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a quick fastening process might be crucial. Even more, if someone is injured and crampons are obligatory for the medical rescue, an easy and fast binding system is very helpful.

Besides, the problem is commented with regular users of crampons, and it is observed that there is no simple and reliable binding system for crampons available in the market. Currently, the fastening process takes about two minutes, and different tricky steps are necessary to be accomplished (see section 2.4.). Furthermore, the low temperatures and difficulties of the land at those high altitudes have to be taken into account.

Due to these reasons, a new binding system for the crampon is required to be designed in order to create a fast and simple system to attach the crampon to the boot. The new design has to fulfil the requirements of safety and reliability. In addition, it has to ensure that the boot is attached to the crampon safely under pressure; thus, no clearances are formed between the boot and the crampon.

As it is shown in section 2.2, after analysing the type of crampons available in the market, it is concluded that the binding system of the front part of the step-in crampon, which is independent of the rear part, is already simple and fast, and it provides a reliable binding. Therefore, due to lack of time to develop the binding systems of all type of crampons, it is decided to focus on the rear-part binding system of the step-in crampon. With the current crampons, it is necessary to undo the gloves and six different steps have to be accomplished in order to fasten them. Even if the unfastening process is not as difficult as the fastening process and it is not necessary to remove the gloves, five different steps are unavoidably to perform to unfasten the crampon. Hence, the steps to be covered for the attachment process are desired to be diminished and simplified.

Moreover, the new design is estimated to be absolutely practical due to its simplicity apart from reducing the time consuming of the fastening and unfastening processes in general; even more when mountaineers have to go through a short ice stretch where they have to fasten and then unfasten them again after walking a few meters.

It is determined that an improvement of the crampon is possible to create analysing already accessible mechanisms of binding systems for different applications in the market. A period of three months and a half is available for developing the work, which is considered sufficient for solving and adapting the problem for the rear-part binding system of the step-in crampon. An exhaustive planning of the steps to be covered is implemented (see Appendix A) organising the time in order to collect the required data, to make a new design of the binding system, to determine the manufacturing process as well as the materials and to make an estimation of the cost of the product.

It is considered that the product being developed might possibly have a large response in the market, as the exigency for it is obvious due to the reasons mentioned above. Nevertheless, in order to make the product attractive to the producer, it is necessary to take into account that apart from creating a high quality product, it has to
In cross-country skiing, the attachment between the boot and the ski is very simple. Most of the companies use the SNS system, which has two different types of bindings. The single axis (Propulse and Profil) has one connection point between the boot and the binding system, consisting in a metal axis on the soul of the boot fixed in a slot at the binding system (see figure 13).

![Figure 13: Single axis cross-country skiing binding system (Nordic Skater)](image)

Otherwise, the double axis (Pilot) has two connection points: apart from introducing the metal axis in the binding system, another metal axis is connected to the binding with a bar, which helps in the sliding action (Nordic Ski Source).

There is another ski modality that combines cross-country, downhill and Telemark skiing with mountaineering: ski mountaineering (see figure 14).

![Figure 14: Ski mountaineering binding system with 3 different positions (Epic Ski, 2009)](image)

This modality spans to ascend a mountain searching both for its summit and virgin powder and then to descend the mountain as in downhill skiing. Therefore, this binding system has three different positions that are established by moving the heel piece. Two of them are for ascending; one for not very inclined slopes and the other one for steeper slopes. In both cases, only the toe piece is attached to the boot. The third position is used when descending the mountain; as it is shown in figure 14, in this position the boot is totally fixed to both the toe and the heel pieces of the ski by the binding system (Ski Touring, 2009).

Another automatic binding system consists in the mechanism used for attaching the boot to the bicycle’s pedal: clipless pedals, where with a movement of the foot the soul of the boot attaches to the pedal due to the special design (see figure 15).
There are two main types of clipless pedals: one is for mountain bikes (MTB) being usually double-sided as they have a binding on both sides. The other one is for road bikes, which are typically one-sided as they have just one binding, as it can be observed in figure 15 (Cell Bikes, 2009).

Another example of an automatic binding system is the mechanism of a door (see figure 16).

As shown in figure 16, when the door is pulled, the force is transferred to a metal triangle component which is connected to a spring; thus, the spring compresses and the door moves if the load of the spring is exceeded. Therefore, when a force is applied to the door, it is transferred to the mechanism making it activate. As a result, the door moves following the stroke of the triangle side till it exceeds it. At this point, as no force is applied to the mechanism of the door, the spring decompresses and the mechanism returns to the position in the beginning due to the force of the spring, locking the door.

2.3. KNEE AND ANKLE MOVEMENT LIMITATIONS

Due to the anatomy of the human being, the movements that can be performed are limited. In this case, leg and foot movements are limited by the anatomy of the knee and the ankle. Consequently, these movement limitations are analysed in order to evaluate when they might occur when climbing with crampons.

As regards to the knee, it provides the possibility of movement in the three planes of the space: sagittal, coronal and axial planes (see figure 17).
catastrophic consequences if it occurs when trying to descend the mountain. Conversely, a spring has a longer life with no need of maintenance.

As regards to the weight, concept 5 and 6 are rated with 4 points while concept 8 is given 1, as using a pneumatic cylinder implies including different metal components which are heavy, while a spring is only one component which is not heavy even if it is composed of metal.

In the same way, as a pneumatic cylinder is more expensive than a spring, 3 points are given to concept 5 and 6 while 1 point is given to concept 8 concerning the price criterion.

Furthermore, the dimensions of the three concepts are the same, either compared between them or compared to the reference crampon; hence, 3 points are given to the three of them concerning the criterion of having reduced dimensions.

Finally, as regards to the ergonomics, concept 6 and 8 are given 4 points while concept 5 is given 3, as even if all the concepts are ergonomic, concept 5 requires bending down in order to unfasten the crampon with the hand. With concept 6 and 8 the unfastening is performed with an extension of the hand instead, requiring a less bending of the user.

As it can be observed in table 4, the determined weight is applied for each of the scoring and the results are summed. As a result, a ranking of the concepts is obtained: concept number 6 has the highest scoring achieving a 12.5% higher scoring than the second concept (see figure 20).

As a result, it is concluded to dismiss the other two concepts and to continue developing the concept number 6. The solution concept that is achieved consists in the action of a spring. As shown in figure 20, the fastening process is activated by pressing the binding with a boot. The whole binding moves during the attachment process, having free moving with respect to the framework of the crampon. The binding is attached at the rear-part groove of the boot. A security system consisting in a clip ensures that the binding system is not released while climbing. In order to unfasten the crampon, an extension of the hand is used to release the binding.
The end of the supporting bar, which includes a flange (g), is introduced into a hole (h) in the framework, which has a specific shape, as shown in figure 29. This specific shape of the hole permits the supporting bar to turn a determined angle, from the storing position to the attachment position of the binding. The width of the hole of the framework is restricted by the thickness that the whole framework has: as mentioned above, the framework is built from a 2 mm steel sheet, being 2 mm the maximum width that the hole can have.

The fixing covers are introduced through the end of the supporting bar and the hole in the framework tightly. As it can be observed in figure 29, due to their joint this mechanism permits to turn the bars from the attaching position to a position where the binding can lean on the framework in order to reduce the dimensions when storing the crampons.

Even if the supporting bars are jointed to the framework tightly by the fixing covers and to the axis also tightly by the axis covers, the risk of the supporting bars suffering a displacement outwards the direction of the axis can occur due to the vibrations and utilization of the crampons. This can occur if the friction between the mentioned components is exceeded, leading to the disassembling of the binding. Otherwise, as a pin is introduced through the axis and the axis covers and this last component is blocked to the supporting bars as it is shown in figure 28, the possible displacement of the supporting bars outwards the direction of the axis is dismissed, blocking every axial displacement.

**ADDITIONAL COMPONENTS**

In order to avoid dirt to penetrate into the mechanism and obstruct the functioning, such as water that might freeze or dust that can damage the components, caps and seals are used. As it can be observed in figure 22, both the rear (6) and the front (7) caps, include an orifice to enable the disassembly. Two V-seals, named V-SEAL-10A (Argensold, n.d.), are included at the contact place between the axis covers and the cover of the binding, to make the cover to rotate with respect to the cover axis with no friction between these components. The function of avoiding dirt to penetrate into the mechanisms is accomplished at the supporting bars by the fixing covers, as shown in figure 29.

**SECURITY SYSTEM**

Even if the binding system is designed in order not to release under any circumstances, the design includes a security system as whether the crampons are removed from the boot when climbing, the life of the user can be endangered. As stated in section 3.1.1, it is estimated that the best solution consists in a clip that can withstand hard pulls. Nevertheless, when security systems of this kind are searched in the market, it is observed that the Fasty strap is the system that bears the highest forces (see figure 30).
Design, Verification and Manufacturing of a New Binding System for Crampons

... treatment coatings, so they are prepared for standing extreme conditions. Otherwise, the seals do not stand any forces; thus, there is no danger of breaking. Besides, the reference step-in crampon also contains steel made commercial elements, standing the forces they are suffering for a long time in the same extreme conditions. As a result, the suitability of the commercial elements is ensured for this application.

3.3. MANUFACTURING PROCESS

To determine the process to manufacture each component of the design, the Value Engineering Method is used. The components are divided depending on the materials they are composed of, and concerning the similarity of their characteristics and shapes. The function provided by each component determines the accuracy of the finishing that it requires, while the shape of the components restrict the possibility of the processes to be used.

Firstly, all the components are separated into groups depending on the material they are manufactured at or if they are commercial elements in order to establish the manufacturing processes to create the different parts of the new design (see table 8).

<table>
<thead>
<tr>
<th>PE-HD</th>
<th>AISI 4130</th>
<th>Commercial elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover</td>
<td>Axis</td>
<td>Spring</td>
</tr>
<tr>
<td>Slider</td>
<td>Supporting bars</td>
<td>Screws</td>
</tr>
<tr>
<td>Lock</td>
<td>Fixing cover</td>
<td>Pins</td>
</tr>
<tr>
<td>Axis covers</td>
<td></td>
<td>V-seals</td>
</tr>
<tr>
<td>Front cap</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rear cap</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8: Division of the components of the binding and supporting system concerning their materials or being commercial elements.

In order to reduce costs in the manufacturing process, commercial elements are used when possible in the design, as mentioned in section 3.1.2. The purchasing of commercial elements is more economical, as they are produced in large quantities and by companies that are focused on those products. Hence, the savings with the acquisition of these products instead of producing them are relevant. Apart from reducing the costs, these elements provide advantages in the design, as their measures and tolerances are normalised. Moreover, the normalisation of their parameters benefit in the assembly process.

As described in section 3.2, a wide variety of manufacturing processes exist to produce PE-HD polymer components. However, due to the shapes and profiles of the components in the design, it is estimated that the most suitable process is the injection moulding. This process requires a low operation cost. The same mould is used for producing lots of components and the loss of scrap during the manufacturing is insignificant; therefore, the environmental impact of the injection moulding is minor. It provides high precision tolerances; thus, once the component is removed from the mould, the necessity for the finishing process is minimal. The disadvantage of the injection moulding consists in the high price of the tools used during the process (Quickparts, 2012). Nevertheless, even if the required infrastructure for this process is
expensive, if many components are manufactured using the same mould, the investment is rapidly recovered. As a result, it is concluded that the injection moulding is the optimal process for the manufacturing of the polymer components.

Another substantial aspect of the injection moulding is the wall thicknesses that it might provide to the components. In the case of PE polymers, the thickness that the process provides varies from 0.7 mm to 5 mm, which involve the required thicknesses for the components that form the new design.

Some of the most important parameters when creating pieces using the injection moulding are the melting temperature, the mould temperature and the injection pressure. Regarding the melting temperature, PE-HD is heated up to 220 – 260 °C, twice its natural melting point, which is 130 °C. Moreover, the mould is heated up to a certain temperature depending on the wall thickness of the component that is created. The components that are necessary to manufacture for the design have wall thicknesses below 6 mm; consequently, the temperature of the mould must be heated up until 95 °C. The injection pressure varies depending on the component that are produced; however, the pressure varies between 700 – 1050 bar (China Plastic, 2012).

Regarding the production of the components that are composed of the chormoly steel AISI 4130, different manufacturing processes are established depending on the characteristics of the components. On one hand, due to their design, the axis and the supporting bars are possible to extract from purchased bars mechanising them. Bars with the same diameter as the required one in the design are available in the market in order to produce the axis (Longhai Steel, 2011). Therefore, the manufacturing process that the axis demands consists of cutting the commercial bar to the necessary length and accomplishing two transversal holes to introduce the pins through it. As well as the axis, chormoly steel AISI 4130 bars are found with the desired diameter for the supporting bars (Longhai Steel, 2011). As a result, in order to obtain the supporting bars, the purchased bars are required to be cut to the necessary length; the thread where the screw is inserted is then performed, apart from creating the specific shape at the end of the bar, which involves the flange.

It is concluded that a metal cutting circular saw is the best option in order to cut the acquired bars to the required length. Even if the cutting blade enters the material more smoothly, the cutting time is reduced compared to other saws. Furthermore, it leaves the materials cooler after the cut; thus, no time is required to wait for the components to cool before mechanising them. It also provides a cleaner cut than other processes. (Rodriguez, G., 2013).

In order to perform the stated mechanisation processes to the steel bars to achieve the final design of the axis and the supporting bar, it is estimated that a CNC milling machine is the optimum process. It provides the simplest and fastest way to manufacture this kind of components. This machine can be working 24 hours a day the whole year, only stopping for maintenance. The design can be simulated without building a prototype using software, what saves time and money. When the design is ready, exactly the same product can be manufactured as many times as desired, obtaining a precise and accurate finishing. Even if CNC machines are more expensive
### COMMERCIAL SPRING

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_s$</td>
<td>Stiffness of the selected spring</td>
<td>25.9 N/mm</td>
<td></td>
</tr>
<tr>
<td>$l_{s0}$</td>
<td>Natural length of the selected spring</td>
<td>50.8 mm</td>
<td></td>
</tr>
<tr>
<td>$l_{smin}$</td>
<td>Maximum deformation that the selected spring can stand</td>
<td>31.2 mm</td>
<td></td>
</tr>
<tr>
<td>$d_{spring}$</td>
<td>Maximum diameter that the selected spring obtains</td>
<td>14.5 mm</td>
<td></td>
</tr>
<tr>
<td>$d_{hole}$</td>
<td>Minimum diameter that the hole where the spring is placed has to have</td>
<td>15.8 mm</td>
<td></td>
</tr>
</tbody>
</table>

Table 9: Assigned spring

Therefore, it is possible to determine the forces that the spring transfers to the system:

\[ [1] \& [2] \rightarrow F_{s_{comp}} = k_s (l_{s0} - l_{comp}) = 513 \text{ N} \]  
\[ [6] \]

Where $F_{s_{comp}}$ is the force that the spring transfers when it is compressed at one side of the stroke in the binding system.

\[ [1] \& [2] \rightarrow F_{s_{decomp}} = k_s (l_{s0} - l_{decomp}) = 331 \text{ N} \]  
\[ [7] \]

Where $F_{s_{decomp}}$ is the force that the spring transfers when it is decompressed at the other side of the stroke in the binding system.

Apart from that, once that all the components and their materials are established, it is possible to calculate the masses of the different components of the crampon:

\[ m_{binding} = 50.7 \text{ g} \]
\[ m_{supporting} = 21.2 \text{ g} \]
\[ m_{framework} = 402.1 \text{ g} \]
\[ m_{secsys} = 13.4 \text{ g} \]

Where $m_{binding}$ is the total mass of the binding system, $m_{supporting}$ is the total mass of the supporting system, $m_{framework}$ is the total mass of the framework and $m_{secsys}$ is the total mass of the security system.

\[ m_{crampon} = m_{binding} + m_{supporting} + m_{framework} + m_{secsys} = 487.4 \text{ g} \]  
\[ [8] \]

Where $m_{crampon}$ is the total mass of the crampon.

### VERIFICATION OF THE ATTACHMENT PROCESS

The forces acting during the attachment process are determined to ensure the functioning and comprehend the forces that are necessary to apply to make the mechanism to function for the designed parameters. In order to simplify the analysis, it is concluded that even if the forces act on a surface, they are analysed as point forces. As the critical areas as regards to the attachment process consist in the contact surfaces between the axis, the cover and the slider, these are the analysed components. This estimation is concluded because the displacement and rotation occurs between these components. Besides, whereas a friction force occurs between the cover and the slider when the mechanism is activated, as these contact surfaces are lubricated as stated in section 3.4, the friction force between these components is neglected. Furthermore, it is...
included in the situation where the holes of the cover and the slider are aligned in the instability position (see figure 48).

![Figure 48: Instable situation when the lever is pressed and the mechanism is activated at the hole of the binding](image)

As it is observed in figure 48, the worst situation is considered, being the force of the spring transferred perpendicularly directed to the surface of the hole. Hence, only the moment created by the load applied at the lever is making the mechanism activates.

In reality, an infinitesimal displacement occurs when the lever is pressed, hence, a little angle exists at this instability instant, which makes the moment of the force of the spring to be directed upward the hole. This produces the binding advances with respect to the axis and collaborates in the activation of the mechanism. As a result, it can be ensured that the required load that is obtained to be applied at the lever is totally feasible in reality.

The sum of the moments at point 0 with respect to the x axis is calculated to obtain the required results.

\[
\sum M_{0x} = F_{fas} d_1 - F_1 r - F_2 r - W y_1 = 0
\]  \[15\]

Where \(F_{fas}\) is the force applied at the lever with the boot required for activating the fastening mechanism and \(d_1 = 21\) mm is the distance between where the force applied at the lever and point 0 in the y axis, the distance creating the moment with respect to this point.

\[
[10],[11]&[15] \rightarrow F_{fas} = \frac{(\mu_1 + \mu_2) F_{scomp} r + m_{binding} y_1}{d_1}
\]  \[16\]

At this case, as the force applied at the lever to activate the fastening mechanism has to exceed the friction force, the friction coefficient that is used is 0.4, the maximum static friction coefficient between the metal and the plastic (Tribology-abc, n.d.). Therefore, for any lower static friction coefficient, the mechanism is also activated.

\[
[13]&[16] \rightarrow F_{fas} = \frac{2\mu_{s max} F_{scomp} r + m_{binding} y_1}{d_1} = 54.2\ \text{N}
\]  \[17\]
of the spring; hence, it is established the load that the spring is transferring when it is in its maximum compression (see figure 56).

![Diagram 56: Modelling of the axis](image)

As shown in figure 56, two different forces are acting at the axis: one is the force of the spring transferred to the axis through the slider and the other one is the force of the spring transferred to the axis through the cover, as stated above and shown in figure 44. In reality, this force is transferred to the axis in the contact surface between these components; thus, the force is acting at the radial area (see figure 57).

![Diagram 57: Forces acting at the axis at the radial area](image)

The maximum force is transferred in the middle of the distributed load, which corresponds to the direction at which the spring is transferring its load. The force acting between the two surfaces decreases while the contact surface is further from the direction at which the spring load is transferred, as it is observed in figure 57. Nevertheless, the distributed load is simplified in one point force with the stated direction. Even if this is a simplification, if the model is analysed in this way and the obtained maximum stress is valid, it is ensured that in reality the axis will also withstand the load, as a point force with the same value of the load transferred by the spring creates a higher stress than a distributed one.

As the axis is introduced tightly into the axis covers and it has no possibility to rotate with respect to the axis covers due to the pins introduced through the axis and the axis covers, at both sides the axis is modelled as being fully constrained. In order to obtain the reactions at these points, a free-body-diagram is accomplished (see figure 58).
As stated in section 3.1.2, the load of the spring is directly transferred to the lock. The lock transfers this force to the cover through the thread; hence, the lock is in compression. However, the cover is in traction: the force of the spring makes the cover to move opposite the direction of the axis, but as this movement is blocked by the axis that is introduced through the cover, stress is created in the cover. On the other hand, the spring transfers its load to the slider from the other end. Due to this force, the slider is pushed towards the axis, but it is not moved because the axis is introduced through the slider. As a result, the slider stress from compression, as shown in figure 61. The weight is neglected as its low value has no influence on the stresses, as well as being located in another direction.

The following expression determines the tensile stress created by traction and compression forces:

\[
\sigma_{tensile} = \frac{F_{tensile}}{A_{tensile}}
\]

Where \( \sigma_{tensile} \) is the tensile stress created by traction and compression, \( F_{tensile} \) is the traction or compression force and \( A_{tensile} \) is the area of the section where the traction or compression forces are acting.

In order to perform the calculus of the tensile stresses, the higher load transferred by the spring is used, which corresponds to the position when the spring is totally compressed.

\[
F_{tensile_s} = F_{S\,comp}
\]

Where \( F_{tensile_s} \) is the maximum force transferred by the spring.

With the purpose of ensuring that the tensile stresses created by the traction and compression forces do not exceed the value of the yield tensile strength for the plastic...
As it can be observed in table 10, the spring costs 2,4 € (Leespring, 2013); each pin used in the design costs 0,01 € (Pasadores Elásticos, 2012), each V-seal costs 0,46 € (Alibaba.com, 2013), each screw costs 0,08 € (Tecnico-Productos, n.d.) and the security system costs 1,9 € (The Roof Box Company, 2012). The table 10 also shows the number of units of each commercial element used in one crampon; as there are two crampons, the number of units is duplicated. As a result, the total cost of the commercial elements is 10,8 €.

Regarding the raw materials that are used in the new design, their costs are shown in table 11.

The weight of each raw material is obtained adding the weight of each component in the design, as it can be observed in table 11. An estimation of the weight of the trash material that is wasted when manufacturing the components is added in order to get the initial required weight before the manufacturing. However, the required weight of polymer and steel is very small; as a consequence, the costs in raw material that PE-HD (Plasticker, 2013) and AISI 4130 (Alibaba, 2012) components have can be neglected when determining the price of one pair of crampons.

On the other hand, the manufacturing processes that are used to get the components from the raw materials make the costs rise. Nevertheless, it is almost impossible to determine the manufacturing costs that each component of the new design has.

However, it is possible to determine the costs to produce the plastic components (Protomold, 2013), as is can be observed in table 12.
As it is shown in table 12, the price to obtain the plastic components is not too high. Otherwise, the costs of the moulds to produce the components are very high, around 17000 €. In order to determine real prices of the pieces, the amount of pieces that are manufactured and the amortisation parameters of the mould must be taken into account. These parameters cannot be estimated to achieve an accurate cost of the plastic components, as there is no evidence of the production size. Furthermore, the costs of the manufacturing processes of the metallic parts are very difficult to determine. Consequently, the manufacturing processes to produce the new components are compared to the manufacturing processes used for the reference crampon in order to determine which of the two processes is costlier.

The metallic parts that are used in the reference crampon have less exigent manufacturing operations that the ones used in the new design as explained in section 3.3. The operations that the metallic parts require in the reference crampon are low demanding bending operations. However, in the new design, CNC machine operations are required. As a result, the new design is more expensive concerning the metallic parts.

Regarding the plastic parts, the reference crampon has also plastic components, which are made using the injection moulding, as in the new design. However, the reference crampon has fewer elements. Consequently, the new design is also more expensive than the reference crampon concerning the plastic components.

In addition, the reference crampon has commercial elements as well. Nevertheless, the new design contains more commercial elements, which make the new design even more expensive.

As a result, it is estimated that the created crampons are more expensive than the reference ones. The framework and the front-part binding system are the same, being no difference in their production costs. On the other hand, the binding and supporting systems of the new crampons are costlier.

<table>
<thead>
<tr>
<th>Component</th>
<th>Mould price (€)</th>
<th>Piece price (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover</td>
<td>4622,8</td>
<td>2,21</td>
</tr>
<tr>
<td>Slider</td>
<td>2657,2</td>
<td>1,9</td>
</tr>
<tr>
<td>Axis cover</td>
<td>2736,5</td>
<td>1,91</td>
</tr>
<tr>
<td>Lock</td>
<td>3669,9</td>
<td>1,88</td>
</tr>
<tr>
<td>Front cap</td>
<td>1242,8</td>
<td>1,86</td>
</tr>
<tr>
<td>Rear cap</td>
<td>2507,7</td>
<td>2,74</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>17436,9</strong></td>
<td><strong>10,29</strong></td>
</tr>
</tbody>
</table>

Table 12: Price of the moulds and pieces for PE-HD components
As a result, this force creates a moment which leads the binding to release; however, when the force directed upwardly in the edge makes the binding start to rotate with respect to the axis, there are two forces opposing this action from occurring. On one hand, the edge makes contact with the vertical surface of the groove, where, due to the normal force of the surface against the edge, a moment is created making the binding rotates in the opposite direction to the releasing direction. On the other hand, when the binding starts to rotate, the strap of the security system is tautened, making a force that creates another moment in the opposite direction to the releasing direction.

Consequently, it is ensured that the binding does not release even if the user pushes up with the highest force that a human can, as the strap and the clip stand a load of 400 kg. The only detail consists in the fact that the strap of the security system always has to be as tautened as possible; thus, whenever the binding starts to release, the security system acts immediately against this movement, not letting any clearance be created between the boot and the crampon.

One of the objectives consisted in the fact that the binding system has to withstand a force of 300 N without releasing. Actually, the load that the spring transfers when the binding is fastened is higher than that force; however, it is not the force that the binding stands without releasing, as this force is not transferred into the groove. This occurs because if the slider would advance with respect to the cover until it would make contact with the groove, any kind of dirt that might damage the mechanism could be possible to get inside the binding. Therefore, the mechanism is designed to be totally closed; thus, the moment avoiding the binding to release is produced by the friction force.

Lastly, to accomplish the unfastening of the binding mechanism, a maximum force of 76 N is necessary to be applied at the hole that is placed at the upper part of the binding system when this is placed vertically. This maximum force has to be applied to make the binding start rotating in order to release it; thus, the force has to exceed the friction force when the binding is static. It is estimated that any user of crampons is able to apply a force higher than 100 N with an ice axe or a walking stick at that position. Besides, this force is only necessary to be applied at the first moment, until the friction force is exceeded and the binding starts rotating. Once it rotates, the required force to keep the binding turning substantially decreases; hence, it is ensured that any user is able to perform the unfastening process.

Once that the releasing process starts, the binding rotates and advances with respect to the axis, until it is placed horizontally with respect to the framework. Contrary to what it is believed, even if the slider is advancing back with respect to the cover making the spring to compress, the higher load transferred by the spring does not suppose that a higher unfastening force has to be applied. At the horizontal position, when the spring is transferring its maximum load, the force that is necessary to apply in order to continue moving the binding is a quarter of the required force at the beginning position, when the spring is transferring its minimum load. This occurs because the direction of the applied force is more influencing than the load that is necessary to be exceeded. At this position, the binding accomplishes a turning of 90° with respect to the fastened situation. Due to the advancing of the binding with respect to the axis, the axis
is moved from the downer part of the holes of the cover and the slider, and it is placed in the upper part of these holes. The binding is therefore unfastened and stable again.

Moreover, analysing the unfastening mechanism, it is ensured that, when the unfastening force is applied, the binding rotates and it is possible to remove the boot from the crampon. Nevertheless, it is observed that the possibility of the binding not moving to the unfastened position exists. Depending on how the unfastening force is applied, the possibility that the binding only rotates with respect to the axis exists. This might occur as it is necessary to compress the spring in order the slider to advance backward with respect of the cover, while the whole binding rotates, as stated in section 3.1.2.

In this way, the axis would not move relatively to the holes of the cover and the slider, and it would stay at the downer part of the holes. Consequently, it would be possible to remove the boots from the crampon, whereas the binding would not be ready to fasten it again. As a result, it would be necessary to grab the binding with the hand and press it down from the back part of the binding in order to make the binding advances with respect to the axis. This is necessary to perform until the axis is placed at the upper part of the holes in the slider and the cover, in the unfastened position of the binding. Besides, this action would be performed after removing the boot from the crampon. It might even be done back at home, if the crampons are only necessary to wear once, as the binding systems are possible to place in their storing position even if the rear-part binding system is in the fastened position with the axis at the downer part of the holes.

The critical components of the binding and the supporting systems that are created are analysed in order to ensure that all the components of the design withstand the forces that they are suffering. It is concluded to establish a security factor that all the components have to fulfil in order to ensure their durability. The analysis is accomplished, and it is ensured that all the critical components of the design bear the stresses created on them with a security factor of 4.

Besides, it is determined that all the sharp edges of the created design are rounded in order to avoid stress concentration in those edges. This is accomplished with accuracy at the critical components, such as the flanges of the supporting bars.

Nevertheless, it is necessary to enlarge the sizes of the diameter of the axis and the area of contact of the flange with the hole of the framework in order all the components to bear the stresses they are suffering. As a result, after the redesigning, it is possible to calculate the new weight of the crampon:

\[
m_{\text{binding}} = 51.8 \text{ g} \quad m_{\text{supporting}} = 21.9 \text{ g} \quad m_{\text{framework}} = 403.3 \text{ g} \quad m_{\text{secsys}} = 13.4 \text{ g}
\]

Where \(m_{\text{binding}}\) is the total mass of the rear-part binding system after the redesign, \(m_{\text{supporting}}\) is the total mass of the supporting system including after the redesign and \(m_{\text{framework}}\) is the total mass of the framework including the front binding after the redesign.

\[
m_{\text{crampon}} = 490.4 \text{ g}
\]

Where \(m_{\text{crampon}}\) is the total mass of the crampon after the redesign.
5. CONCLUSIONS

The main goal of the project is achieved: a new design of the rear-part binding system of the step-in crampon that provides a simpler and faster attachment process of the crampons without having to remove the gloves is created.

The fastening process is diminished from six difficult steps to be performed with the hands, having to remove the gloves for it, to two simple movements of the hands and one simple movement of the foot that does not require removing the gloves. Furthermore, the unfastening process is reduced from five difficult steps to be accomplished with the hands to three simple movements of the hand. Neither in the fastening process nor in the unfastening process the action of moving the rear-part binding system from its storing position to its attachment position, and then moving it back again to its storing position, is taken into account in the stated movements. Nevertheless, as in the reference crampon the same process is necessary to perform, it does not make a difference as regards to this action.

The design that is created is totally adaptable to any kind of boot available in the market for the step-in crampon: as depending on the boots the height of the rear-part groove varies, the height of the edge that is inserted in the groove is regulated with the screws that perform the joining between the rear-part binding system and the supporting system. This regulation is obtained by introducing the screws more or less in the supporting bars. As the stroke of these screws is of 10 mm, it is possible to regulate the binding system for a height of the groove of the boots between 30 − 40 mm. Hence, the requirement of the suitability for all types of boots is fulfilled.

As the designed crampon provides the option of changing the position of the binding systems to a storing position, it has reduced dimensions. The length and the width of the crampon are determined by the framework of the crampon, which is not changed; thus, they continue having the same values as in the reference crampon. On the other hand, when the binding systems are positioned for storing and the two crampons are placed together with the prongs pointing to each other and intertwined with each other, the height of the two crampons is 100 mm. Consequently, it is ensured that they fit in a bag with dimensions 250 mm x 120 mm x 120 mm.

Besides, when the crampon is fastened, the rear-part binding system protrudes 28 mm from the back of the framework of the crampon, being this the maximum projecting; hence, the requirement that the binding system has to exceed less than 50 mm from the framework is fulfilled. Moreover, as the height of the rear-part binding is possible to be regulated, it is ensured that the boot is tightly connected to the crampon, without any kind of clearance.

The components of both the supporting and the rear-part binding systems are made of recycled materials. In addition, they are designed in order to be recyclable after the disassembling: as the joining of the components is performed mechanically, when the assembly is dismantled each component only has one homogeneous material. The only exception occurs with the slider and the cover, which contain a cover of rubber at the lower part of their holes. Nevertheless, these parts can be separated applying the lever law; thus, it is ensured that all the components are recyclable.
confusing. As there is no evidence of how many crampons might be produced, even if it is feasible to estimate the price of production of each component, it is not possible to determine the amortization of the machines that are required for the manufacturing process. Therefore, as the machines and the tools involve the highest cost of the process, it is decided to compare the required production for the reference crampon with the one for the created crampon.

Generally, the project is conducted regularly according to the planning of the time that is performed at the beginning, as shown in the Gantt diagram in Appendix A. Nevertheless, more time than expected is spent in the new design, due to the problems stated above. Apart from that, the planned time is spent fulfilling the tasks, even if the rest of the implementation parts are necessary to accomplish barely faster due to the time consumed at the design part.
Design, Verification and Manufacturing of a New Binding System for Crampons


