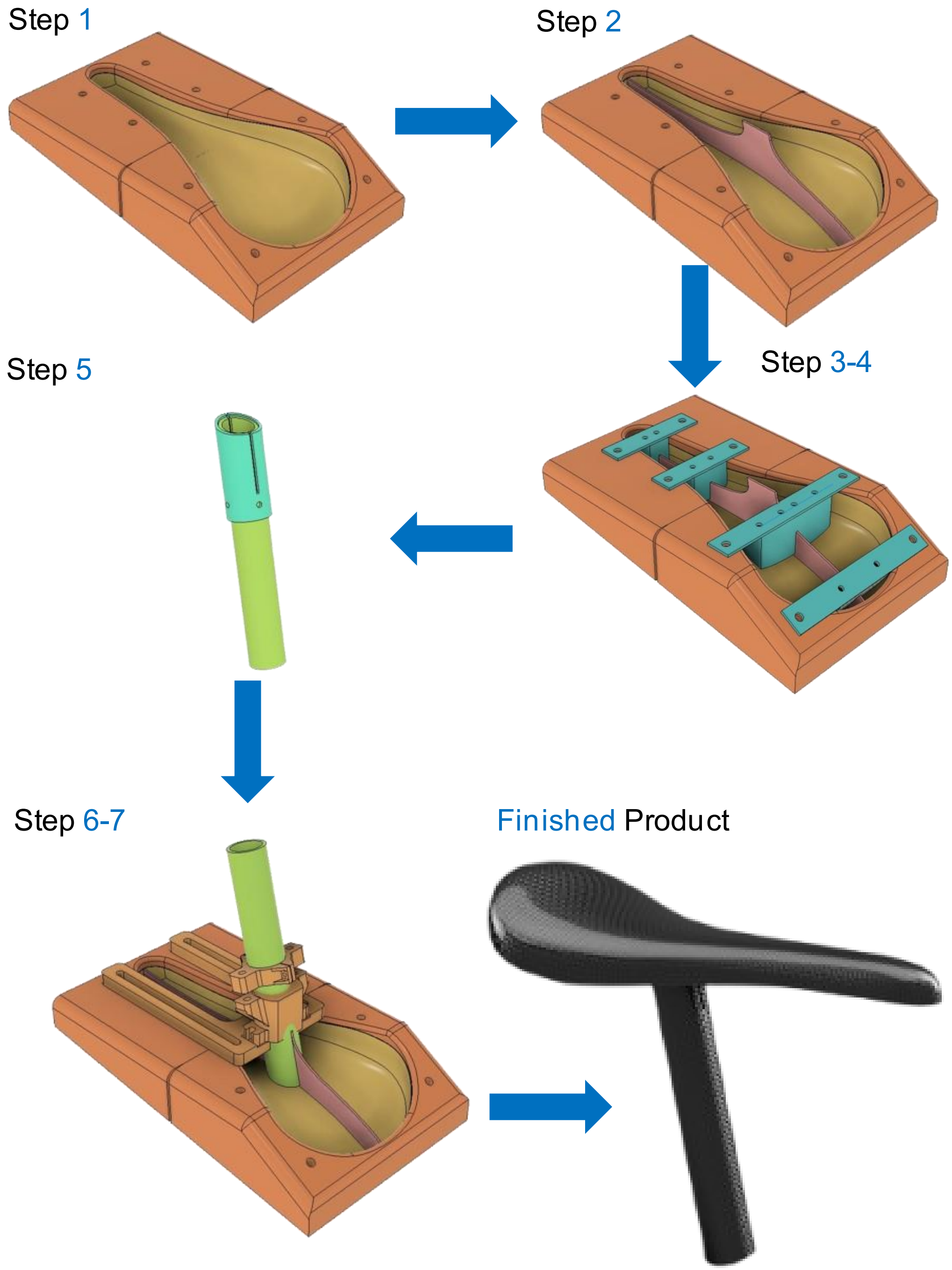
This data was utilized to finalize the CAD model and design modular gauges for bonding the rib and the seat post.

Thanks to the modular design of the bonding jigs, it will be possible in future to adapt the angle and spacing for other versions in the existing formwork in a user-defined way. The system can therefore also be customized for other riders.

The final production process is as follows:

1. produce saddle shell via resin infusion (45 / -45 / 0 / -45 / 45)
2. cutting of the saddle shell and the rib (1.8 mm CFRP sheet material; CNC-controlled cutting)
3. bonding of the rib
4. reinforcement of the rib at the bonding (fillet)
5. slitting the seat post
6. bonding of the seat post
7. reinforcement between rib, seatpost and shell (wet layup)

Weight	131 g
Layup	(45/-45/0/-45/45)
Cost	~120 €
Weight reduction	123 g / 48 %
Labour	~ 150 h



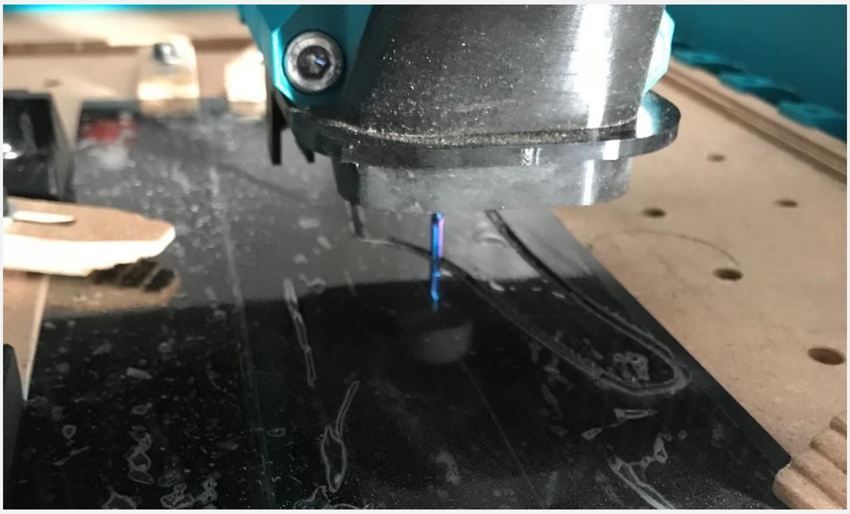
Two-piece molded part for the saddle shell

Printed in PLA and sanded with sandpaper (up to 600 grit)

Saddle shell after initial cutting

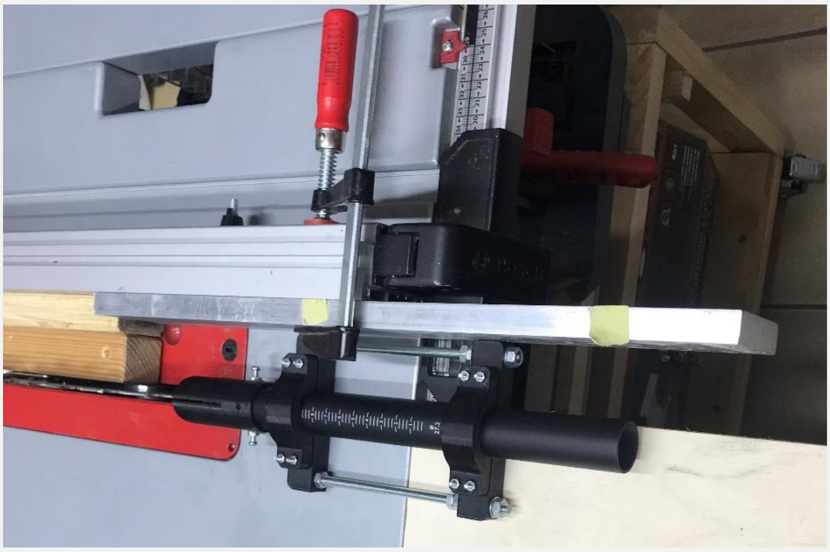
Surface immediately after demolding

PVA-based release agent used



Slotting an existing seat post using a 3D printed template and jig on the table saw

Slotting an existing seat post using a 3D printed template and jig on the table saw



Fixture setup for final bonding of the rib

Form serves as a reference surface

Bonding of Seatpost, rib and shell

Compression ring around the seatpost for compaction between the seatpost's top surface and the saddle shell.

Reinforcement of the adhesive bond with biaxial fabric combined with rovings (filler material at the seam)

Wet-laid laminate with vacuum bag, breather, and peel ply

Final weight of the finished saddle-seatpost combination 131.04 g

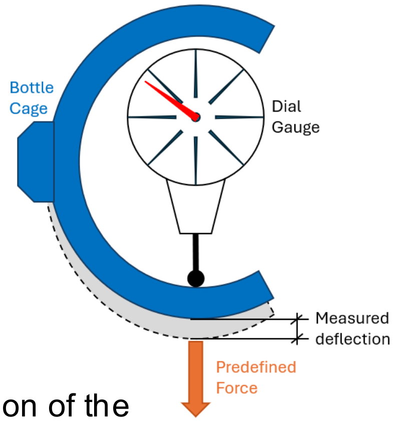
03 Bottle Cage

As the previous projects have shown, filigree work offers the best ratio of understanding new techniques and at the same time minimize expenses, the next component to be chosen was a bottle cage.

For this purpose, the stiffness (K) and clamping force ($F_{clamping}$) of one of the "arms" of the holder was first determined using an existing bottle holder.

In order to maintain the clamping force for the new bottle cage system while reducing the weight, the stiffness of the cross-section must be increased to maintain the same clamping force. Instead of a flat profile, a round tube profile is therefore chosen. This has significantly increased rigidity due to the "Steiners law".

The diameter of the required profile can be calculated using a simple replacement system with the length "l" as pictured on the right. The diameter of the tube for a desired pre-deformation of 5 mm is calculated at 3 mm. Due to the small calculated dimension, which makes manufacturing more difficult the diameter is increased to 5 mm. The back-calculated pre-deformation is therefore only 1 mm per side in order to apply the desired force of 6N to the bottle and to keep it in position while riding over roughter terrain.

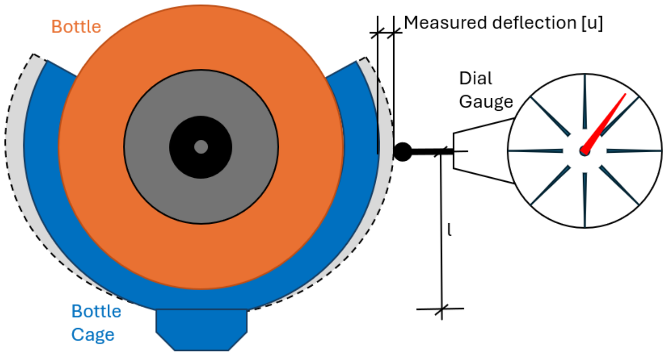


Test setup to determine the stiffness of an existing bottle cage (depicted below)

Calculation of the clamping force acting on the bottle

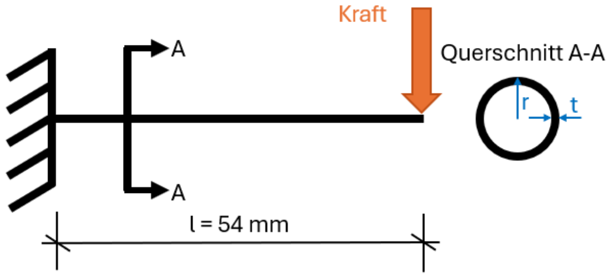
$$K_{Bottle\ Cage} = \frac{F}{u} = \frac{6{,}18\ N}{2{,}24\ mm} = 2{,}76\ N/mm$$

Force	Deflection
2,1 N	0,75 mm
4,2 N	1,51 mm
6,2 N	2,24 mm



$$F_{clamping} = K_{Bottle\ Cage} * u = 2{,}76\frac{N}{mm} * 2{,}4\ mm = 6{,}6\ N$$

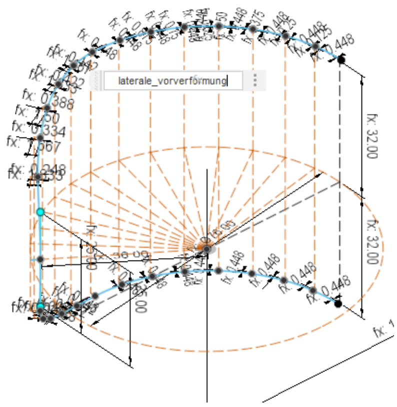
$$u = 5mm = \frac{6{,}62\ N * 54^3 mm}{3 * 42500\frac{N}{mm^2} * \frac{\pi * (r^4 - (r-t)^4)}{4}} \rightarrow r = 1{,}47\ mm$$



Diameter of the tube determined with calculated laminate stiffness of 42500 N/mm² and the principle of virtual displacements for the given system with a maximum pre-deformation of 5 mm per side

For manufacturing reasons, the tube diameter was adjusted to 5 mm. To keep the clamping force on the bottle constant, the pre-deformation has to be reduced to 1 mm per side.

This figure shows the parametric drawing of the tube in CAD, adjusted for the required pre-deformation.



In order to be able to make adjustments to the clamping force in the future, a complex parametric model of the arms was created, which takes the pre-deformation into account as an input variable.

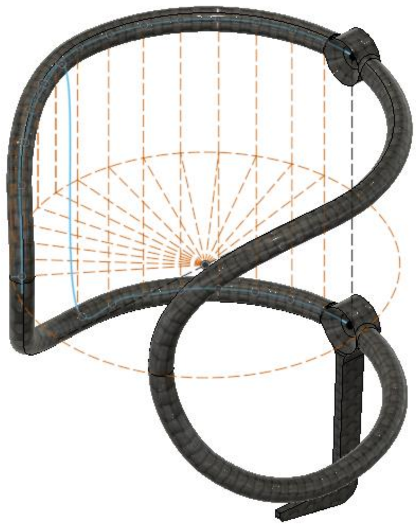
In addition to the tubes, connecting nodes are designed according to the 65 mm hole spacing of the bottle cage screw connection. These lock the bottle cage to the frame and fix the bottle in the axial direction.

To manufacture the connection points compression molding is choosen. The filigree components (1g or 1.5 g) can be given their final shape by subsequent post-processing (drilling and countersinking). For the Tubes themselfe a negative with an inflatable bladder is used

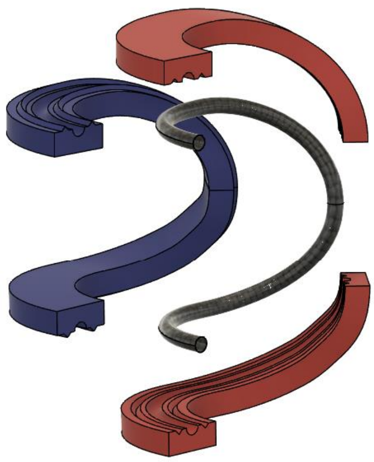
In the current project state, the connection points are finished as simple blanks. However, initial tests to produce the extremely delicate hollow profiles are already producing promising results. The aim is to complete the project by the end of 2025.

Weight	5,7 g
Layup	Braided sleve (single layer)
Cost	~ 80 €
Weight reduction	15 g / 72 %
Labour	currently 100 h

Parametric sketch to adjust clamping force and diameter for future iterations

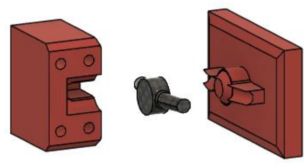


Hollow tubes manufactured using a negative mold and an inflatable silicone bladder inside the tube to achieve a wall thickness of approximately 0.2 mm for the tubes

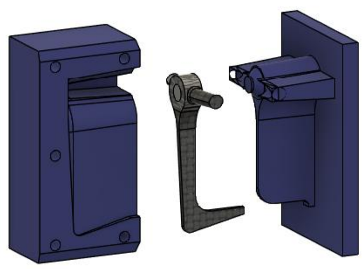


Compression molding of the upper and lower connection

Upper connection:



Lower connection:



Lower connection:

[1,5 g]

Prototype tubing

[1,1 g]

Upper connection:

[1,0 g]

04 Aero Bars

Finally, I would like to present my current project from the collaboration with the “Chair of Lightweight Construction and Product Development” at TUM.

As part of a research project on “modular bicycle frames”, my project partner and I were given the opportunity to produce an aerodynamically optimized time trial trailer.

First of all, I designed a parametric model of the trailer. The input variables for the trailer model are shown on the right.

Various variants were then printed from PLA to test the geometry for different anatomies.

In order to be able to adjust the aero-bar as flexibly as possible fordifferent riders, both the handle insert and the pad are interchangeable and individually adjustable.

After successful form-finding, the final version could be designed for production.

The aim is to laminate the bars using the prepreg process and consolidate them using a vacuum bag inserted inside the mold in addition to the autoclave.

Therefor a two-part mold is used, which is equipped with a resin channel and screw connection to facilitate stripping and alignment.

The illustrations shown reflect the project status to date. This project is scheduled for completion by the end of August 2025.