Manufacturing of composite bicycle handlebar

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Sammandrag:

Syftet med detta examensarbete var att undersöka hur det är möjligt att tillverka ett cykelstyre ut ur komposit material i Arcada – Nylands svenska yrkeshögskolas utrymmen. Vanligtvis tillverkas styre formade ihåliga sömlösa rör med industriella maskiner som är inte tillgängliga på Arcada. På grund av detta bestämde det att tillverka en expanderande laminerings form. Denna form fungerar på följande vis, ett flätat komposit material kombinerat med harts i sock form lagas runt en expanderbar blåsa. Blåsan med material runt den lagas in i en form som har en kavitet form av ett styre. När blåsan uppfylls med hjälp av tryckluft så expanderar komposit materialet så att den får formen av formens kavitet. När hartset har härdat kan formen öppnas och färdiga styret kan tas bort. För detta jobb tillverkades två former, den första var en prototyp form var över 20 test lamineringar tillverkades. Baserat på den information som erhållits från test lamineringarna konstruerades och byggdes den andra och slutliga full storleks form för styret. En av de viktigaste informationen med testen lagade med prototyp formen var att slutliga formen måste vara ett sluten konstruktion. Med hjälp av ett sluten form konstruktion var det möjligt höja på trycket upp till 7 bar, med högre truck expanderar komposit materialet bättre inne i formens kavitet. Några problem uppkom med de första testen som lagades med full storleks form för styret. Problemet var att komposit materialet inte expanderade tillräckligt som ledde till stora lamineringsfel på styret. Problemet löstes med att forma komposit materialet till formen av styret före formverktyget stängdes. Med användning av denna metod var det möjligt att producera högkvalitativa cykelstyren. Alla slutliga styren tillverkades med hjälp av 6K och 3K flätade kolfiber sock material kombinerat med epoxiharts. Slutliga produktens yta granskades med hjälp av ett optiskt mikroskop för att hitt potentiella mindre laminerings fel. Cykelstyrets böjnings styvhet testades också med hjälp av en materialkontroll maskin.

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Abstract:

The aim of this thesis work was to study how it is possible to manufacture a composite handlebar in the Arcada University of Applied Sciences premises. Composite handlebar shaped seamless tubes are normally manufactured using a filament winder, pultruder or a filament braiding machine. Not having the possibility to use these kind of machinery, it was decided to design and manufacture an expanded lamination mould in which the handlebar could be produced. An expanded lamination mould works by placing a bladder with composite sleeve material combined with resin around it inside a mould that has a cavity shaped like a handlebar. The bladder is then filled up using air pressure so that the composite material will expand and get the shape of the moulds cavity. When the resin is cured the mould can be opened and the finished hollow handlebar can be taken out.

For this work two expanded lamination moulds where built, the first one was a small prototype mould in which over twenty test lamination were made. With the knowledge given from the test lamination a full sized handlebar mould was built. One of the most important things learned from the test lamination was that the full sized mould had to be built to a closed mould construction. By having a closed mould construction it was possible to use up to 7 bars of pressure, using high pressure the composite sleeve material can expand better inside the moulds cavity. There were some problems to get the composite material to expand to the whole moulds cavity in the first few lamination test made using the full sized handlebar mould. This lead to having large lamination faults on the handlebar. The problem was solved by pre-forming the material to the shape of the cavity before closing the two mould halves. Using this method it was possible to produce high-quality bicycle handlebars. All the full sized handlebars was made using 6K and 3K carbon fibre braided sleeve material combined with epoxy resin. The final products surface quality was inspected using an optical microscope to find potential minor lamination faults. Using a material testing machine a full sized carbon fibre bicycle handlebars bending stiffness was also tested.

Keywords:	Manufacturing, Composite, Handlebar, Mould, Carbon fibre, Lamination, Bladder
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ABBREAVIATIONS

F	Force $[N]$
m	Mass $[kg]$
g	Acceleration $[m/s^2]$
σ	Stress $[GPa]$
E	Young´s Modulus $[GPa]$
ε	Strain [ ]
r	Radius $[mm]$
I	Second Moment of Inertia $[mm^4]$
D	Stiffness $[N \cdot mm^2]$
l	Length $[mm]$
6K	6000 carbon fibres filaments in one yarn
3K	3000 carbon fibres filaments in one yarn
UD	Unidirectional
Stem	Component that the connects the handlebar to the bicycle frame

FOREWORD

The reason I wanted to build an expanded lamination mould to produce a bicycle handlebar was to learn more about the whole manufacturing process. To manufacture an expanded lamination mould from scratch out of aluminium was challenging process. But when I got final full sized mould done and learned a manufacturing method how to produce a high-quality bicycle handlebar made out of carbon fibre the process was very rewarding. During working on my thesis work I learned a lot of things related to how to use different designing and manufacturing software's and in particular how to use machinery needed to manufacture all the parts for the mould. Before I got the final product done I made a total of over thirty test lamination where I used different sorts of composite materials and tried a variety of manufacturing methods. I learned a lot about how composite materials behaves when using different kind manufacturing methods and equipment.

I would like to thank Erland Nyroth who is a laboratory engineer at Arcada University of Applied Sciences. Erland showed and taught me how to use all the machinery needed to produce the two expanded lamination mould manufactured for this thesis work.

I would also like to thank my thesis supervisor Rene Herrmann who is a lecturer in natural sciences and composite materials at Arcada University of Applied Sciences. Rene helped me with problems that I had during working on my thesis work. He also gave me some good advices how to improve the manufacturing process of the composite bicycle handlebar.

Helsinki, April 2016

Peter Mörsky

1 INTRODUCTION

1.1 Composite bicycle handlebar

The purpose of this thesis is to find a manufacturing method to produce bicycle handlebar made out of composite materials. Using composite materials it should be possible to produce lighter and stronger handlebars compared traditional materials, generally aluminum/steel.
There are different manufacturing methods for producing composite handlebar shaped seamless tubes, they are pultrusion/pullwinding, filament winding and filament braiding. Not having the possibility to use one of these manufacturing methods at the Arcada University of Applied Sciences premises, it was decided to design and build an expanded lamination mould. Using dry braided composite sleeve produced with a filament braiding machine, I had the possibility to make a handlebar made out of composite material.

General shape criteria for my handlebar design are it has to be flat in one direction, this is due to having only a 3axis rather than a 5axis milling machine for mould manufacturing. The dimensions of the handlebar are going to be made according to standard sizes.
My handlebar will be a so called flat handlebar meaning it can be a completely straight or slightly bended towards the driver, in my case it will have a bending of 6 degrees. Figure 1 shows a drawing of the full sized handlebar.

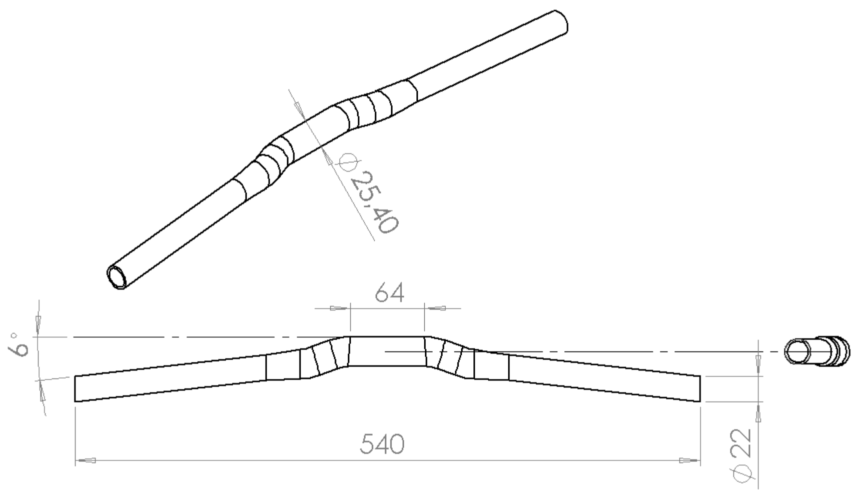


Figure 1: Drawing of the full sized handlebar.

To be ensured that the produced handlebar would be safe to use, the sustainability criterion is that it has to stand a static bending load of a 100 kg weighing person would ride a bicycle. Using a 3-point bending test machine the produced handlebar will go through tests to ensure its sustainability criteria will be fulfilled. The surface quality will also be examined using a microscope to find lamination faults as cracks and air pockets.

Handlebars made out of composite materials can be found to some extent from the market at the moment. One company that specialized in manufacturing composite bicycle parts is FSA. They have a wide range of parts what they produce out of composite materials like stems, seat posts, rims and handlebars. The company produces different kinds of handlebars for various uses. One of their models K-Force flat bar is similar to the type that is planned to be manufactured for this work. Figure 2 shows a picture of the K-Force flat bar. The handlebar is a carbon composite constructing which weighs 120 g (600 mm length).FSA does not tell you how the part is manufactured. [1]

The price of this handlebar is 164 €. Similar products have a price range from 100 € to 300 €. [2]

Figure 2: K-Force flat bar. [1]

Based on the known information about the K-Force handlebar, the manufactured product has an engineered price of 164 €/0,120 kg that equals to1366 €/kg. The carbon fiber sleeve that is intended to be used to manufacture the bicycle handlebar cost in itself 417 €/kg. This leaves for other materials, marketing and engineering
1366 €/kg – 417 €/kg = 943 €/kg.

1.2 Objectives

- Design and manufacture a composite mould suitable to make an bicycle handlebar
- Calculate the necessary bending stiffness for the handlebar as a tube
- Inspect surface defects of produced handlebar
- Test bending stiffness of the produced handlebar

2 LITERATURE REVIEW

2.1 Manufacturing of seamless composite profiles

Different manufacturing methods each with some characteristics limitations and product properties are reviewed.

2.1.1 Pultrusion/Pullwinding

Pulrusion is a process where composite fibers are drawn from fiber reels through a resins bath into a heated die. From there the cured composite profile that has the shape of the die is drawn out and cut to a desired size. Pultrusion is a continuous processing method and therefore has a high throughput. Pultrusion processes largest limitation is, that the cross section of the part normally must be constant, although both hollow and solid parts as well as many profiles can be made. [3]

Pullwinding is a more advanced version of a pultrusion machine. Otherwise, the process is the same in both machines but in pullwinding a transvers reinforcements of fibers are incorporated in the process. Pullwinding process gives better mechanical properties to the made product compared to a pultrusion process. [3]

Figure 3 shows a picture of a pullwinding machine. Part number 2 in the diagram (winding unit) is what makes it a pulltrusion machine, without the part it would be a traditional Pultrusion machine.

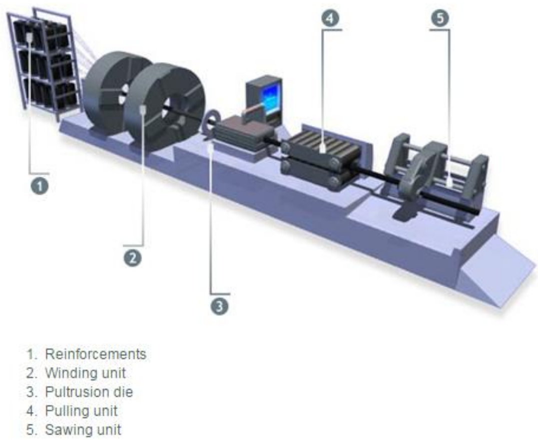


Figure 3: Pullwinding machine. [4]

The advantages of pultrusion/pullwinding technique are:

- Fast process with a high throughput rate.
- Can give the product a high resin content.
- Has a high material usage compared with set-up. (simplicity of the machine) [3]

The disadvantages of pultrusion/pullwinding technique are:

- Produced parts must have a uniform cross section.
- When using quick curing systems, the mechanical properties are often scarified.
- If fibers and resin are gathered and build up at the die opening, the equipment can jam due to friction. [3]

2.1.2 Filament winding

Filament winding is a process where a band of continuous fibers are wrapped around a mandrel and cured to produce close-formed hollow parts. The process can be done in two different ways, they are wet winding and dry winding. In the wet winding process the fibers are passed through a resin bath before winding on the mandrel and then cured in a high temperature. For dry winding the process is the same, but the fibers used are pre impregnated with resin. The curing for a dry winded product is /could be (usually) made in an autoclave. [5]

The filament winding process is done with a machine that is specially designed for this task. The machine works by wrapping fiber bands around the mandrel in adjacent repeating patterns. These processes cover the mandrel surface to produce one complete layer. [5]

Figure 4 shows a schematic drawing how the filament winding process works.

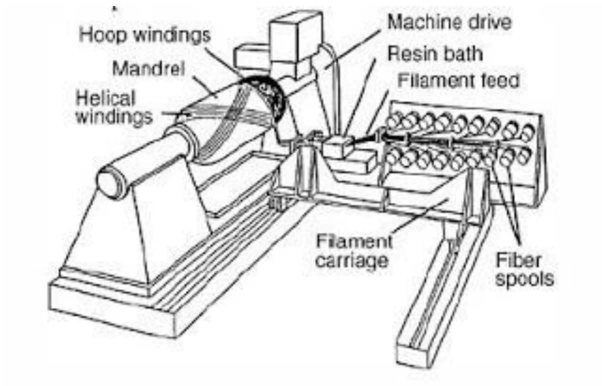


Figure 4: Filament winding machine. [6]

The advantages of filament winding technique are:

- Large structures can be manufactured
- Relatively low material cost in relation to prepreg materials.
- Continuous fibers are placed in the loading direction of the manufactured part. Directional strength can be easily assured by changing winding angle and winding pattern.
- Cross section can change.
- Fast way to produce parts with continuous design. [5]

The disadvantages of filament winding technique are:

- Parts with reverse curvature cannot be produced.
- Mandrels are indispensable in the process and they can be complex and expensive to produce.
- Shape of the component that is produced must be such that the mandrel can be removed and used again.
- Poor surface quality, unless polished later. [5]

2.1.3 Filament braiding

Filament braiding is a process that can be easily explained when takin a look at dance called maypole dance. In the dance boys and girls are holding on to a band that is fastened on the top of a pole. When the girls and boys are dancing around the maypole in opposite direction and bypassing the incoming dancer alternating from inside and outside in a figure-eight pattern, they create a braided structure around the whole pole. [7] Figure 5 shows how the maypoles dance work.

Figure 5: Maypole dance [8]

A filament braiding machine works on the same principle as the maypole dance. Instead of dancers holding bands it uses rotating bobbins that are special made holders for fibre spools. The maypole is replaced with a mandrel that is held by a moving robot. In the process it is also possible to add fibres along the mandrels axis, so-called UD threads that are fibres in 0 degrees. The machine produces a hollow tubular formed shape that can be braided straight on the mandrel. A filament braiding machine is capable of producing parts on mandrel that has a very complex shape. [7]

Using the same machine it is also possible to produce a continuous tubular braid or sleeves that is then gathered into rolls. [9] Figure 6 shows the working principle of a braiding machine, how the bobbins move and the produced materials pattern.

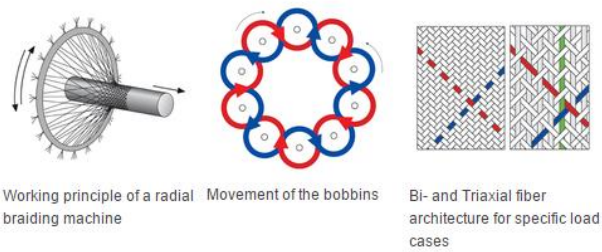


Figure 6: Working principle of a braiding machine. [7]

2.1.4 Dry filament braiding

In this process the braided filaments are dry, meaning that no resin is added in the process. This method is normally used to produce continuous tubular braid or sleeves that are then post-processed to some application.

Dry braided sleeves are often used when producing parts that have changing geometries. Sleeves can easily be expand open to fit moulding tools or cores, accommodating the form of the moulding tool/ core, much like a sock adapts easily to a foot. [10]

2.1.5 Wet filament braiding

In this process the fibres are pre-impregnated with resin or goes through a resin bath before braided to a desire shape. Usually wet filament braiding is used when producing continuous same and shaped product that can be later cut to a desired size. [11]

Advantages of filament braiding are:

- Fast and almost fully automated that can make the process cost low.
- Almost every shape is possible to produce.
- Possibility to use wet and dry fibers in the process. [7]
- Possible to produce a continuous tubular braid or sleeves that can be used in other manufacturing techniques. [9]

Disadvantages of filament braiding are:

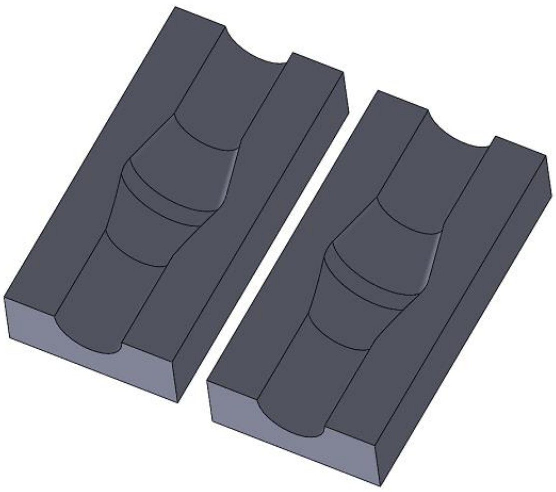
- Mandrels are indispensable in the process and they can be expensive to produce.
- Filament braiding machines are very expensive. [7]

Table 1: Summary of manufacturing methods of seamless profiles.

Process	Advantages	Disadvantages
Pulltrusion/pullwinding	Fast process with high throughput rate.	Produced parts must have a uniform cross section.
Filament winding	Cross section can change.	Parts with revers curvature cannot be produced.
Filament braiding	Almost every shape is possible to produce.	Mandrels are indispensable in the process.

2.2 Expanded lamination process

The composite handlebars that are going to be produced for this thesis is done using a manufacturing method called expanded lamination process. The following chapter explains how to process work.



First the bottom and top mould halves, which are in this case identical have to be cleaned properly. After that a release agent is applied an all mould surfaces so that the resin and composite material that is later used in the process would not stick on them.

Figure 7: Expanded lamination process step 1.

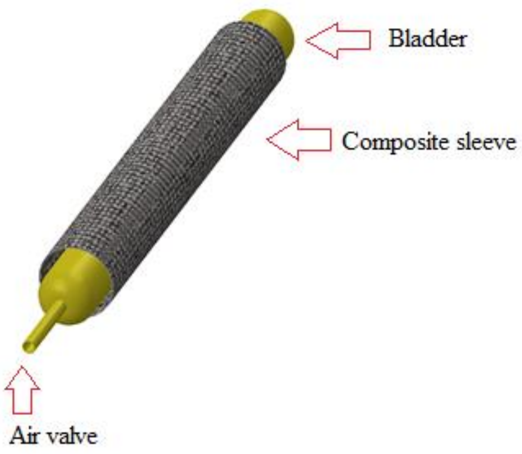


Figure 8: Expanded lamination process step 2.

The next step is to place the dry composite sleeve material around an air inflating bladder. At this point the bladder can be completely empty or alternatively partly filled that makes it easier to put the sleeve material around it. When the wanted amount of sleeve layers are added around the bladder it time to apply resin mixed with hardener on the composite material.

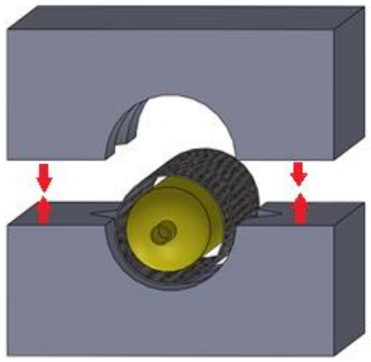


Figure 9: Expanded lamination process step 3.

After the resin has been added to the composite material the bladder with wet composite sleeve around it is placed in the bottom mould half's cavity. When ensured no material is outside the bottom mould half´s cavity the top mould is placed on it and attached using retaining screws or some other desired way.

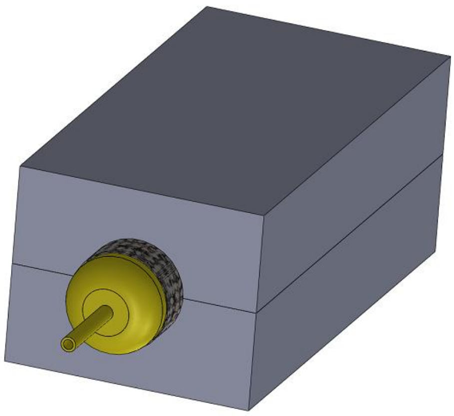


Figure 10: Expanded lamination process step 4.

After assured that the mould halves are tightly attached to each other it is time to fill the bladder through the air valve. When the bladder with the composite sleeve around it is filled with air they both expand and fill up the mould halves cavity space. The air pressure inside the bladder is held constant until the composite material has cured.

The last step in this expanded lamination process is to open the mould and remove the bladder from inside the laminated part. Now the strong and light hollow composite tube with an asymmetrical shape is ready.

Figure 11: Expanded lamination process step 5.

2.3 Composite materials

A composite material consists of two or more materials that are combined to each other to produce a material that has better properties than the materials alone. Usually a composite material consists of a bulk material, also called matrix and a reinforcement. In this project the used reinforcements are glass and carbon fibres and the used matrix is a polyester or epoxy resin. Fibre reinforced composites (FRP) main advantages are their high strength and stiffness combined with low density. Fibre reinforced composites are much lighter compared to bulk materials like steel, and for that reason it is an ideal material to produce light and strong parts. [12]

Carbon fibre-reinforced polymers (CFRP)

Carbon fibres consist of filaments with a diameter only about 0.005-0.010 mm. Thousands of filaments are twisted together to form a yarns, that can then be woven into fabric. [13] Carbon fibre fabrics can be produced with various patterns for different purposes. For this project the final produced bicycle handlebars was made using a dry carbon fibre 6K and 3K braided fabric in a sleeve form combined with epoxy resin. The braided sleeves fibres are in the normal state +/- 45 degree angle. Squeezed together the materials braid thickens and when stretched the braid thins out. [14]

The 6K stands for 6000 carbon fibres filaments in one yarn, and 3K for 3000 carbon fibres filaments in one yarn. [15]

2.4 Product shapes

Different shapes of bicycle handlebars

Handlebars can be categorized in two shapes: drop and upright. Drop handlebars are used in long distance and racing bikes due to their multiple hand-positions and an aerodynamic riding stance. [16] A typical drop bare shape has a straight middle section that curves from both ends downwards and toward the rider. Figure 12 shows a typical shape of a drop handlebar.

Figure 12: Typical shape of a drop handlebar. [17]

Upright handlebars are the most commonly used shapes for most bikes. When talking about upright handlebars it usually refers to flat bars and riser handlebars. The shape of a flat handlebar can be completely straight although in most cases, there is a very slight bend toward the driver. Road, city and comfort bikes are usually equipped with a flat bar due to ergonomic driving position and easy fastening possibilities for accessories like speedometer and headlight. [18]

Figure 13 shows a typical shape of a flat handlebar.

Figure 13: Typical shape of a flat handlebar. [19]

Riser bars are fundamentally longer flat bars that rises from the centre clamp area and usually also bend slightly toward the driver. These types of bars are mostly used on mountain and downhill bikes because it gives the driver more leverage that makes turning easier and require less energy. Riser bars also gives the driver more leg space that makes it easier to make sharp turns. Figure 14 shows a typical shape of a riser handlebar.

Figure 14: Typical shape of a riser handlebar. [20]

General geometry summary

Bicycle handlebars are made in several different sizes from 22.2 mm to 31.8 mm. This sizes prefers to the diameter of the clamp area in the centre of the handlebar also called the stem clamp size. For the handlebar that will be design and manufacture is a flat handlebar with a step clamp size of 25.4 mm that is a standard I.S.O. size used in on the majority of newer bicycles with upright and drop handlebars. [21] Table 2 shows other clamp sizes and their application.

Table 2: General handlebar dimensions. [22]

Handlebar dimensions				
Stem Clamp Size		**Grip Area Size**		**Application**
22.2 mm	**7/8"**	**22.2 mm**	**7/8"**	Steel bars. Mainly **BMX**, older Mountain bike bars.
23.8 mm	**15/16"**	**22.2 mm**	**7/8"**	Obsolete **British** size for steel handlebars, common on older **3-speeds.** This size was also used for older British steel **drop bars**.
25 mm		**23.5 mm**		Obsolete **French** size.
25.4 mm	**1"**	**22.2 mm**	**7/8"**	Standard **I.S.O.** size, used on the vast majority of newer bicycles with upright handlebars. This size was formerly common for steel drop bars.
25.4 mm	**1"**	**23.8 mm**	**15/16"**	Standard **I.S.O.** size, used on most bicycles with drop handlebars. Also used on older British aluminium upright handlebars.
25.8 mm		**23.8 mm**	**15/16"**	Unofficial in-between size used by some Italian handlebar makers for handlebars designed to be usable in either ISO (25.4) or Italian (26.0) size stems.
26.0 mm		**23.8 mm**	**15/16"**	**Italian** standard for drop bars, other bars made to fit Italian stems and some high-end aftermarket drop bars. This is sometimes incorrectly called "road" size.
26.4 mm		**23.8 mm**	**15/16"**	Older Cinelli and Cinelli copies. Cinelli changed over to 26.0 mm in 1998.
27 mm		**23.8 mm**	**15/16"**	Titan (obsolete).
31.8 mm	**1 1/4"**	**23.8 mm**	**15/16"**	Road oversized.

2.5 Stiffness and Strength

To ensure that the produced handlebar would be safe to use, the sustainability criterion is that it has to stand a static bending load of a 100 kg weighing person riding a bicycle. This means that the handlebar must have a certain strength, which refers to a measure of the maximum force that can be placed on a part before it permanently deforms or breaks. In this case the handlebars minimum strength must maintain 981 N. This result can be calculated using the following equation $F = m * \text{a}$ [23]

$$F = Force(N)$$
$$m = Mass\ of\ object\ (kg)$$
$$a = g = 9{,}81\ Acceleration\ (m/s^2)$$
$$F = 100kg \cdot 9{,}81\frac{m}{s^2} = 981N(1)$$

According to Euler Bernoulli [24] the beam deflection causes a stress:

$$\sigma = \frac{Mc}{I} = \frac{Flc}{I_{tube}} = \frac{Flr_{out}}{\frac{\pi}{2}(r_{out}^4 - r_{in}^4)} = \frac{981N \cdot 0{,}6m \cdot 0{,}0127m}{\frac{\pi}{2}(0{,}0127m^4 - r_{in}^4)} \qquad (2)$$

The necessary inner diameter of the tube becomes:

$$r_{out}{}^4 - \frac{Flr_{max}}{2\pi\sigma} = r_{in}{}^4 \qquad (3)$$

Carbon fiber lamina is expected to have an estimated strength of $\sigma = E\varepsilon = 30GPa \cdot 0.01 = 300MPa$. [25]

For an example design the parameters become:

R_{out}(outer radius)	12,7 mm
F(force)	1000 N
σ(sigma)	300 MPa
R_{in} (inner radius)	12,18 mm

The lamina thickness is the difference between inner (R_{in}) and outer (R_{out}) diameter and it was calculated to be 0,52 mm.

The thickness of a handlebar prefers to how much material has been used in the manufacturing process. Having a handlebar with a thin wall thickness means it is going to be light but not that strong. For example when making a handlebar for a mountain bicycle the handlebar must withstand large forces so its wall thickness has to be large. Figure 15 shows a graph over how the wall thickness of a handlebar made out of carbon fiber affects the durability. Readings in the vertical direction prefers to wall thickness (mm) and horizontally how much force the handlebar will withstand (N).

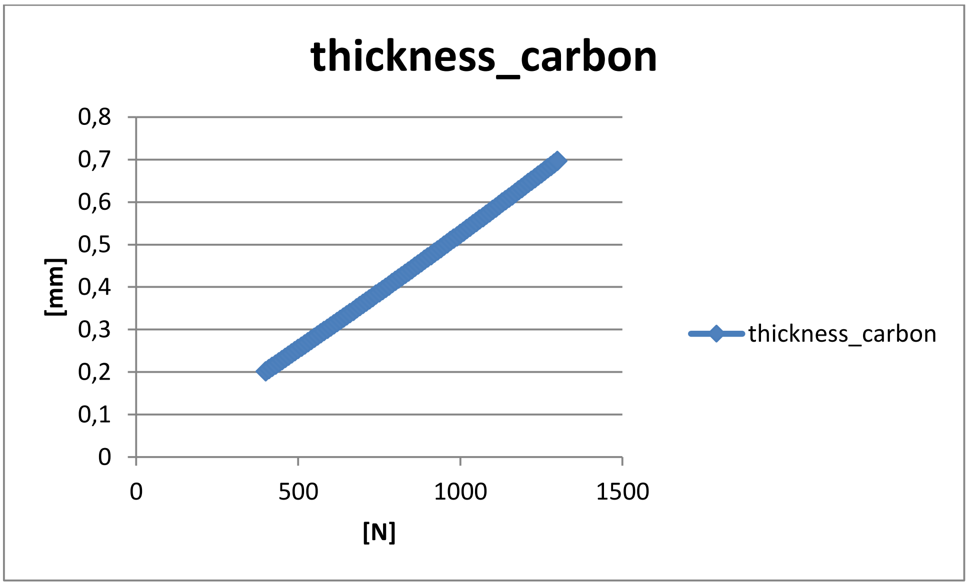


Figure 15: Necessary wall thickness as function of load for a tubes.

Carbon fiber is not the only composite material that can be used to produce a bicycle handlebar. Glass fiber is a widely used composite material to produce laminated products. Glass fiber does not have as good mechanical properties as carbon fiber so more material has to be used to have the same strength as a handlebar made out of carbon fiber. Figure 16 shows a graph over the needed wall thickness for glass and carbon fiber to be equal as strong. Readings in the vertical direction prefers to wall thickness (mm) and horizontally how much force the handlebar will withstand (N).

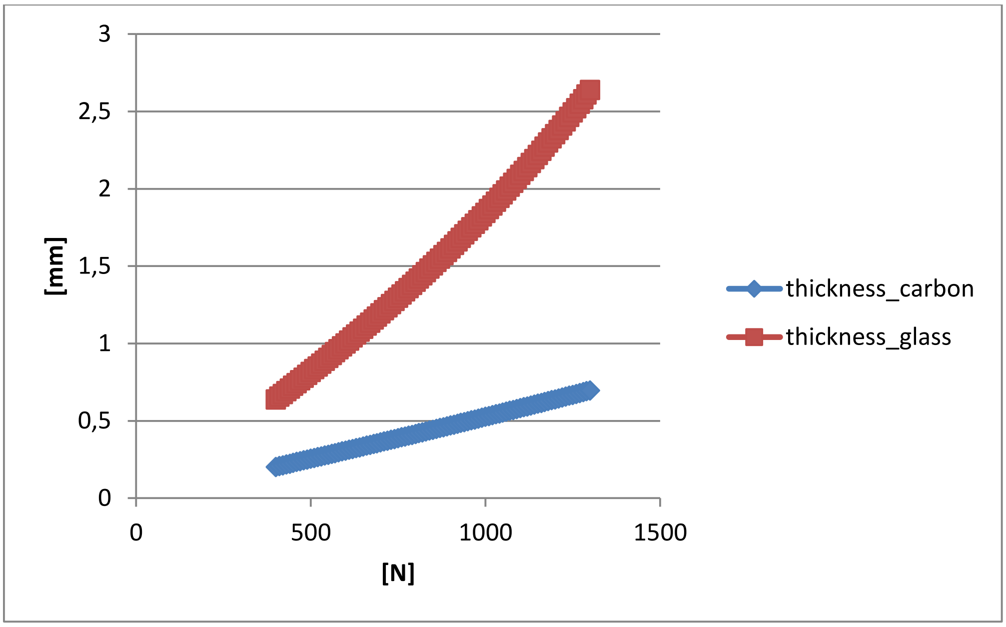


Figure 16: Comparison of necessary wall thickness for glass and carbon fiber tubes.

3 METHOD

3.1 Prototype

3.1.1 Part - shape

When designing the first prototype handlebar numerous different shapes where made before ending up with the design that can be seen from figure 17. The handle bar total length is only 225 mm long but otherwise the dimensions are the same as in a standard size flat bar. The stem clamp has a diameter of 25,4 mm and length 50 mm. From there the handlebar narrows to 22 mm and also has a back sweep of 5 degrees. The narrowed area between the stem clamp and grips was intentionally designed to be quite steep, because it was wanted to research if it’s possible to produce durable and good surface finish products with this kind of design. The length of prototype 1 is only 225 mm due to multiple test was to be done, and therefore the material cost would have been much higher using a full scale prototype.

Prototype 1 was designed using Solidworks 2015-2016 edition. Solidworks is a solid modelling computer-aided design (CAD) and computer-aided engineering (CAE) software program. [26]

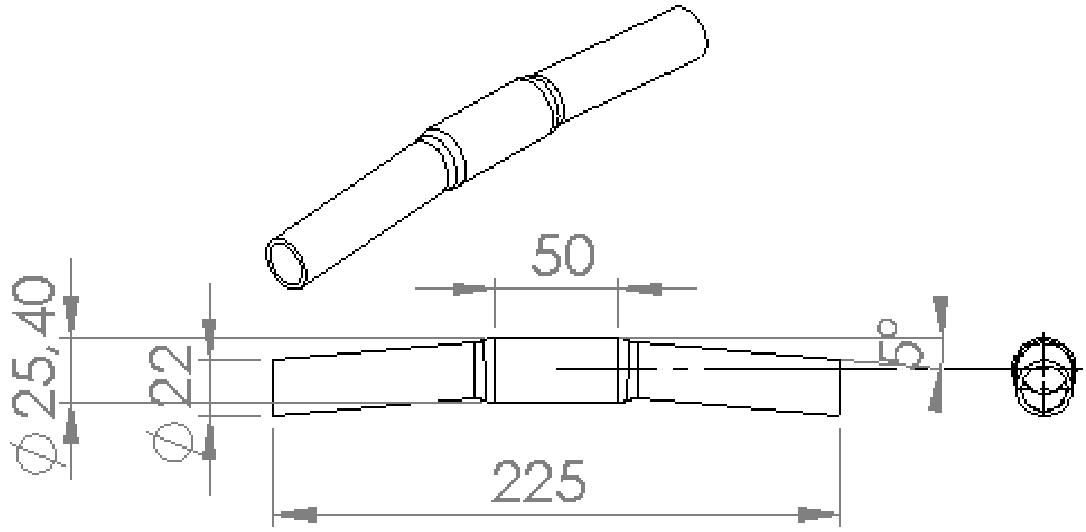


Figure 17: Design of prototype 1.

3.1.2 Mould – for prototype

The mould for Prototype 1 was also designed using software programme Solidworks. The mould consists of two mould halves with a parting line in the centre of the handlebar in the longitudinal direction. This means that both mould halves has a cavity of half of the handlebars shape.

Figure 13 shows a drawing and dimensions of the bottom mould half. The circles in the drawing indicate holes for various uses. The holes at the upper edges are for guide pins that are used to align the mould halves exactly in top of each other. In the centre the four overlapping holes are for retaining screws and the two remaining holes are for screws to open the mould. The mould is attached to each other from the top so the top mould half have straight holes and the bottom half has threads for the screws. When opening the mould it is don from the bottom. Only the bottom mould half has holes with threads, so the screws are twisted straight to the top mould halves inner surface. This method allows you to separate the mould halves easily without damaging the mould or the freshly laminated handlebar. Figure 18 shows a 3D-drawing of the complete mould.

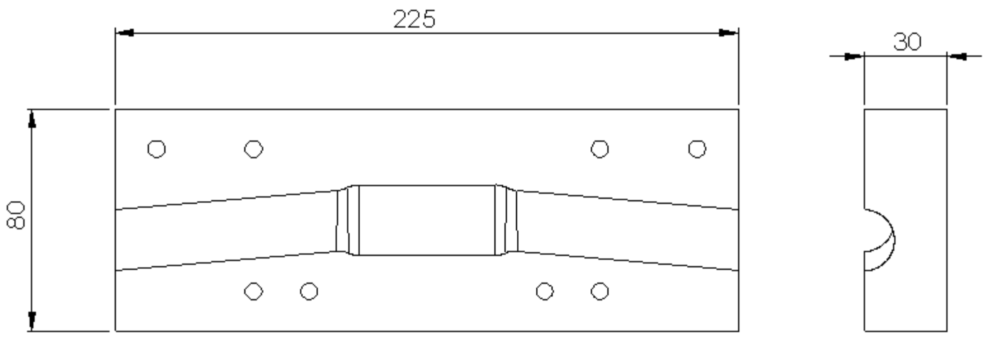


Figure 18: Drawing of prototype bottom mould half.

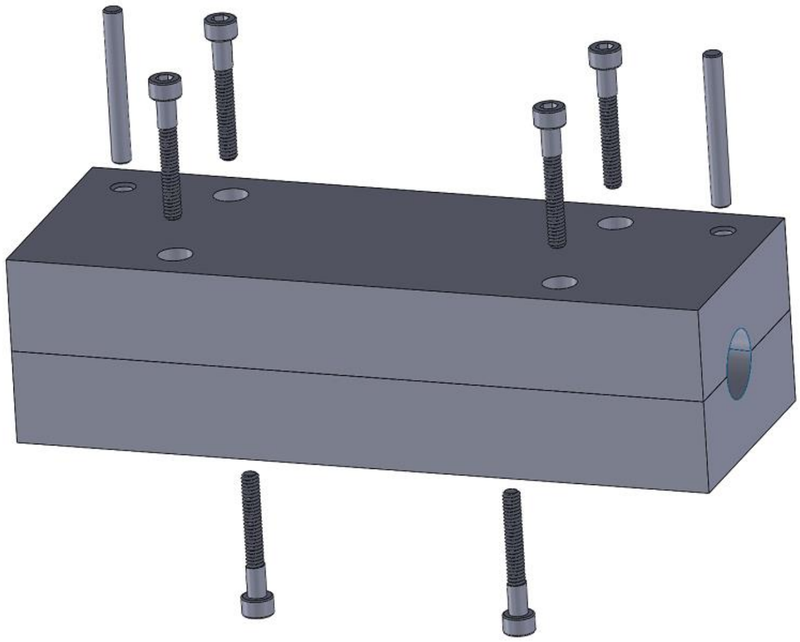


Figure 19: Drawing of complete prototype mould.

When the design for prototype 1 mould was complete it was time to start plan how to make an actual mould out of aluminum. First all solid 3D-drawings was transferred to a software program called Mastercam X9. Mastercam is machining software used to design and manufacture parts using a CNC milling machine. [27]

To produce a well-functioning milling program took a lot of research. The most difficult step was to create a program that would produce a good surface quality in a reasonable machining time.

When the milling programs for the handlebar shape, and the holes for screws and guide pins was finished it was saved as a G-Code, that's is a generic name for control language for CNC machines. It tells the CNC machine how to move, speed and all other parameters needed to get the machining done. [28]

Using the CNC machine a test milling of the bottom mould half was done in a piece of wood as can be seen in figure 20. This was to done to check that all cutting parameters was correct. After changing few parameters the mould was completely milled out of aluminum as can be seen from figure 21. Threads for the retaining and opening screws were manually made after the milling operation. Figure 21 shows also the screws and guide pins used in the mould.

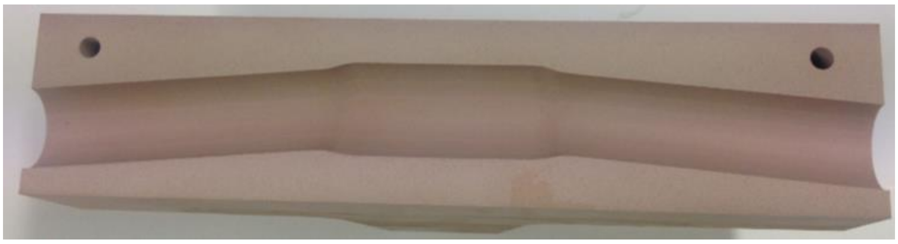


Figure 20: Test milled bottom mould half.

Figure 21: Prototype 1 complete mould.

3.1.3 Manufacturing procedure

Test 1

First lamination test was made by using one layer of glass fibre sleeve. The bladder used in this lamination was a modified bicycle inner tyre that was cut open in on place so that it was possible to fit the glass fibre sleeve around it. To get the inner tube air-tight again a short piece of a garden hose was placed inside the inner tube, where it had been cut open. Compressing the inner tube and hose together on both sides using hose clamps it was air-tight again. The inner tubes original valve was removed so that it could be inflated using a compressed air pistol. Figure 22 shows the lamination set up.

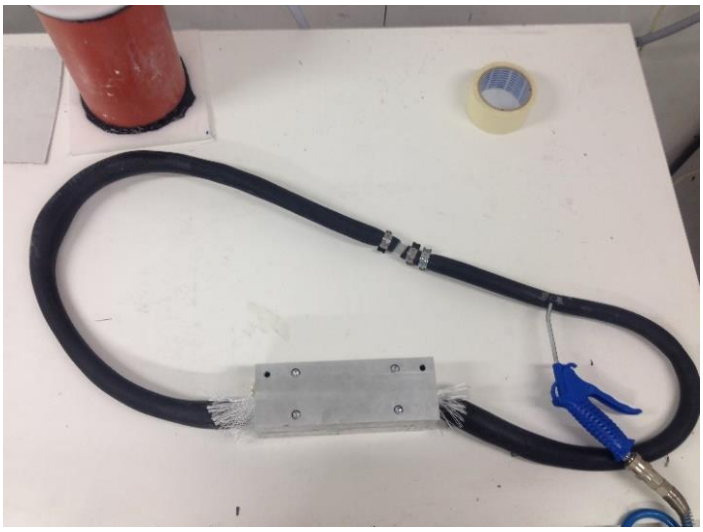


Figure 22: First lamination set up.

The lamination process was made by adding resin on the glass fibre sleeve using a brush. When this was done the bladder with the impregnated glass fibre sleeve around it was placed in the mould, and then the mould was closed. The bladder was then inflated using 1 bars pressure and the lamination was left to cure over the night.

The outcome of the first test was not that good; some glass fibre material had been trapped between the mould halves leading to a deformation of the lamina and some resin leakage. Figure 23 shows a picture of test lamina 1.

Figure 23: Test lamination 1.

Test 2-5

First five lamination test was done using polyester resin and a single layer of glass fiber sleeve and the bladder same as in test 1. The bladder proved to be a challenge in many ways. Even when the bladder was empty its circumference was larger than the moulds cavity, due to this the bladder had to be stretched so it could fit inside the mould. To stretch the bladder with the glass fiber sleeve around it, and at the same time trying to place it inside the mould halves proved to be impossible. In all the first tests some glass fiber material had been trapped between the mould halves. One other problem was the bladders durability. The bladder filled up unevenly and blew up using pressure over 1 bar.

Test 6-15

For the following lamination test a bicycle inner tire with a smaller circumference was used. To get more pressure into the bladder, plastic tubes were places on both sides of the mould preventing the bladder to fill up unevenly. Figure 24 shows how the setup was done.

Figure 24: Prototype manufacturing setup.

With this setup the max pressure that could be use was 2.5 bars. Tests 6-15 were done using polyester resin and 3 layers of glass fiber sleeve. In two test cellulose fiber was added to the resin to get higher viscosity. The results were a disappointment, all the test pieces had large lamination faults. The faults were large air pockets especially at the narrowing areas between stem clamp and grips. Also the orientation of the glass fibers was messed up at in many places.

The conclusion from the first 15 lamination test was that the soft rubber bicycle inner tire was not suitable for this process. The high friction between the soft rubber and glass fibers led to that the glass fibers could not move freely to take its correct shape.

Test 16-20

For test 16-20 the composite material was changed to carbon fiber and resin to epoxy. The used material was a 6K carbon fiber sleeve. The bladder used in this tests was a silicone tube with an outer diameter of 16 mm and a wall thickness of 4 mm. All the test was done using 2 layers of carbon fiber sleeve and the lamination setup was same as in test 6-15.

The results for these test was quite poor. The biggest issue was the open mould lamination setup which resulted in that not enough pressure could be applied to the bladder without it blowing up. Otherwise the silicon tube worked fine but with this setup the max pressure that could be used was 2.5 bars. The lack of pressure caused lamination faults because the carbon fiber sleeve material could not expand enough to fill the whole mould cavities.

Test 21-25

For these tests, the lamination setup was changed to a closed mould construction so that more pressure could be used. To get higher pressure, plugs were placed in the ends of the cavities inside the mould. One of the plugs was hollow and modified so that an air house could be attached to it as can be seen from figure 25.

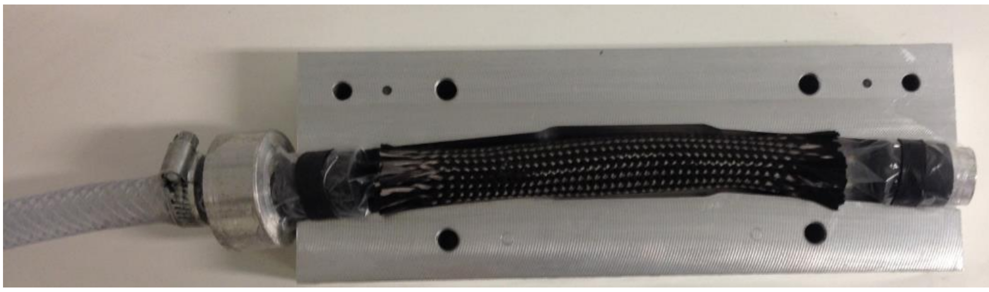


Figure 25: Test 21-25 setup.

By placing the plugs inside the bladder ends and closing the mould it was possible to get it completely air tight. Using this setup it was possible to use a pressure up to 7 bars. The bladder used in this test was a plastic foil tube that allowed the carbon fiber material to move easily and takes it shape due to low friction. The first test using this closed mould construction (test 21) was made using epoxy resin and two layers of carbon fiber and the results was immediately promising. Due to modification of the mould construction the test piece was only 15 cm long, but it was enough to give all the necessary information needed. The piece had only a few minor lamination faults at the surface but otherwise the end result was very good as can be seen from figure 26.

Figure 26: Test 21 result.

Tests 22-25 were made using the same setup and materials and all the results were good. The conclusion from these tests were that by using high pressure in this cases 7 bars was the key to get a good laminated parts. By using high pressure, it reduces the change of air being trapped between the cavity surface and material which leads to lamination faults as air pockets.

At this stage, it was decided that we have received enough information from test 1-25 to build the mould for the full sized handlebar.

3.2 Full size handlebar

3.2.1 Part-Shape

The design for the full sized handlebar differs quite much from the prototype. The biggest change is the area between the stem clamp and grips that has now a shallower design. This design change was done due to having lot of lamination faults with the prototype design. The shallower design should help the composite material to settle to its shape in the lamination process. Not having steep edges will also improve the strength of the handlebar. In the design there is also a small curvature from the stem clamp to the grips, this makes it possible to adjust more on the riding position. The total length of the handlebar is 540 mm and it has a back sweep of 6 degrees. Otherwise the handlebar is design according to standard dimensions, the diameter of the step clamp is 25,4 mm and grips 22 mm.

The full size handlebar was designed using Solidworks 2015-2016 edition. Solidworks is a solid modelling computer-aided design (CAD) and computer-aided engineering (CAE) software program. [20]
Figure 27 shows a drawing of the full sized handlebar.

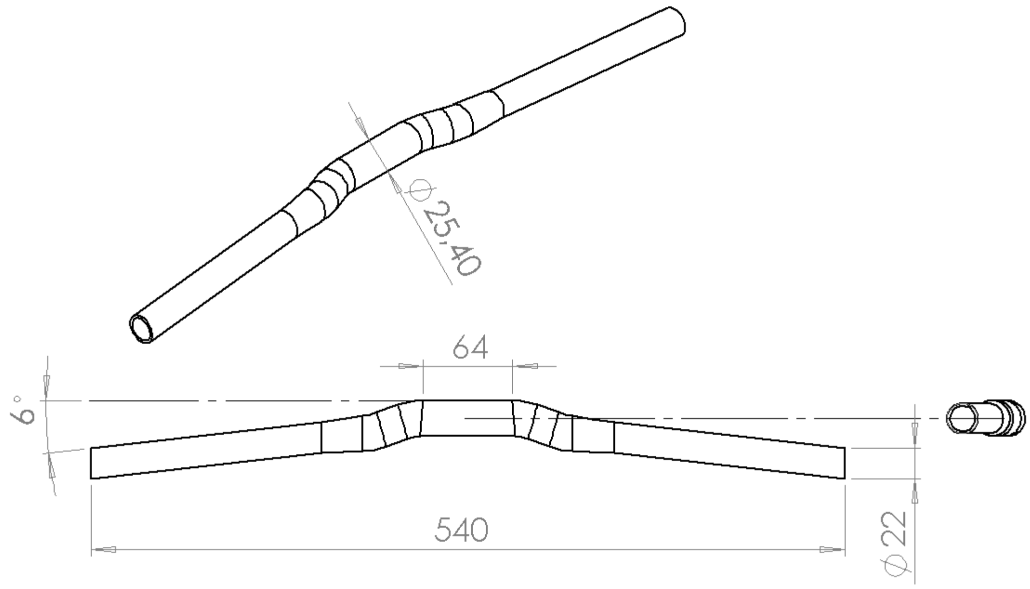


Figure 27: Drawing of the full sized handlebar.

3.2.2 Mould

All the over twenty test lamination which was done using the prototype mould gave us a lot of information how to design and produce the full size handlebar mould. One of the biggest problems with the prototype mould was not getting enough pressure inside the mould. The lack of pressure caused lamination faults because the composite material could not expand enough to fill the whole mould cavities. To overcome the pressure problem the full sized handlebar was designed to be a closed mould construction. This air tight construction was made by placing plugs on each ends of the moulds cavity. Figure 28 shows one of the two mould halves, from where the places for the plugs can be seen. There are also two grooves on both end, they are fore O-rings which improves the air-tightness and holding the bladder on place.

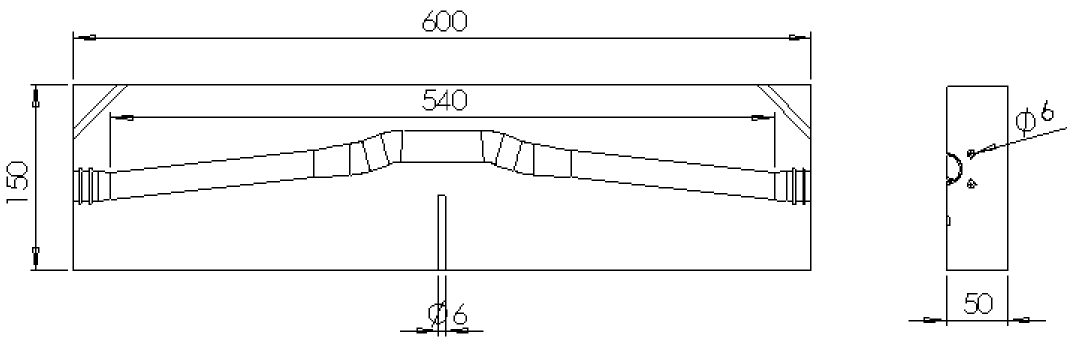


Figure 28: Full sized handlebars mould half.

To get air to inside the mould one of the end plugs are hollow with a quick release air valve attach to it. For ensuring that the end plugs would remain in place end plats where used that were both attached with fore nuts. One of the plates had a round hole with a diameter of 17 mm so that the air valve with a diameter of 10 mm would fit inside it. The diameter of the plug was bigger (24 mm) so it could not fit through the plate's hole. Figure 29 shows a schematic drawing of the air valve setup.

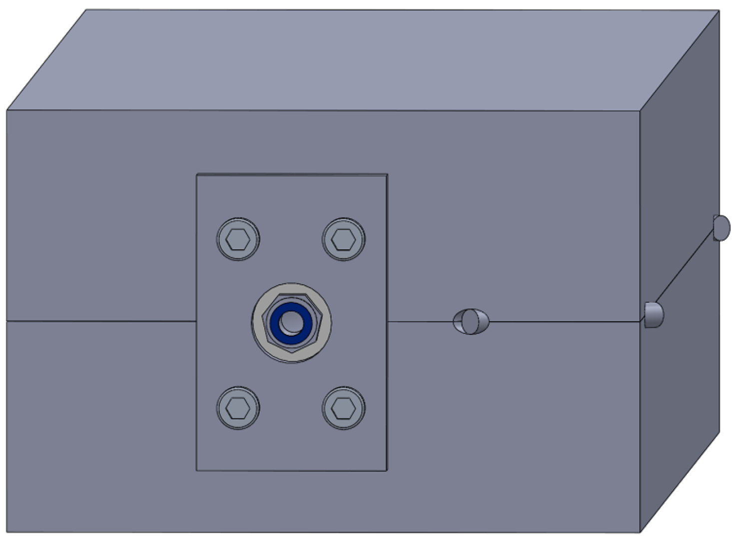


Figure 29: Full sized moulds air valve setup.

Another problem with the prototype mould was when laminating some resin always got between the mould halves. The resin then got in to the vertical positioned holes for guide pins, retaining and opening screws. When the resin cured, it was hard to open the jammed screws and a lot of cleaning had to be done before the next lamination was possible to perform. To overcome this problem in the full sized mould, the guide pins where designed to be in the horizontal direction between the mould halves. No retaining screws was needed for this mould. The mould was presses together with a hydraulic press during the lamination process. Figure 30 shows a schematic drawing of the complete full sized mould with parts numbered and named.

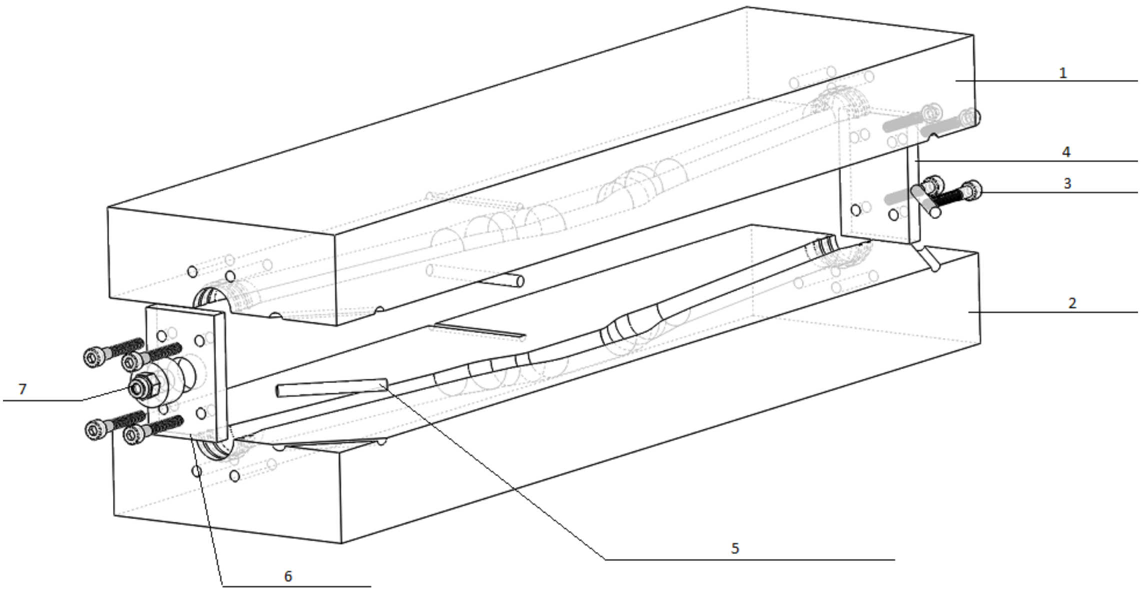


Figure 30: Schematic drawing of the complete full sized mould.

1. Top mould half.
2. Bottom mould half.
3. Fastening screws for end plates.
4. End plate.
5. Guide pin.
6. End plate with a hole in the middle for the air valve.
7. Plug with air valve attached to it.

Figure 31 below shows the complete mould with all parts numbered and named.

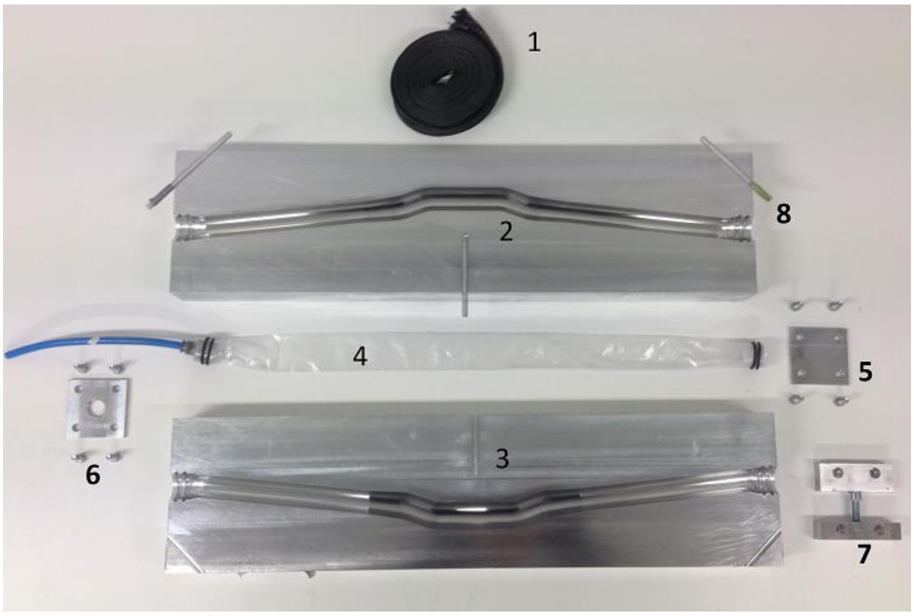


Figure 31: Complete full sized mould.

1. Roll of dry carbon fiber sleeve.
2. Bottom mould half.
3. Top mould half.
4. Plastic bladder with plug in each end with O-rings around them. Plug on the left side is hollow and has an air valve attached to it.
5. End plate.
6. End plate with a hole in the middle for the air valve.
7. Moulds opening mechanism.
8. Guide pin.

3.2.3 Manufacturing procedure

Using the full sized mould a total of 7 handlebars were produced. All the handlebar was made by using epoxy resin.

The first two test was made by using two layers of 6K carbon fiber sleeve. Both of these test had the same problem, the material did not fill the whole mould cavity especially from the stem clamp area to the grips which resulted in large lamination faults. For test number three the carbon fiber material was folded once so that there would be more material to expand in the problematic areas. The outcome was that whole cavity had filled up but the material was still slightly folded. For test number four a third layer of carbon fiber sleeve was added. The third layer made the whole material stiffer and it could not expand as well anymore resulting in a poor lamination with many faults. Figure 32 shows the lamination faults in test number 4.

Figure 32: Lamination faults in full sized handlebar, test number 4.

To overcome the problem with not having a fully filled mould cavities the carbon fiber sleeve material was again slightly folded for test number five, but the result was the same as for test number three. In all the previous tests the sleeve material had been slightly pre-expanded, but for test number six the material was expanded as much as possible and also pre-formed. By pre-forming the material to the shape of the handlebar before closing the mould an adding pressure was the key for a good lamination. The outcome of test number six was an almost perfect carbon fiber bicycle handlebar with only two minor surface lamination faults. At this point the 6K carbon fiber sleeve that was reserved for the thesis work ran out. For the last test the material was changed to a 3K carbon fiber sleeve. In this test we used three and a half layers of carbon fiber sleeve. The half 20 cm long piece was placed between layers two and three in the center of the handlebar to add more strength to the stem clamp area. A 10 mm stripe of UD-carbon fiber was also added in the longitudinal direction on the top of the handlebar. Uni-Directional (UD) carbon fiber is carbon reinforcements with all the fibers going in one direction, in this case in the longitudinal direction of the handlebar. UD-carbon fiber are used to add stiffness for the produced part. [29] Test number seven was made using the same technique as in the previous test and the results was again great.

Table 3 below shows more details of the conducted tests. Vf stands for fiber volume fraction that is the percentage of fiber volume in the entire volume of a fiber-reinforced composite. The fiber volume fraction can be calculated using the following equation,

$$V_f = \frac{v_f}{v_{tot}}$$

V_f =Fiber volume fraction

v_f =Volume of the fibers (dry)

v_{tot} = Volume of the total composite

[30]

Table 3: Full sized handlebars test 1-7.

Tests number	**Layers of sleeve**	**Pressure (Bar)**	**Mass of dry material (g)**	**Total mass (g)**	$\boldsymbol{Vf}$ **(%)**	**Results**
1	2	7	34,9	45,5	76,7	Material between form halves. Air pockets.
2	2	7	35,1	46,2	76,0	Material had not filled up the whole cavity.
3	2	4	33,8	47,2	71,6	Material folded. Minor lamination faults.
4	3	7	48,7	73,6	66,2	Large air pockets in the area between clamp and grips.
5	3	7	45,5	66,2	68,7	Material folded. Air pockets.
6	3	7	46,6	70,1	66,5	Only minor surface lamination faults.
7	3.5+1stripe of UD-carbon fiber on the top	7	45,5	56,8	80,0	Only minor surface lamination faults.

All the full sized handlebars were produced using up to 7 bars of air pressure. Due to the high pressure the handlebar mould halves wad pressed together using a 10 tons hydraulic press. Figure 33 shows the manufacturing setup for the full sized handlebar.

Figure 33: Full sized handlebars manufacturing setup

4 ANALYSIS

4.1 Surface defects

Visual inspection of the produced final size bicycle handlebar (test piece number 7) was made using an optical microscope that was connected to a digital camera. Using a five time enlarging optic lens pictures where taken of the surface of the handlebar. Pictures were taken from different parts of the handlebar, figure 34 show the inspected handlebar and also the sections A and B where the magnified pictures where taken.

Figure 34: Surface quality analyze, sections A and B.

Section A is the area between the stem clamp and grip zone. This area was the most challenging section in the lamination process because of the bending and at the time narrowing design. At this section the first laminations that were made had lamination faults in a form of large air pockets because the material had not filled up the whole mould cavity. The handlebar that is now analyzed the carbon fiber material had filled up the whole section of the cavity but there was still some minor lamination faults at the surface as can be seen from figure 35. The lamination faults are small air pockets in average, 0,5 mm located only on few places on section A.

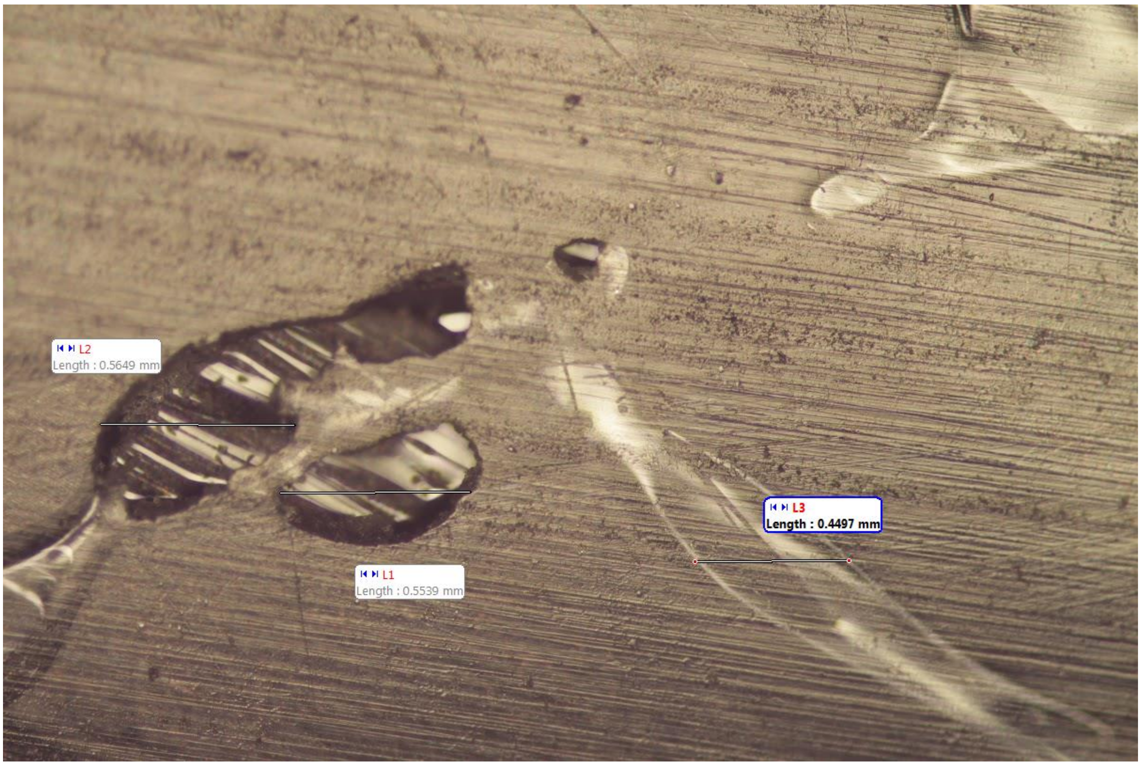


Figure 35: Surface quality analyze, section A.

Section B is located on the handlebars grip area. This part of the handlebar has a uniform diameter and is therefore easier to get a good surface quality. Figure 36 shows a picture taken from the section B surface. From the picture it is possible to see a small dent with a diameter of 0,1782 mm. The dent has emerged probably from an air bubble or an impurity which has got in to the mould. Otherwise the surface quality on section B is excellent.

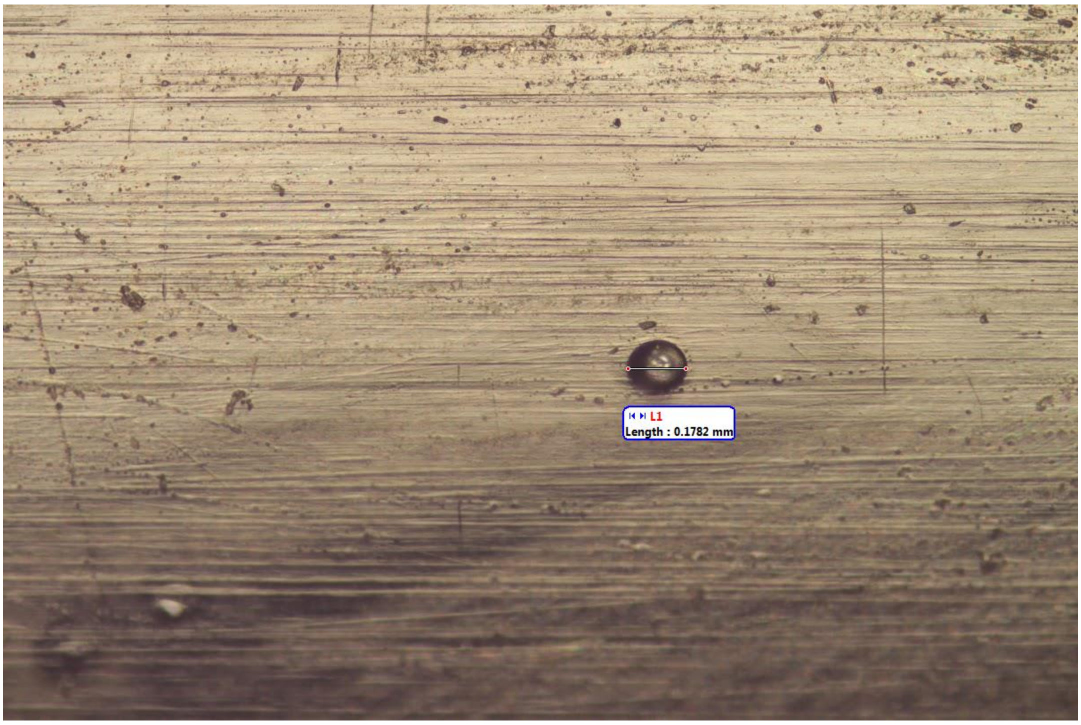


Figure 36: Surface quality analyze, section B.

4.2 Bending stiffness

The bending stiffness of one produced full sized handlebar was tested using a material testing machine. The test that was conducted was a 3-point bending test, figure 37 shows how the test setup done.

Figure 37: 3-point bending tests setup.

The test was done by placing the handlebar on two 80 mm stationary holders, replicating human hands that where 300 mm apart from another. In the center of the handlebar was also a 40 mm holder replicating a bicycle stem on to which an even force was applied until the handlebar broke apparat. Using the given information from the test (figure 38) the bending stiffness could be calculated from the slope of the bending data.

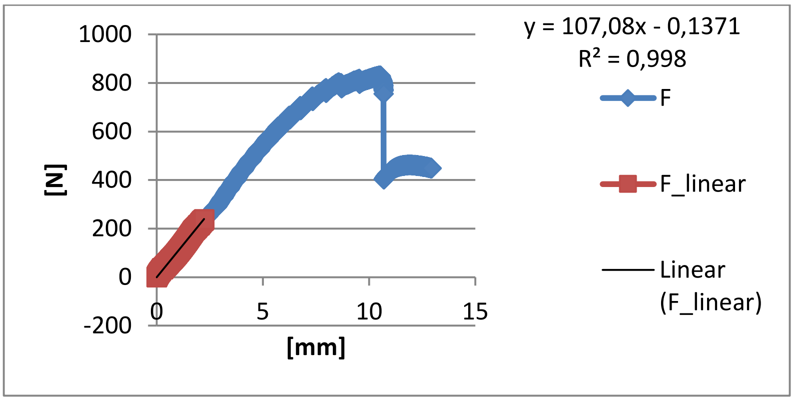


Figure 38: 3-point bending results.

The slope was measured to be 107 $\frac{N}{mm}$.

3-point bending is defined by [31]

$$y = \frac{FL^3}{48EI}$$

This solved for F(y) gives:

$(D = EI)$

$$F(y) = y\frac{48EI}{l^3} = y\frac{48D}{l^3} = y\ 107$$

This leaves the stiffness as $D = EI = 107 \cdot \frac{l^3}{48}$

$$D = 107 \cdot \left(\frac{300^3}{48}\right) \qquad (1)$$

$$D = 60{,}1875 \cdot 10^6 \qquad (2)$$

$$I = \frac{\pi}{2}({r_{out}}^4 - {r_{in}}^4) = \frac{3{,}14}{2} \cdot (25{,}4^4 - 24{,}4^4) \qquad (3)$$

$$E = \frac{D}{I} = \frac{60187{,}5 \cdot 10^3}{96991{,}3} \qquad (4)$$

$$E = 0{,}62\ GPa \ (5)$$

Earlier discussed on page 23 said that a carbon fiber lamina should have at least a theoretical E=30 GPa (Young´s Modulus [32]). The poor result compared to the theoretical value is a resultant of few things, one is that the calculations made from the test are done according that the handlebar would have the same diameter the across its length with an even wall thickness. In reality the handlebars has a changing diameter and is bended the stem clamps areas diameter is 25,4 mm and grips 22 mm. The changing diameter means that wall thickness is not even because the carbon fiber material has to stretch more in places with larger diameter resulting in thinner wall thickness. This means that the second moment of inertia is estimated far too high. One other reason for the poor results were that test was carried out using a handlebar with substantial lamination faults (full sized handlebar test number 4) as can be seen from page 36 figure 32. The lamination faults significantly weaken the structure of the handlebar. Although the handlebar that was tested had substantial lamination faults, it was calculated that it would stand a static bending load of at least 70 kg weighing person riding a bicycle.

For quality control the manufactured handlebars from this mould could be bended safely by 3-4 mm and the slope being measured. The measured slope is then an indicator for the lamina properties.

5 RESULTS

For this work over twenty test lamination were firstly made with an expanded lamination prototype mould, using the knowledge from these test a full sized handlebar mould were manufactured. Using the full sized handlebar mould totally of seven handlebars were produced. When overcoming some lamination problems with the full sized handlebar mould, a way was finally found to produce high-quality bicycle handlebars made out of carbon fiber. Figure 39 show a picture of the seventh and final handlebar produced that is attached to a stem.

Figure 39: Final full sized handlebar produced attached to a stem.

This handlebar has three and a half layers of 3K carbon fiber sleeve in the longitudinal direction. The half 20 cm long piece was placed between layers two and three in the center of the handlebar to add more strength to the stem clamp area. There is also layer of UD-carbon fiber on the top of the handlebar to give more strength to the whole structure. The total weight of handlebar is 56,8 g and length 540 mm. The manufacturing price for this handlebar became to a total of 23 €.

6 DISCUSSIONS

The purpose of this work was to see how it's possible to produce a high-quality composite bicycle handlebar by using a self-designed and manufactured expanded lamination mould. To manufacture the two mould used in this work proved to be one of biggest challenges. The mould cavities have an irregular shape combined with a very smooth surface. In order to get the desired outcome of the produced moulds the amount of work exceeded all expectations. Due to this time for making test laminates and developing the process decreased significantly. But in the end a way was found to manufacture high-quality bicycle handlebars made out of carbon fiber.

7 CONCLUSIONS

When laminating the full sized handlebar we had some problems with the carbon fiber sleeve material to expand the whole mould cavity. This problem was fixed by pre-forming the carbon fiber material to the shape of the handlebar before closing the mould. Other important things that was learn during test were using a right kind of bladder and using high pressure. During testing with the prototype handlebar mould few different types of bladder materials was used. The first test laminations was done a bicycle inner tube which was found as inappropriate material for this work. The high friction between the soft rubber and carbon fiber material led to that the material could not move freely to take its correct shape. All the full sized handlebars was made using plastic foil tube that allowed the carbon fiber material to move easily and takes it shape due to low friction. Using high pressure that was achieved due to the closed mould construction of the full sized mould also improved significantly the capability of the material to expand and taking the shape of the moulds cavity.

8 SUGGESTIONS FOR FURTHER WORK

To produce a composite bicycle handlebar with the expanded lamination mould designed and built for this thesis was a quite slow process. To produce a handlebar the mould always had to be cleaned after a lamination, bladder and composite material cut to correct size and adding plugs and air valves to right places. The resin used had to be mixed and added on the composite material, closing and securing the mould inside a hydraulic press before adding pressure. All of this things that had to be done took several hours plus the curing time for the resin used in the full sized handlebar was around 5-6 hours. So the conclusion of this is that only one handlebar could be produced in a day.

To speed up and simplify the process in the future one suggestion would be to use pre-cut and pre-impregnated carbon fiber sleeve material. By using pre-impregnated material the process would be less messy and you would have more time to pre-form the material to the shape of the mould cavity that is the most important step in the whole process. The pre-impregnated material cures when applying heat to it. This would not be a problem, thermal resistors could be easily added to the handlebars mould cavities.

To manufacture a handlebar with less effort compared to the produced product done for this thesis work the handlebar should have a simpler design. By a simpler design refers in this case ta a design without any curvature. Having a more straight design would help the composite material to adapt easier to the shape of the moulds cavity in the manufacturing process.

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