BIKE BRAKE LEVER DESIGN

Continuum Mechanics

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1. MATERIALS, SOLICITATIONS, INFORMATION RESEARCH AND PRELIMINARY DESIGN.

1.1 Basic function and working key points.

The basic function of brake levers is to activate the brake mechanism, which allows people to slow down or stop while they are riding a bike. There are two types of mechanism: mechanic brakes or hydraulic, and both functioning and effectiveness are really different. Also there are differences between all kind of modalities there are in the world of biking, without taking into account if they are hydraulic or mechanic and different kind of materials, depending on the quality of them.

The functioning of brake levers is very simple. If we talk about a mechanic brake lever, first of all we need to push it. This action stretches a metallic sane that permits the two brake pads put pressure on one of the two wheel rims. The functioning of hydraulic brakes is a bit different. Here in order to stop the bike, the brake lever pushes special oil making pressure and making the bike slow down or stop.

The task that brake levers have to carry out makes them to reach some essential properties. So they have not only hardness and stiffness but also lightness and resistance. And this has a simple explanation; these levers have to be able to support an extremely hand-push without breaking or deforming, so they make possible for people to slow down the bike without any danger.

In order to show how to resume the most important characteristics of brake levers, there are some examples:
### SRAM FORCEDOUBLE TAP CONTROLS

- **Weight:** 302g
- **Speeds:** 10 rear
- **Technology Highlights:**
  - Double Tap with ZeroLossTM on the front
- **Material:** Carbon Brake Lever, Magnesium Shift Lever, Titanium
- **Price:** 444€

### ML940 (MTB)

- **Weight:** 74 grams/wheel
- **Technology:**
  - Super Lightweight
  - Ergonomic lever design
  - Stainless steel hardware
  - 2 finger lever blade
  - For use with Rapid Fire shifters
- **Materials:**
  - Full carbon fiber lever and alloy bracket
- **Colour:** Carbon
- **Price:** 110.99$ (USD)

### RL879 (TRI/TI)

- **Weight:** 77 grams/wheel
- **Technology:**
  - Ergonomic lever design
  - Pivoting cable stop to minimize cable friction
  - For use with caliper or canti brakes
  - Expanding plug clamp style
  - Internal cable routing
  - Return spring
- **Material:**
  - Aluminium body and lever blade
- **Colour:** Black or silver
- **For use with:** 19-20.6mm ID aero bars
- **Price:** 59.99$ (USD)

### BX4 Mag (BMX)

- **Weight:** 83 grams/wheel
- **Technology:**
  - Right hand only
  - Precision forged magnesium blade
  - One finger trigger lever
  - 0.8mm triple coiled return spring
  - 10mm barrel adjuster
  - Adjustable reach
- **Materials:**
  - Magnesium, Titanium
- **Colour:** Ti Silver
- **Price:** 29.99$ (USD)
Brake levers for rear and forward brakes have to be placed in the correct way corresponding to the country’s legislation or the habits of the country in what the bike is sold. The manufacturer must indicate how to activate the rear and forward brakes.

In relation with dimensions, the maximum grip dimension, d, measured between the outer surfaces of the brake lever in the designated area that contact with rider’s finger and handlebars or other coating materials, over a distance exceeding 40 mm, as shown in the figure 1.1.1, should not exceed: 90 mm on bicycles that the saddle can be adjusted to provide a maximum height greater than 635mm and 75 mm on bicycles that the saddle can be adjusted to provide a maximum height lower than 635mm.
1.2. Materials selection: availability, difficulty to shape it, resistant and elastic characteristics, density, cost, assays

1.2.1. Material options:

To design the bike brake lever, we need to choose the material we want to use depending on how easy we can get it, the price we would need to pay for it and the properties we need from it. Choosing the material is the first step in this project because the design of the brake lever will depend on this decision. After some research, these are our different material options:

- **Carbon fibre (CFRP):**

  This compound material is often used to produce bike brake levers. Its advantages are its lightness and high resistance (high strength to weight ratio or specific strength), its good rigidity and its resistance to corrosion and fire.

  Anyway, this material is expensive and so difficult to shape. As it has fibres in it structure, depending on how are they distributed, it can be considered as an anisotropic or quasi-isotropic material. The mechanical properties of the CFRP depend on its composition and fibres distribution and size.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Modulus of Elasticity (GPa)</th>
<th>Poisson coefficient</th>
<th>Yield Stress (MPa)</th>
<th>Tensile Strength (MPa)</th>
<th>Vitrification Temperature (ºC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,6</td>
<td>70-150</td>
<td>0.30</td>
<td>550-1050</td>
<td>550-1050</td>
<td>99-180</td>
</tr>
</tbody>
</table>

- **Aluminium:**

  Aluminium alloys are also often used to produce brake levers, but for us it can be hard to find and shape. But we know that there is a plant (Domoli SL) that works on cutting shapes for other companies on aluminium plates so we thought they might get some pieces that are no longer useful for them, such as defective parts and cuts. Of course, the normal way for them to proceed is to sell and recycle those pieces, but we decide to ask them for a small piece of these plates. Thanks to the small size of our design compared to the product sizes they work with, they agree in giving some pieces to us. We needed them to tell us the options of different alloys and thicknesses that they can give us, and the best one seems to be a plate of 3mm thick made of an aluminium alloy with Silicon and Magnesium, among other metals, called 6082 Aluminium. This thickness is too small for the lever we want to make because it would hurt when using it, but we will make two exact brake lever shapes and then stick them together so the result will be as if it was a 6mm plate.

  The way to work on that plate is with a laser machine that is able to cut a shape on it. So, we can sketch a 2D shape and cut it off of the aluminium plate. We also know that the laser machine works with a 0,1mm tolerance, so we need to take this information into account.

\[\text{We will conclude later the reason why we can use two shapes glued as if it was just one (section 2.2.)}\]
when we design the shape to be cut. For sure, that plant knows exactly the mechanical properties of the aluminium they work with and they have told us the alloy data that we need to model the brake lever made of this material. Another consideration is specifically the restrictions on shape that the process of cutting has itself thus our shape design has to be made just with lines and circles. Anyway, we will look for other information and compare those given values. The only thing we will need to pay for is for the machine to cut our sketch onto the plate, which will be more or less 30€.

It is important to highlight that aluminium is quite hard to break by applying forces on it because of its tenacity. Before it happens, it gets plastically deformed. The bright side of this fact is that it is the best option for a real brake lever, when you need to look for safety for the people riding the bike with that brake. If they pushed it so hard to stop in an emergency situation, and it broke, they would get hurt. So, it is much better to make sure that in case someone applied more pressure than the limit considered, no one would get hurt. By the way, the bad part of that fact is that it is more difficult to know the exact stress that makes it get deformed. This makes more difficult to draw conclusions when assaying pieces made of this material. Anyway, nowadays there are methods to get that exact information, such as pressure sensors.

Some mechanical properties of the 6082 aluminium (T6) are:

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Modulus of Elasticity (GPa)</th>
<th>Poisson coefficient</th>
<th>Yield stress (MPa)</th>
<th>Melting point (ºC)</th>
<th>Break load (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.7</td>
<td>70</td>
<td>0.33</td>
<td>260</td>
<td>555</td>
<td>310</td>
</tr>
</tbody>
</table>

- **Methacrylate**:

Methacrylate is not used to produce real brake levers, but besides the options of materials that are common for this purpose, we need to consider materials that can be useful options for our project. The methacrylate option is so similar to the aluminium one. The only differences are, of course, the material properties, and that we will be able to choose the thickness we like the most from 2mm to 10mm. Moreover, the methacrylate cannot be blended when it is cold, so it can be interesting and easier to measure how it breaks than if it would get plastically deformed (like what happens with aluminium). Moreover, even though it is lighter than the aluminium, it is not as resistant as a 6xxx alloy of aluminium.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Melting point (ºC)</th>
<th>Softening temperature (ºC)</th>
<th>Tensile Strength (MPa)</th>
<th>Elongation at fracture (%)</th>
<th>Poisson coefficient</th>
<th>Modulus of elasticity (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.19</td>
<td>200-230</td>
<td>105-120</td>
<td>72-80</td>
<td>4-5.5</td>
<td>0.45</td>
<td>3.2-3.3</td>
</tr>
</tbody>
</table>
Boxwood:

By choosing this option, we have some advantages on making the wanted shape we like to. Thanks to a carpenter that would help us and model the wood, we can make a 2D sketch and cut it off with the thickness we like; but moreover we have the option to draw a more complex sketch, in 3D, and make it of wood. Usually, wood it is not a good option to make pieces you will need to model and simulate it because of its anisotropy. This characteristic leads to mistakes and differences of the results expected and the physical reality. This happens because wood properties are different depending on the direction due to the fibres it has. Actually, we can use some different kinds of wood, but we decide that boxwood is the best wood option that we can afford because its anisotropy is not so bad, and it is a strong and quite light material. The properties of the boxwood are:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>0.885 - 0.960</td>
</tr>
<tr>
<td>Modulus of Elasticity (GPa)</td>
<td>12 - 14 (fiber direction)</td>
</tr>
<tr>
<td>Bend strength (MPa)</td>
<td>144.5</td>
</tr>
<tr>
<td>Crushing strength (MPa)</td>
<td>68.6</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>86 - 112</td>
</tr>
<tr>
<td>Poisson coefficient</td>
<td>0.318 - 0.424</td>
</tr>
<tr>
<td>Janka hardness (N)</td>
<td>12.610</td>
</tr>
</tbody>
</table>

Other options:

We also think of two other options: The first one is using Rapid Prototyping. By this method our hand brake lever can be done from a 3D sketch and the result will be good. The other option is printing a 3D hand brake with a plastic material. The disadvantage of this method is the way those printers work. Our piece will not be as a solid one, for example made by plastic injection moulding; it will look all made of fibres. That makes that the difference between the results on the simulation and what is really happening will be too big.

1.2.2 Material Selection / decision

CFRP: We think this material is a good option to produce brake levers although for this project it is not a good idea because it is too hard to shape and too expensive.

Aluminium: This is the material we will use for our project. Although we know we will need to pay to get our brake lever made of aluminium, we think that it is the best option due to the good properties it has, like its resistance compared to its weight and corrosion resistance, and it would be a good option too for a real brake lever.

Methacrylate: If we were not able to get the aluminium plate, it might be the best option for this project.

Boxwood: It is mainly its anisotropy that makes us think it is not a good option because our results can be wrong or very different from the test results.
**Other options:** Both of them are impractical in spite of some good aspects they would have.

The Rapid Prototyping method is so good, and the result convinces us, but it is too expensive for us to afford it and would take too much time. And the reason why we do not think that 3D printing is a good method is because we would have wrong conclusions for our hand brake lever design due to the fibrous structure that the lever would have and because it is a weak material.

In conclusion, what we will use for our project is a plate of an aluminium alloy called AW 6082 T6 of 3mm thick.
1.3 Maximum permissible force, dispersion and characteristic values.

To design our brake lever was important to know the maximum strength a man can do with one hand. That is because we want to make sure that this man riding the bike with our brake lever will not be able to break it just trying to make the bike stop for example in an emergency situation. But on the other hand, it is important to know the strength that this same man riding the bike in normal conditions would usually do to stop. This means, the hand brake lever must resist the maximum strength one man can do with one hand, for example, if he is in a risk situation and because he is scared he makes much more strength than necessary. But the normal strength to make the brake work must be comfortable for the man riding the bike. So, if someone using the bike wants to stop, the strength he must need must be a little high so he will only stop on purpose, but not that high that he would get tired by using the brakes.

It is important to highlight here that our decisions will be different doing this project than they would be if doing a real project design. This is due that we will not use the same data than we would because we want to be able to test the lever and compare the results with those we will get by simulation. So all along this section we will distinct the values we would use for a real design of a brake lever, and the values we decide to use for our prototype.

First of all, in this section we will try to find out the maximum force that a person can grip strength. The idea is getting an empirical statistical study and we will see what the result is. The best way to do it is with a tool called Jamar hydraulic Dynamometer (*Figure 1.3.1.*). With this machine someone just grip strength and we get the force value he is doing. The problem is that a Jamar hydraulic Dynamometer costs about one thousand euros. Then we have two options: on one hand we can try to design an experiment that gets us an idea of this force. On the other hand we can look for other studies that have been done before.

*Figure 1.3.1*

![Dinamómetro hidráulico JAMAR](image)

First we designed an easy experiment. We took metallic recipient with a handle and we put it on a scale. The idea then was to start filling the recipient with dense materials like iron and start to increase the weight. Then the subject had to rise up the recipient with the fingers but supporting the hand palm on a table, for example. In this way, we got the maximum weight that the subject is able to rise up, what is proportional to the maximum
force that this person can grip strength. We tried with one member of our group and the maximum weight with one hand was 40kg ergo 392 N.

This type of experiment is really difficult to carry out because of the waste of time placing and moving weight of the recipient. The maximum force depends also if the palm is more or less near to the handle and the height of the support itself. So we decided to explore the other option and try to obtain more data from external sources.

We found out three studies and we joined them together to get the data (Table 1 and Table 2 and 3). This data fits very well with the only one experiment that we did, what mean it was valid.

![Table 1: Obtained from General Motors España](image)

<table>
<thead>
<tr>
<th>MANO</th>
<th>100%</th>
<th>50%</th>
<th>95%</th>
<th>MEDIA</th>
<th>D. TÍPICA</th>
<th>MIN-MAXIMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominante</td>
<td>178.7</td>
<td>379.9</td>
<td>493.6</td>
<td>366.9</td>
<td>93.6</td>
<td>76.0-554.9</td>
</tr>
<tr>
<td>No dominante</td>
<td>203.1</td>
<td>236.8</td>
<td>472.3</td>
<td>332.2</td>
<td>79.7</td>
<td>99.3-337.1</td>
</tr>
<tr>
<td>120 cm. N.101</td>
<td>Dominante</td>
<td>252.0</td>
<td>412.0</td>
<td>561.5</td>
<td>416.0</td>
<td>82.7</td>
</tr>
<tr>
<td>No dominante</td>
<td>251.7</td>
<td>361.4</td>
<td>501.1</td>
<td>372.4</td>
<td>74.3</td>
<td>185.8-581.2</td>
</tr>
<tr>
<td>140 cm. N.102</td>
<td>Dominante</td>
<td>210.8</td>
<td>342.3</td>
<td>520.3</td>
<td>355.0</td>
<td>83.7</td>
</tr>
<tr>
<td>No dominante</td>
<td>161.2</td>
<td>282.9</td>
<td>441.1</td>
<td>298.8</td>
<td>84.8</td>
<td>256.6-580.1</td>
</tr>
</tbody>
</table>

At this point we need to distinct the force value we would use for a real project and the value we will actually take. If it was a real project, we would like to be sure that the...
The probability of the brake lever to get broken is minimal. For this reason we would use a force value that the 95% of the population is not able to do. To get this value we need to use some statistics combined with the data of the studies we found. As we are looking for the maximum force it needs to bear, we will use male dominant hand force values because they represent the maximum resistance risk. From those we get the results on Figure 1.3.2.

![Grip strength force distribution](image)

**Figure 1.3.2**

Only a 5% of the population can grip strength 535.7 N (54.7 Kg) or more, so if we designed a brake lever prepared to bear this force (or even the value added to a margin of safety), the probability of someone breaking it is very small. Anyway, for our project we want a force value that our team members are able to do so that allows us to test the simulation results.

This is often a good way to proceed: Make a simulation with values you will be able to test with and check if the real results coincide with the simulation ones. If this happens, it means that the simulation is right so you can proceed and trust the results you will obtain with the limit values that you will not test with.

So at this point we decide that, even thought we would use \( F_{\text{max}} = 535.7 \) N, we will take \( F_{\text{max}} = 392 \) N because this is the maximum force we are able to do. So the way to design our brake lever is making it resistant to this strength but we will need to make it to get broken with a stress a little bit higher.

The other part of the information we needed was the comfortable stress that someone riding a bike should make to stop. To know the normal strength that is necessary for a normal ride, we made our own experiments. We needed a chronometer, a bike, a bag, something to write on the floor (chalk) and some weights. We repeated each experiment three or more times to make sure the results were good enough. We draw with chalk two lines on the floor separated 10m one from the other.
We needed some basic information about the experiment so that we could use the results for other situations. This was:

- The rider came trying to pedal at a constant speed. We made the chronometer start when he crossed the first line and stopped it at the second line. With this information we were able to find out what the speed of the bike for our experiment was.
  - 10 metres in 2.8 seconds thus $v=3.57 \text{ m/s}$
- Brake system of the bike by brake pads
- Another important thing was the weight of the boy riding the bike.
  - $M = 80 \text{ kg}$

We turned around the front brake lever of the bike and fix an empty bag on it. The reason why we fixed the bag was so it would not move and the pressure would always work on the same surface. The handles of the bag, fixed one next to the other, had a width similar to a human hand. We looked for this fact to happen to make sure that the pressure made would affect the same way as if someone riding the bike would push the brake lever (Figure 1.3.3. and Figure 1.3.4.).

The next step was simulating a stop the rider would feel comfortable with. The rider came pedalling and at the first line he started to stop as he would do it if it was not an experiment. We noted down what the time and distance were.

The results were: 4 meters and 3 seconds thus $a \approx 1.55 \text{ m/s}^2$

We put some weight inside the bag and note down its total weight. When the rider crossed the first line, instead of using the brake by him, he had to drop the bag and this bag was the one in charge of making the bike stop.
The main results we got were:

<table>
<thead>
<tr>
<th>Weight (kg)</th>
<th>Space (m)</th>
<th>Time (s)</th>
<th>Acceleration (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>13,5</td>
<td>5,6</td>
<td>0,39</td>
</tr>
<tr>
<td>4,5</td>
<td>6,5</td>
<td>3,4</td>
<td>0,96</td>
</tr>
<tr>
<td>5,5</td>
<td>5</td>
<td>2,8</td>
<td>1,25</td>
</tr>
<tr>
<td>6,5</td>
<td>3,5</td>
<td>2,3</td>
<td>1,52</td>
</tr>
</tbody>
</table>

In conclusion, the value of the force we decided to be the best one is 6kg or 58,8N. This is the force we want the rider using the bike with our brake lever to make when he wants to stop.

To sum up, we will take $F_{\text{nom}} = 392\text{N}$ for maximum force applied without problems in our bike brake lever, but a $F_p=58,8\text{N}$ needs to make the bike stop.

Another important datum is the width of the surface of the brake lever where someone riding a bike applies that force to stop. That will mark the value of the pressure applied on the lever, because this pressure we need to know is the force value we already know divided by the surface where it is applied.

First of all, we decided to design our brake lever to be used with four fingers because is the way you can make the maximum force we have found, and on this project we want to create a model and a simulation that we can reproduce and compare both results. So we need to know exactly what we want to test and impose some boundary conditions that imitate as well as possible the real situation. Anyway, if it was a real brake lever design project, we would study the most critical situation, because the stress on the lever could be higher with only two fingers pushing but further from the cotter pins than with all four fingers closer to them (less moment applied).

We made some people pretend they were putting the brake on and measure the width of their four fingers on the brake lever.

Here we need to distinct too two different situations:
If we were trying to make a real brake lever design, we would take a hand width smaller than the 95% of the population for sure exceeds. That is because the pressure applied, with the same force value, is highest if the surface where it is applied is small. So the most critical working point that we would need the lever to bear would be the one with the maximum force we told before (565 N) and the minimal width. This is the way that, added to the margin of safety, we would make sure that our brake lever would not get broken by someone riding the bike.

So we make some statistic with the hand width data we took and we get this:

### Descriptive Statistics: Width

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>N*</th>
<th>Mean</th>
<th>SE Mean</th>
<th>StDev</th>
<th>Variance</th>
<th>Minimum</th>
<th>Q1</th>
<th>Median</th>
<th>Q3</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>amplada</td>
<td>33</td>
<td>0</td>
<td>6.942</td>
<td>0.129</td>
<td>0.740</td>
<td>0.548</td>
<td>5.500</td>
<td>6.450</td>
<td>7.000</td>
<td>7.500</td>
<td>9.000</td>
</tr>
</tbody>
</table>

![Distribution Plot](image)

So we get that the critical point is when the width is 5.725 cm (Figure 1.3.5.). The probability of someone applying the maximum force we are working with (40 kg) or more in less than this width is so small that we can ignore it.

By the way, in this project we want to predict what will happen on the test with our prototype. For this reason we are using data values that we will be able to test with. So, for the same reason we will use 392N instead of 535,7N, we will use our team members hand width, what is, approximately, 70mm.

So finally, we know the data needed for our simulation: Moreover the boundary conditions, we need to impose on our simulation a pressure of $40 \times 9.8/70^*6 = 0.93$ MPa (the lever thickness is 6mm) and because we suppose a uniform pressure and perpendicular to the surface.
1.4 Basic geometric specifications. Preliminary design and prototype construction

Making the brake lever design is an iterative process because we do not know at first how the pressure applied affects it. So we will need to make a simple design and use the ANSYS software for a simulation. With the results we will get we will see the parts of the lever that need to be stronger or that parts that do not support any stress. With this information we will be able to optimize the design and try again the simulation.

Anyway, there are three factors we know that will matter for the design:

- The material, because of its properties such the modulus of elasticity, the Poisson coefficient and the tensile strength.
- The pressure applied, what means the force made and the width of the surface where this force will be applied.
- The part of the brake lever where this pressure will be applied and how close of the cotter pins is.

The first point is something we have already chosen and cannot change it to make it better or worse. The second point is information we already know, but we cannot change it either. The third point is someone we can decide and change to optimize our design at the same time as the rest of the shape.

So to have some data to analyse and optimize the design, we need to make a preliminary brake lever design using SOLIDWORKS. We are using SOLIDWORKS instead of drawing in ANSYS because we can control much better the design tools and we can save the model and keep improving it.

On this preliminary model we only impose the given restrictions, some parameters that are already fixed (Figure 1.4.1). It is important to make sure that all changes we will be doing on our design make it meet the criteria, as the holes diameter where the cotter pins will be, or the distance between the lever and the handlebar.

*Figure 1.4.1*
So, we draw the sketch of the preliminary design:

![Figure 1.4.2](image)

This is the one we will use for the first simulation with the finite element method to get some information and be able to improve it.
2. Finite elements method

2.1 Limitations of the model, boundary conditions, idealization and numeric singularities

So the next step is to import this file of the preliminary design to ANSYS and start the simulation. It is important to highlight that we can assume that the stress on the lever will be the same in every layer all along the thickness. This is the reason why we can do the simulation as a 2D shape with thick instead of a 3D situation.

In order to analyse this static situation in ANSYS it is needed to define some boundary conditions, trying to represent the reality as maximum as possible. It is important too to make sure that the results do not depend on these boundary conditions.

In static situation it is known that the total sum of forces and moments is zero. Analysing the moments, the point P it is used to express them $\sum_{body} F_i = 0$ and $\sum_{body} F_i \times x = 0$.

Now, in the image that we have seen before, we have $\sum_{H} F_i = P_1 - T = 0$, where T is the force make by the rope, which is horizontal because the rope can only make the force in its direction and $\sum_{V} F_i = F - P_2 = 0$. Now, looking up for the momentums $\sum_{body} F_i \times x = TX - FL = 0$, $T = \frac{FL}{x}$, the equilibrium of the solid is completed (Figure 2.1.1).

This force T is the reaction value that we will take into account, make predictions about and measure in the final test of the brake lever (Figure 2.1.2).
We calculate the pressure applied using the maximum force of 40kg and the surface where it is applied of 70*6mm, and we obtain: 

$$ P = \frac{F_{\text{nom}}}{S} = \frac{392}{70\times6} = 0.93 \text{MPa}. $$

So the boundary conditions that have been imposed are no displacement at the cotter pins where the forces $T$, $P_1$, $P_2$ are applied and the pressure $P = 0.93 \text{MPa}$ (Figure 2.1.3). This means that we are working under the hypothesis:

- Punctual contact, what leads $T$, $P_1$, $P_2$ to be punctual forces.
- Static model.
- Uniform pressure $P$ perpendicular to the surface where it is applied.

The first hypothesis makes some singular points appear when solving the model. Deformations near of the cotter pins can be different to reality because we do not impose in the simulation that exists something rigid into the cotter pins.
2.2. Characteristics of the model: finite elements type, material model, mesh

Once we are working with the ANSYS software, we need to define the analysis type, the element characteristics, the mechanical properties of the material we are using and the mesh we want to use. This is:

- Structural analysis
- Structural mass (solid): Solid Quad 8node 183.
- Thick of 6mm. Fix the material as linear, elastic and isotropic. \( E=70000 \) MPa and \( v=0.33 \).
- Meshing. Elements type and size

In the finite elements method we can use different kinds of elements to mesh the model. First of all, they can be triangles or four-sided elements. Between these two types, triangles work worse because as they have fewer nodes, they are less precise. Their interpolation is first graded, so they have too first grade displacements, what means that each element gives a constant value of strain and stress. When working with four-sided elements, we will obtain first grade strain and stress because the displacement in this case is second graded. So, as far as we can decide either which type of element we want to use, it is better to mesh with quadrilateral ones. This fact makes us choose Solid Quad elements on ANSYS for our model.

Besides, we can choose between placing a node in each element vertex or placing also an extra node on each edge. This is the difference between Solid Quad 4node 182 and Solid Quad 8node 183. The first one, which uses places only one node per vertex, uses first degree polynomial functions, and the second one, with more nodes for the same element, uses second degree ones. This is the reason why the Solid 8node 183 element type is more precise: its polynomial functions are able to approximate much better curved edges on the model, as it happens to us due to the brake lever design. With these second degree functions, the element gets adapted to the edges while first degree functions would not take into account the angle variations or bending on edges, what, moreover, would make appear some tangential stresses that are not real. We can see this difference on Figure 2.2.1. and Figure 2.2.2.
We also need to fix the material model. We decide to accept that the aluminium on our brake lever behaviour as linear, elastic and isotropic.

When we say that the model is elastic, means that ANSYS will works under the hypothesis that the material is in its elastic region. For this reason, this software needs the Young modulus data, which in this case is $E = 70$ GPa and the Poisson coefficient, of $v = 0.33$. This elastic region is also considered as linear (Figure 2.2.3).

And finally, aluminium is an isotropic material because its properties do not depend on the direction on the structure. This is due to the metallic bond and internal structure.

Even though the brake lever is a 3D shape instead of a 2D shape, we can model it as a plane structure because the stress result will be the same in each parallel plane all along its thickness. We only need to indicate to the ANSYS software that the total thickness of the model is 6mm so it will take this data into account.
Once we have decided the element type, we need to define the mesh. To make a good design, the first thing we know is some basic information about how the stress will be on it, so we will be able to know which regions need to be thicker and which regions could be deleted. So, as we only want to have some idea of the stress distribution on the lever, we will make a basic mesh to get this with the shortest time possible (of the computer calculating). For this reason we will start with the automatic meshing on the preliminary design, of big sized elements, even though we know that the results will not be good.

Figure 2.2.4

Now that we get that main idea of the stress distribution, we will modify the lever design and use this new model on another simulation. Then, the best meshing will not be the automatic one, because we need a smaller element size and a refined mesh in some parts to get precise results and make sure that they are stable. This means that the final mesh needs to be small to get precise and stable results, but not too small because it would take too much time to calculate the simulation. So the way to proceed once we get the final design will be iterative: We will define a mesh size and get the stress results; then make it smaller and get the new results. When the values obtained will look so similar to the previous we got, that will mean that we have a stable model, so we will use that meshing size. It will be the stable model with the biggest possible element sizes, what means, the shortest calculation time for the computer but with stable and valid results.
2.3. Results reliability: refined meshing

We have made the first simulation with the preliminary design and get the stress results:

![Figure 2.3.1; Stress intensity; mesh size 6](image1)

In the zone where the maximum stress is, the meshing is so big, so the results are not precise. We need to make the meshing of that part a little bit smaller. We change the meshing and make a new simulation, in what we get:

![Figure 2.3.2; Stress intensity, mesh size 6](image2)

We know that the yield strength of the aluminium we are working with is 260MPa. On the Figure 2.3.1 and Figure 2.3.2 we can see the stress intensity. This shows that the stress on the lever is too big for the material used and the size it has. The preliminary design is not good, but at this point we knew what parts of the lever need to be thicker and how to improve its shape. So we try a new design.

---

2We have to note that we are plotting Stress intensity, The justification of that will be considered section 3.3
The improvements we make for this new design are:

- We move the part where the pressure is applied closer to the cotter pins to reduce the resultant moment.
- We make the width bigger where the stress is maximal.
- We make thinner the part close to the cotter pins where the stress is small to make it lighter.
- We cut off the right part because it is not useful and this way we can reduce the weight too.

So with the new design we make the new model and the simulation with the same boundary conditions. And the results of the stress are:

Now is time to stabilize the results. We will observe just one node and we will see if the stress intensity remains constant until some element size. We will try that the node will be always the same but in fact it is impossible. However we can chose to nodes close enough to get us an idea of meshing stability.

We chose the node with coordinates x=60,6158mm and y=31,9633mm.
<table>
<thead>
<tr>
<th>Element size</th>
<th>Sint (MPa)</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>157,573</td>
<td><img src="image" alt="Figure 7" /></td>
</tr>
<tr>
<td>6</td>
<td>155,63</td>
<td><img src="image" alt="Figure 6" /></td>
</tr>
<tr>
<td>5</td>
<td>151,17</td>
<td><img src="image" alt="Figure 5" /></td>
</tr>
<tr>
<td>4</td>
<td>153,847</td>
<td><img src="image" alt="Figure 4" /></td>
</tr>
<tr>
<td>3</td>
<td>153,76</td>
<td><img src="image" alt="Figure 3" /></td>
</tr>
</tbody>
</table>

As we can see at size 4 the mesh is stable. In fact, we have 0.05% variation in Sint between element sizes 3 and 4. So we will take the element size 4 as the optimal meshing model.
We can see that there is a singular point as we expected for the hypothesis made before.

![Figure 2.3.5](image)

After observing the results, we can see that the singularities created are not close to the zone where we know that stress intensity is higher, so they do not affect this part.

It looks like the new design would be able to bear the maximal force that someone could do on it with one hand. So the next step is to make the failing simulation. We were using $F_{nom} = 392\text{kg}$ for the maximum force. For this new simulation we need the load to be between $1,2F_{nom}$ and $1,3F_{nom}$ and the stress on the lever should be higher than the yield stress, so it has to deform plastically. We proceed and simulate the same model changing the pressure value$^3$.

$^3$ We will see this modelling at section 3
2.4. Infinitesimal displacement hypothesis, nonlinear calculation

In order to proof that linear approximation is correct we must start a nonlinear calculation to determine it (Figure 2.4.1. and Figure 2.4.2).

![Newton Raphson convergence](Figure 2.4.1)

![Left side (nonlinear deformation)-Right side (linear deformation)](Figure 2.4.2)

After this study we can appreciate that the approximation made with the linear calculus is correct as we have at the same point the same stress intensity for the both studies, with a value of 153.81MPa (Figure 2.4.3.). Afterwards, we conclude that the approximation is quite good to determine the stresses in our lever.

![nonlinear stress intensity; Left side (nonlinear)-Right side (linear)](Figure 2.4.3)
3. Results analysis

In this section we will show and analyse ANSYS results. We will present the displacements, principal strength distribution and then we consider a failure criterion. This is a really important section because we will know if the piece will resist or not. In next sections we will optimize the design. But now we are going to analyse the results.

3.1. Current displacement

Before analysing the displacement and the deformed shape, we should know that the hypothesis of linear approximation is based on little deformations, quite different from considering little displacement. When considering the first one, we know that depends on the previous length of the piece, like $\varepsilon = \frac{\Delta L}{L_0}$, different from the second one. As we can see in figure 3.1.2 the strain is quite small.

Then we test the lever with a pressure applied of 1,12MPa, corresponding to 1,2 of the nominal pressure, to find the limit value for the brake lever to fail and improve the design.

The results obtained are in Figure 3.1.1, Figure 3.1.2 and Figure 3.1.3.
Figure 3.1.2 deformed shape

Figure 3.1.3; Total strain

<table>
<thead>
<tr>
<th></th>
<th>Ux</th>
<th>Uy</th>
<th>Uz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement (mm)</td>
<td>0.32856</td>
<td>-2.3256</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

ANSYS does not show up the real Uz displacement because it works only on one plane and we are considering just a surface (taking into account the real thick to get the results).
3.2. Principal strength distribution

Before analysing the results, we must know the distribution of stresses. That is, the upper part in traction and the lower part in compression (Figure 3.2.1.). The lever is in a state of plane stress for two reasons. First, we are not applying any force perpendicular to the surface of the lever and then we are not considering the volume force created by the gravity that is negligible compared with the force we are applying. However, this does not mean that the second principal traction is always zero as there are nodes where the other principal directions are either in traction or in compression. Moreover, in the nodes where we have only compression, the z direction becomes the first principal direction, and where we have traction it becomes the third. Obviously, when a node presents traction and compression at once, that direction becomes the second principal (Figure 3.2.2, Figure 3.2.3 and Figure 3.2.4.).

![Figure 3.2.1 Principal strength distribution](image1)

![Figure 3.2.2 Sigma I](image2)
Figure 3.2.3 Sigma II

Figure 3.2.4 Sigma III
3.3. Failure criteria. Equivalent stress distribution

First of all we have to realize that we are dealing with aluminium. This means that we have to choose failure criteria that fit with it. Among the options we have, Tresca-Guest and Von Mises (on Figure 3.3.1.), we have considered that Tresca-Guest is more suitable as it is more restrictive. Then to study the results the equivalent stress will be stress intensity. If the equivalent stress is higher in some node then the brake lever will plasticize.

\[
\sigma_{VM} = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}} \geq \sigma_Y \quad \sigma_{tresca} = \sigma_1 - \sigma_3 > \sigma_{max}
\]

*Figure 3.3.1; Failure criteria (Tresca-Guest; Von Mises)*

*Figure 3.3.2; stress intensity distribution*
The results are stable, but we want to ensure that they are valid. We want to make sure that the boundary conditions represent the reality, but that the stress results do not depend too much on them. So we are going to change the boundary conditions we had for another hypothesis that can work too. We will fix the same upper point, with $$U_x=0$$, but now we will impose on the lower pin, only rotation permitted (with symmetry ANSYS option). Then we get that:

- **Figure 3.3.3:** Symmetry boundary conditions
- **Figure 3.3.4.a:** First boundary conditions
- **Figure 3.3.4.b:** Symmetry boundary conditions

<table>
<thead>
<tr>
<th></th>
<th>Stress intensity when stabilizing</th>
<th>Reaction solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial boundary conditions</td>
<td>153.847</td>
<td>865.95</td>
</tr>
<tr>
<td>Changed boundary conditions</td>
<td>153.847</td>
<td>860.27</td>
</tr>
<tr>
<td>%variation</td>
<td>0</td>
<td>0.66</td>
</tr>
</tbody>
</table>

So we can conclude that the results do not depend on the way we impose some restrictions, what makes it a robust valid model.
3.4. Security coefficient and load at failure

3.4.1 Security coefficient

Security coefficient is the relation between the maximum permissible stress, in our case, the yield stress (260MPa) and the suitable equivalent stress (stress intensity). It is imposed that this value must be between 1,2 and 1,3, so in order to be accurate we try to get 1,25 knowing that it will be difficult to be exactly at this value.

The maximum stress intensity we obtain in nominal test is 172,73MPa (without taking into account the numeric singularities). In this case we get $\gamma = 1,51$ that is far away from the interval imposed. That result means that we must optimize our lever in order to reduce the security coefficient, and try to get the entire lever working at the same stress intensity. This aim is certainly impossible, but we have to attempt to, at least, that there is no part of the piece that is not working.

\[ \gamma_G = \frac{P_{W,\text{max}}}{P_{W,k}} = \gamma_M \gamma_W > 1 \]

*Figure 3.4.1.1*

3.4.2 Load at failure

One of the aims of that study is to get the maximum reaction force in the upper pin with the minimum mass of the lever. So it is important to know the reaction at first and try to improve it, making it higher and reducing all the mass that is not bearing any stress.

Analysing the lever in ANSYS when the material fails we obtain a reaction of $R_f = 865,95 \text{ N.}$
4. Optimization of the design, construction, test and conclusions

At this point we find a model that fits our specifications unless the security coefficient. Now is time to make it lighter. So in this section we will pass throw an iterative process. We will start with this last model and we will begin to pick out mass and see if the piece is still resisting. On this way we have to learn by assign and error the way to optimize the piece.

4.1 Optimization of the design and final results

4.1.1 Optimization process

In this section we will impose 1.2 times the nominal force in order to assure that the piece does not break before we want. As we have seen before we have to consider stress intensity.

We start with this design; stress is lower than the yield stress so we could pick out some material to make it less resistant and at the same time that mass that does not bear any stress.

First of all we remove some mass near to the holes and in the right part of the lever, where there is a big zone that is not working at all. As we can see the piece is still resisting.
We note that there is still some inner mass that is not working, as some in the right part of the lever. So, we try to remove some mass realising that the lever fails.

To solve this failure we decide to make a bridge to avoid it. We observe then that it is not enough.
With that last bridge we see that the failure has been solved. Thereupon, we try to reduce mass in the right side, where there is a region where mass is not working at all.
Finally, after having completely modified the first design we had, the final design is done. The optimization process has allowed us to reduce considerably the mass of the lever and to make some parts of the lever be working at higher stress intensity. It is quite obvious that we could still going on the optimization process, but we consider our lever is enough sophisticated.

![Stress intensity diagram](image)

*Figure 4.1.6; Stress intensity*
### 4.1.2 Refining mesh process

For that refining process we have fixed the point nearer from $X=59,70\text{mm}$ $Y=32,40\text{mm}$.

<table>
<thead>
<tr>
<th>Element size</th>
<th>Sint (MPa)</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>141,87</td>
<td><img src="image1.png" alt="Figure" /></td>
</tr>
<tr>
<td>6</td>
<td>151,97</td>
<td><img src="image2.png" alt="Figure" /></td>
</tr>
<tr>
<td>5</td>
<td>152,53</td>
<td><img src="image3.png" alt="Figure" /></td>
</tr>
<tr>
<td>4</td>
<td>160,91</td>
<td><img src="image4.png" alt="Figure" /></td>
</tr>
<tr>
<td>3</td>
<td>152,1</td>
<td><img src="image5.png" alt="Figure" /></td>
</tr>
</tbody>
</table>
As we can see at size 5 the mesh is stable, in fact we have 0.28% variation between size 3 and 5. We notice at size 4 stress intensity is considerably higher than size 5, but this might be for the simple reason that in each mesh we do not have exactly the same nodes, so the coordinates used are a little bit different.

4.1.3 Current displacement

![Displacement](image)

<table>
<thead>
<tr>
<th>Displacement (mm)</th>
<th>Ux</th>
<th>Uy</th>
<th>Uz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.28</td>
<td>-2.99</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

4.1.4 Linear VS nonlinear calculus

We must analyze the final design with a nonlinear calculation in order to determine if is far away or not from the linear one.

![Newton Raphson Convergence](image)
When we obtained the results we have chosen a point, of all we have looked for, as an example of the little variation in stress intensity. The values are expressed in the next table.

<table>
<thead>
<tr>
<th>Stress intensity when stabilizing (MPa)</th>
<th>Reaction Solution (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear calculus</td>
<td>152.54</td>
</tr>
<tr>
<td>Nonlinear calculus</td>
<td>154.38</td>
</tr>
<tr>
<td>%variation</td>
<td>1.20</td>
</tr>
</tbody>
</table>

After obtaining the results, we notice there are some differences between nonlinear and linear calculus, as we expected, but these differences are very small. Thereupon, we conclude we can still work with the linear hypothesis, unless we want to be more precise.
4.1.5 Principal stress directions

Analyzing again the principal stress directions we obtain similar results than the previous study. We have a zone in traction and zones in compression. We notice all the lever is working.

Figure 4.1.5.1; Sigma I,II,III

Figure 4.1.5.2; Sigma I
4.1.6 Security coefficient

At the final design we got a maximum stress intensity of 214.8MPa for the nominal force applied $F_{\text{nom}} = 392N$, obtaining $\gamma = 1.21$. So, a $\gamma$ value between the intervals imposed has been reached.
4.1.7 Reaction force

As we have said before, when testing it will be difficult to get the exact value of 1,25 of the nominal reaction, so we calculate the maximum and minimum force of the interval 1,2-1,3 in order to enclose the reaction force between two limits. We only need to change the pressure value (P = 0,93MPa) for the nominal multiplied for this interval coefficient and analyse again the lever stress distribution and reaction.

So with the final design:

- Using the right limit of the interval (γ=1,3) and a pressure of 1,21 MPa we obtain a reaction force of 1086 N.
- Using the left limit of the interval (γ=1,2) and a pressure of 1,12 MPa we obtain a reaction force of 1005,2 N.

Without ANSYS we also can estimate the reaction, we just have to impose static and compute total momentum. We obtain 1086,6 and 1005,7 N.

Now we have a brake lever that would be able to bear the maximum force that we can grip strength with one hand. But there is another point we need to work on: We need to ensure that this brake lever would make the bike stop when somebody pushes it with 6kg more or less.

We start a new simulation with the final design and the same boundary conditions and finite elements method characteristics and mesh, but changing the pressure value to

\[ p^2 = \frac{6 \times 9,8}{70 \times 6} = 0,14 \text{ MPa} \]

And the reaction force obtained in this case is R =124,15 N. We consider that this reaction force is enough to make the bike stop.
4.2 Final design and building process

Once we have the optimized the brake lever it is important to know how is it going to be made. The building process is known as laser cutting. It consists in a laser that follows the different profiles of the design and cuts the aluminium plate in order to do the piece. From the beginning we know that the plate thickness is 3mm, so to get our design we have to stick with special glue two profiles in order to get our brake lever.

Here we have two pictures that show this type of process.

![Laser cutting process](image)

*Figure 4.2.1.1; Laser cutting process*

We made some research and look for the way we could produce these brake levers if it was a real project and we needed to make series of this product.

The best way seems to be aluminium extruding. As this was only a prototype, we used laser cutting on a plate, but if it was a massive production, we would design an extruding die with the lever shape and then proceed with the aluminium extruded using the alloy billets. The next step would be cut layers on the profile and smoothen every brake lever.

This way, the brake levers design is sustainable because all defective pieces and excesses would be recycled (and the lever itself once it has been used). This way to shape the lever optimizes production related to energy and time invested.
BIKE BRAKE LEVER DESIGN - Continuum Mechanics

Expressió Gràfica a l'Enginyeria

Thick 6mm

Brake Lever

Group
Professor
Grades

23
Jordi Bonada
2.1
4.3. Environmental impact and bill

The material we decided to use for this project is Aluminium. This decision was based on its properties and characteristics that were important for our lever design. But moreover, the aluminium has another important advantage: It is almost 100% recyclable. This fact is making the use of aluminium grow because of the man trying to be less destructive for the Earth. The opportunities of recycling the aluminium means it will not be left out somewhere like a garbage dump damaging the environment. And it is important to highlight that aluminium recycling is quite easy and obtaining aluminium form used aluminium only requires a 5% of the total energy needed to get it from the bauxite mineral. This makes aluminium producers be interested in dealing with aluminium pieces that are not useful anymore to recycle them.

Therefore, our brake lever is recyclable, what makes it viable and sustainable, and it is positive now that this characteristic is considered as a very important one.

The bill for the construction of the brake lever prototype is the following one:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate</td>
<td>0€</td>
</tr>
<tr>
<td>Time invested by Domoli SL</td>
<td>0€</td>
</tr>
<tr>
<td>Laser cutting: (2u x 14,44€/u)</td>
<td>28,88€</td>
</tr>
<tr>
<td>Gluing</td>
<td>5€</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>33,88€</strong></td>
</tr>
</tbody>
</table>
5. Test and conclusions
6. References


