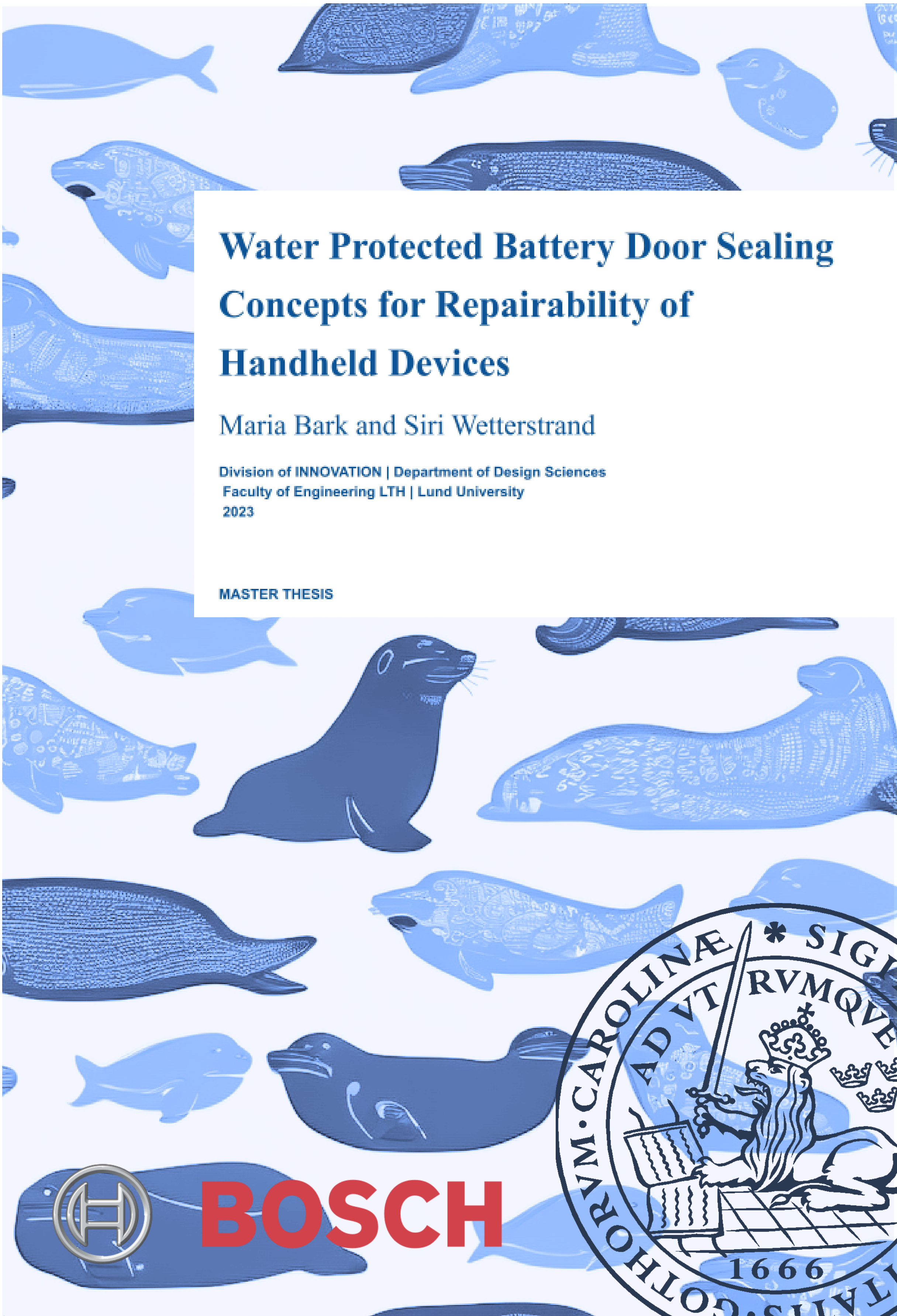

Water Protected Battery Door Sealing Concepts for Repairability of Handheld Devices

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Division of INNOVATION | Department of Design Sciences
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MASTER THESIS

Water Protected Battery Door Sealing Concepts for Repairability of Handheld Devices

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Abstract

This project is a cooperation with Bosch, which is a German multinational company specialized in mobility, industrial technology, building technology and consumer goods. As a part of the mobility work, the office in Lund is developing computers for e-bikes. The e-bike products, along with many other Bosch products, will be affected with upcoming regulations regarding repairability requirements.

There are already new regulations in place to increase the obligations for companies to improve the repairability of products, and in the next few years additional regulations will come into effect in the EU, the US and other regions. At the same time, many handheld electronics devices are irreversibly assembled with adhesive. In many cases, this makes repairing the devices impossible.

This project aims to increase the repairability of handheld electronic devices, without compromising key features such as water ingress protection or economical viability.

Adhering to Ulrich Eppinger's guidelines for product development, the lid concepts emerged. In this report both radial and axial sealing designs are developed and evaluated. Different types of gasket design and sustainable choice of material is also discussed. The solutions were developed with both environment, users and profits in mind. These concepts were then thoroughly tested for waterproofness and test user satisfaction.

Finally, the concepts were evaluated based on set metrics which had emerged through interviews with both Bosch employees and test users. The evaluation took environmental, economical and usability factors into account as well as the requirements for certifying the product for ingress protection.

Keywords: *product development, repairability, battery lid, gasket, water ingress protection*

Sammanfattning

Detta projekt är ett samarbete med Bosch, som är ett tyskt multinationellt företag specialiserat på mobilitet, industriell teknik, byggnadsteknik och konsumentvaror. Som en del av arbetet med mobilitet utvecklar kontoret i Lund datorer för elcyklar. Elcykelprodukterna, tillsammans med många andra Bosch-produkter, kommer att påverkas av kommande regler om krav på reparabilitet.

Det finns redan nya regler på plats för att öka skyldigheterna för företag att förbättra möjligheterna för reparation av produkter, och under de närmaste åren kommer ytterligare regler att träda i kraft i EU, USA och andra regioner. Samtidigt är många handhållna elektronikprodukter irreversibelt monterade med lim. I många fall gör detta det omöjligt att reparera enheterna.

Detta projekt syftar till att öka möjligheten för reparation av handhållna elektronikprodukter, utan att kompromissa med viktiga funktioner som vattentäthet eller ekonomisk lönsamhet.

I enlighet med Ulrich Eppingers riktlinjer för produktutveckling togs de olika koncepten fram. I denna rapport utvecklas och utvärderas både radiella och axiella tätningssystem. Olika typer av utformning på packningar och hållbara materialval diskuteras också. Lösningarna utvecklades med tanke på både miljö, användare och ekonomisk hållbarhet. Dessa koncept testades sedan noggrant för både vattentäthet och användarnöjdhet.

Slutligen utvärderades koncepten baserat på uppsatta metriker som hade framkommit genom intervjuer med både Bosch-anställda och testanvändare. Utvärderingen beaktade faktorer gällande miljö-, ekonomi- och användbarhet, samt kraven för vattentäthetscertifiering av produkten.

Nyckelord: produktutveckling, reparabilitet, batterilock, packning, vattentäthet.

Acknowledgments

This project would not have been possible without the generous resources and support from the Bosch office in Lund. We especially want to thank our supervisor Mats-Åke Ekbladh who has been vital to the progress of the project and who has shared his abundant experiences in the product development field.

We also want to thank the other colleagues at Bosch, who have cheered us on and been incredibly generous with their time and knowledge. An extra thank you to our team manager Christoph Jabs, without his efforts we would never have gotten the opportunity to do this project.

A special thanks to Sigma Connectivity as well, who were kind enough to let us borrow their facilities for evaluating the waterproofness of our concepts. Oliver Bengtsson's efforts to juggle his own master's thesis at the same time as helping us with the tests at Sigma's laboratory are not forgotten and we are truly thankful for his help.

Lastly, we want to thank our supervisor Katarina Elner-Haglund who probably is one of the country's sharpest experts when it comes to plastic products and their manufacturing. Her advice and insights have lifted this project to levels which otherwise would have been immensely difficult to achieve.

Lund, January 2023

Maria Bark, Siri Wetterstrand

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List of acronyms and abbreviations

IP	Ingress Protection, an international standard for rating the degree of protection against ingress of solid foreign objects and liquids
PC	Polycarbonate
ABS	Acrylonitrile-butadiene-styrene
E-waste	Electronic waste
FDM	Fused Deposition Modeling
SLA	Stereolithography
SLS	Selective Laser Sintering
Subj.	Subjective
Lo-Fi	Low-fidelity
s	Seconds
SEK	Swedish krona
LSR	Liquid Silicone Rubber
2k	2K injection molding, a process using two different materials injected into a mold to create a single part with diverse colors or properties
R&D	Research and development
AI	Artificial Intelligence

1 Introduction

1.1 Background

1.1.1 About Bosch

Bosch was founded by Robert Bosch in Stuttgart, Germany, in 1886. One of the first products, a magneto ignition device, is today represented in the Bosch logo. Since then, Bosch has grown to a global company employing more than 420,000 associates worldwide [1]. They provide a wide array of products and services, being a leading supplier of mobility solutions, industrial technology, consumer goods, energy and building technology [1].

The Bosch site in Lund is a research and development (R&D) center, with emphasis on software related to connectivity, security and AI. In addition, there is a division with hardware and mechanics working with development of new products and solutions. This team, and in particular the project around e-bike computers, have been the inspiration to the topic of this master thesis.

Figure 1: *The Bosch office in Lund.* Photo: Bosch.se

1.1.2 The project context

Today, many electronic devices are sealed with adhesive to provide adequate protection against water intrusion in many of Bosch's products. Simultaneously, there are several upcoming EU regulations, aiming to improve the repairability and recyclability of electronic devices, that will be enforced over the coming years. As a result, companies like Bosch will need to develop new sealing solutions to comply with these regulations.

One such instance is the sealing of computers for bicycles by Bosch. These devices require a tightly sealed battery door to withstand high water pressure. Currently, this is achieved through the use of adhesive during assembly. However, this method makes them difficult to repair and will no longer be permissible once the new EU regulations take effect.

The objective of this project is therefore to explore alternative solutions for sealing battery doors that can withstand high water pressure, all while being repairable.

1.1.3 The current solution

The reference product, an e-bike computer developed at Bosch in Lund, has a housing that is currently made of an alloy between two different thermoplastics. The first one being Polycarbonate (PC) and the second one being acrylonitrile-butadiene-styrene (ABS).

The plastic lid is irreversibly sealed to the product's housing with an adhesive. If the battery malfunctions it cannot be repaired. Instead the product will be replaced by Bosch if it breaks during the warranty period. This product holds the IP classification of IP69K.

1.2 Target and problems to solve

The aim of this project is to create a plastic lid for a handheld device that is easily opened, waterproof and environmentally sustainable. The concepts will be generated with battery covering doors in particular, although the aim is to discover solutions that are also applicable on other types of doors on electronic devices. In addition appropriate materials are to be chosen for the concepts.

The lid should allow and increase the repairability of the product. Therefore, it should not be overly complex to open. Yet, the solution should also prevent unintentional opening. Furthermore it would be desirable to fulfill the requirements of the ingress protection (IP) standard, IP69K, which means that the product should be completely dustproof, withstand a washdown of 80 to 100 bar at temperatures of up to 80°C.

However, for this project it would suffice to fulfill the IPx5 requirements. This means that the solution has to withstand waterjets, but not resist particle ingress or high temperature waterjets. Higher IP classifications will be in mind for future development but not thoroughly tested for. See Table K.1, Appendix K for all of the different IP classifications and their requirements.

When evaluating concepts, important factors to consider will be cost, size efficiency and usability. A requirement is the possibility to open and reseal the concept several times without impacting the robustness of the door. In addition, the door should not break if a user attempts to disassemble the product in an incorrect way. The concept also has to be suitable for a variety of products with different requirements. The design also has to be reasonable for industrial manufacturing and assembly.

1.3 Delimitations

- Only the door is to be designed. The enclosed volume or the seal's corresponding contact surface will not be designed in detail.
- Tolerances will not be set in this project since the concepts will be altered to fit each product before production.
- Tooling is seen as an investment and not amortized into the estimated cost per lid since the production volume is unknown.
- The product development stage of production ramp-up will be simplified.

2 Theory

2.1 The sustainability movement

The sustainability movement has a long history of activism leading to change through government regulations. In the late 1800's conservation groups began operating to protect wilderness areas and wildlife. Logging, mining, dam constructions started to become regulated [2].

Since then regulations have been strongly connected to the sustainability movement, and regulations concerning leaded gasoline and ozone damaging chemicals have been established since the first protected national parks in the 1800's [2].

2.1.1 Current issues

The growing problem of waste management and garbage reduction is one of the modern day's current issues. It is estimated that there is currently between 75 to 199 million tons of plastic [3] waste in our oceans, and although this plastic consists largely of the plastics from packaging, the world still throws away a weight of electronic waste corresponding to 800 laptops every second. The electronic waste comprises 70% of our overall toxic waste, with only 12,5% being recycled [4].

One way to reduce electronic waste is to extend the lifespan of electronic devices and thereby reduce the need for new products as well as the amount of waste created. An important factor in achieving this is by making more products repairable which can be promoted through regulations.

2.2 Regulations of repairability

2.2.1 Enforced EU-regulations

2.2.1.1 Legal guarantee period

The legal guarantee period is defined by the sale of goods directive [5]. It strengthens the consumers rights in the sense that a company can’t sell a product in a faulty state without providing a free repair, replacement or reimbursement [5]. The company's obligation to do this is during a limited period of time, and the consumer can’t make any claims after the guarantee period if the product is faulty.

2.2.1.2 The Ecodesign directive

The ecodesign directive provides a framework of requirements for energy-related products. For some specified products it defines minimum requirements such as availability of spare parts and accessibility of maintenance information [6].

One example of a product regulated by this directive are electronic displays. For electric displays there are specific requirements concerning labeling, operation efficiency and material selection [7]. The requirements differ depending on the specified product, and far from all types of products have mandatory requirements stated in the ecodesign directive [6].

2.2.1.3 EU taxonomy and sustainable investments

The repairability of a product weighs in when a company is evaluated for classifying as a ‘’Sustainable Investment’’ according to the EU taxonomy [8]. The EU-taxonomy is a classification system which allows financial and non-financial companies to share a common definition of sustainable operations and activities [8].

By increasing the market transparency, it creates security for the investors, protects investors from greenwashing, and helps companies become more environmentally sustainable [8]. Therefore, it also indirectly scales up sustainable investments in the EU and therefore also promotes businesses which takes repairability to heart.

2.2.2 Pending EU-regulations

2.2.2.1 Common rules for the repair of goods in the EU

A possible upcoming regulation, called Document 52023PC0155, is one about common rules that would promote the reparation of products [9]. The motive of the suggestion is sustainable consumption but also increasing the consumer power of the European citizens.

The suggestion contains a package of six recommended alternatives [9]:

- *Prioritizing repair when it is cheaper to replace them*
- *An online platform on national level which matches consumers with repairers and promotes renovated products.*
- *An obligation for a repairer to give a set price and conditions for a repair on request in a standardized form.*
- *An obligation for a manufacturer to inform about their duty to repair.*
- *A voluntary EU-standard for simple repair services.*

However, the most relevant regulations for a company like Bosch are communicated in Article 5. This part of the suggestion contains some rules for manufacturers which strengthens the consumers right to repair their products [9]:

- *The member states of the union have to make sure that the manufacturer will repair products for free or at a reasonable price.*
- *If the manufacturer is not available inside of the union, the importer will fulfill the duty of the manufacturer.*
- *The manufacturer has to make sure that independent repairers have access to spare parts, information related to reparations and tools.*

2.2.2.2 Batteries

There is also a pending directive from 2020 which also touches on repairability. It states new design requirements for portable batteries, where the lowest ambition is to strengthen the obligation on removability of the battery at the end of the products lifecycle [10].

However, the directive is also suggesting a new obligation of replaceability and it also touches on the subject of interoperability of batteries which would dramatically increase the repairability of electronic devices [10].

2.2.3 Other international regulations

2.2.3.1 In the United States of America

In the USA further "Right to repair"-legislation has been encouraged by president Joe Biden [11]. Although the legislation differs from state to state, this has resulted in bills pending or enacted on this topic in several states. The first bill concerning electronics took action on July 1, 2023 in the state of New York [12].

This bill states that all companies that produce and sell electronic devices that fall under the regulation, must make repair equipment and information available to independent repair shops as well as device owners [12]. It is to be expected that more states will pass similar bills in the coming years, and that this movement will keep demanding further availability to repair.

2.2.3.2 China

China has passed new regulations in 2022 that clarifies the responsibilities for manufacturers of private vehicles. It declares that it is mandatory for a seller to offer repairs or to be returned for free of charge for a faulty vehicle, if it is within the guarantee period of 60 days and the vehicle's mileage doesn't exceed 3000 km [13].

It is highly unusual for factories to offer any warranty for other types of products than vehicles, and the consumer is therefore forced to find any faults with the products before making a purchase [14]. In addition to this, the right to repair is strictly constrained in China. This is due to its strong protection of both technology and intellectual property [15].

2.2.3.3 Japan

The Japan Business Council in Europe, made a statement in May 2023 where they announced their support of the proposal for a directive on common rules promoting the repair of goods [16]. However, they insist that it must be allowed to replace a defective product with a refurbished one. Japan's motivation behind this is that it would provide efficiency and a viable circular economy [16].

In addition to this there is a movement of repairability in the collaboration between The Japanese Four Electrical and Electronic Industry Associations [17]. There are almost a thousand Japanese companies which are members of the Basel Task force which consists of known businesses such as Fuji Xerox, Canon, Sony and Mitsubishi. One of their missions is to work according to the ''Mottainai Spirit'', a traditional value to reduce waste. They are currently developing and running operations for repairing and refurbishing used products in countries such as Thailand and Malaysia [17].

2.3 IP-classifications

Ingress protection rating, or IP-rating, is a standardized way to communicate the products resistance to dust and water ingress. The IP-rating consists of the letters IP followed by two or three numbers. The first number stands for solids, which can be the protection against dust or sand. The second water stands for liquids and can show the resistance against water immersion or water jets. Lastly, the third represents the resistance to mechanical impact [18].

Adding the third number is optional, and the IP rating would then just contain two numbers. However, it is not possible to just remove the intrusion protection or moisture numbers from the IP-rating. If one of them is to be left out, it has to be replaced with the letter X. For example, IP4X or IP1X depending on what you want to communicate. What the qualifications are for each number and Ip-classification can be seen in Table K.1, Appendix K.

Another important aspect about IP-classifications is that the scale isn't linear. Which means that a product which received a higher rating, doesn't necessarily mean that the product also is able to perform in the conditions given by a lower rating. For instance, a product may be able to pass the test of water immersion and therefore receive the IPX7 rating, but it is possible that the same product isn't protected against water jets and therefore fails the IPX5 rating [18].

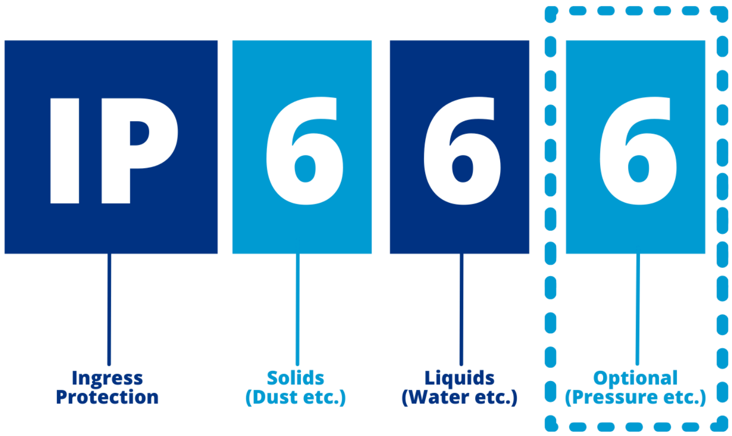


Figure 2: *Nomenclature for IP classifications.* Photo: Clarionuk.com

2.4 Material properties

2.4.1 Shore hardness

There are different scales that describe the hardness of materials. The Shore-scales are commonly used within softer polymers and rubber-like materials. The softest , most gel-like, materials are often measured in Shore 00, flexible injection moldable elastomers are usually measured in Shore A and the stiffer, semi-rigid materials are commonly measured in Shore D. The scales are overlapping, for example a 95 Shore A is the same as a 45 Shore D [19].

Softer, non-metallic materials' hardnesses are measured with a durometer which pushes a needle into a sample of material and measures the indentation [19]. In this report shore hardness will be measured in the A-scale since this is the most common scale for elastomer gaskets.

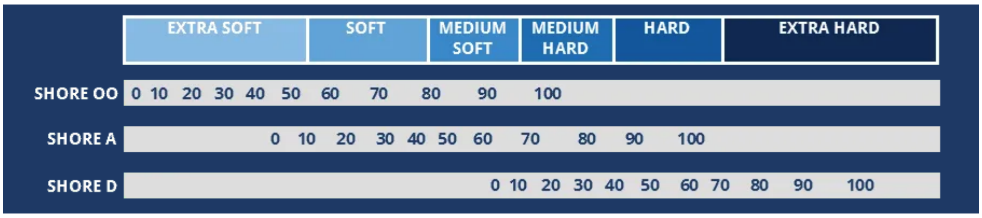


Figure 3: *An illustration clarifying the shore hardness scales. Photo: Smooth-on.com*

2.4.2 Compression set

Compression set is the permanent deformation after a material has been affected by heavy pressure for a set period of time [20]. It is important to evaluate the compression set when selecting the gasket materials for example. The reason for this is simple, the gasket will lose its sealing abilities if it also loses its shape.

The compression set is defined as the percentage of the initial compression. It is calculated by Equation 1 [20], but the value for a plastics compression set can usually be found in the data sheet of the manufacturer.

h0 = Original seal height before compression
h1 = Height after compression
hS = Height during compression

$$\frac{h_0 - h_1}{h_0 - h_s} x100 \qquad (Equation\ 1)$$

2.5 Polymer materials

2.5.1 Plastics

Plastics is the largest group among the polymeric materials [p. 600, 21]. They have the characteristic that they have structural rigidity under load and are therefore not easily deformed. However, all of the plastic materials are not brittle. Some plastic materials are even quite flexible and can be bent a lot before breaking.

This group of materials can be divided into thermoplastics or thermosetting plastics. Thermosets have a crosslinked molecular structure when cured making it irreversibly hardened whilst thermoplastics can be remelted. It is common that the plastics are divided depending on this ability. For this project, because of manufacturability and recyclability, only injection moldable thermoplastic compounds are of interest and will be discussed.

2.5.1.1 Acrylonitrile-butadiene-styrene (ABS)

ABS is a group of plastics which has excellent strength and toughness. It has the benefit of being resistant to heat distortion and, since it belongs to the thermoplastics, it is also recyclable. The largest benefit of all is that it is cheap to purchase and to manufacture, making it one of the most common materials in products ranging from toys to automotive applications [p. 601, 21].

2.5.1.2 Polycarbonates (PC)

Polycarbonates are a type of thermoplastics that contain carbonate groups in their molecular structure [22]. They have excellent properties in regard to strength and finish. Because of the combination of dimensional stability, mechanical properties and electrical properties they are a popular choice in consumer electronic goods. Polycarbonate is also commonly used as an alternative to glass [22].

2.5.1.3 Polyesters

Polyesters are engineering plastics and can be found as both thermoplastics or thermosetting polymers. As thermoplastics a common grade of polyester is PET, and thanks to its resistance to fatigue and stress while simultaneously being recyclable it is common in beverage containers.

The thermosetting side of the polyester family has great electrical properties, and thanks to its ability to be reinforced by fibers it can also be used in goods such as helmets, chairs or even fiberglass boards [p. 602, 21].

2.5.1.4 Polyamide [PA]

Polyamide is a polymer with great strength and durability, although it has a tendency to absorb moisture. PA has many applications and is common to cast, injection mold or make into textile fibers. Polyamides are available both as cheaper commodity plastics and as engineering plastics with more refined properties. [42]

2.5.2 Elastomers

Elastomers have the ability to be deformed and then flex back to their original form [p. 312, 21]. This is because the elastomer is both amorphous and composed of crosslinked and twisted molecules. As the material’s chains are straightened under a tensile load, the entropy wants to push the chains back into disorder.

The rapid progress of synthesis techniques have increased the number of different elastomers with a wide range of different properties suitable for different products and applications. However, for a long time the only known elastomer was the naturally occurring rubber.

2.5.2.1 Rubber

Natural rubber is made of the liquid latex tapped from the Pará rubber tree which is grown in tropic climates. There are also other plants that rubber can be sourced from, for example the panama rubber tree. [23]

Rubber can also be produced synthetically by polymerisation of monomers. Unlike natural rubber, synthetic rubber is made from oil. Some common synthetic rubber materials are EDPM, Butyl and Silicone [23]. Synthetic rubbers can differ much in both mechanical properties, ease of manufacturing and price.

Both natural rubbers and synthetic rubbers are of a crosslinked structure, meaning that once hardened they can not be reprocessed. For the 2K molding manufacturing method, not all rubbers can be used.

2.5.2.2 Silicone

Silicone is a slightly more expensive material than other elastomers, but it also comes with several desirable properties. For example it has high flexibility in a wide span of temperatures, from -90C to 250C [p. 605, 21]. It is also very resistant to weather and chemicals and is therefore a common choice for applications with high demands on mechanical properties, such as in engines. Another important property of silicone is that it vulcanizes at room temperature.

2.5.2.3 Thermoplastic elastomers (TPE)

Thermoplastic elastomers are copolymers with soft qualities, making them a good replacement for rubbers, with the added benefits of processing advantages and being recyclable.

Unlike cross linked elastomers, such as rubber or silicone, thermoplastics melt when heated but will regain their qualities when cooled down again, this means that they can be reprocessed. Because of this, scraps created during the forming procedures can be reused. This leads to lower production costs than with thermosets [p. 610, 21].

Commonly used materials within the TPE-family are TPE-s, TPE-O, TPE-V,

TPE-U, TPE-E and TPE-A.

2.6 Industrial manufacture

2.6.1 Injection molding

Injection molding is the most common way to mass produce polymer details of a complex geometry [p. 655, 21]. The plastic melt is injected into a tool which has the inverse geometry to the desired part. The negative space is filled with the polymer melt and hardens when cooled.

This manufacturing method puts some requirements on the mold. For instance, draft angles which allow for the removal of the part from the mold. Recommended release angles depend on the type of plastic which is injected, but normally the span is around 1-2 degrees. More is needed if there is a very rough surface, but it is also possible to go with less if the surface quality isn't a priority.

The location for injection is also important, it can leave marks on the surface. Because of this it is preferred to put it on a side of the product which is less visible, such as the backside or a less visible edge [p. 655, 21].

The split line between the mold parts has to be placed in a manner that allows for the plastic product to be removed from the mold. It is also important to not place the split line in a way for it to interfere with vital details of the molded part. The reason for this is that the split line in most cases will cause quality disturbances along its length, for example in the shape of visible edges as in Figure 4.

Figure 4: *Shows a quality disturbance caused by the parting line.*

Photo: Moldplasticinjection.com

The number of parting lines is usually one due to the two separate parts in a mold, but if the geometry is complex it is possible to create more than two parts of the mold. This would require additional parting lines. However, adding more complex design to the mold itself will quickly add on the cost of mold manufacturing and it is therefore preferable to keep the design of the mold as simple as possible through a minimum number of parts.

Another factor which affects the cost of the manufacturing through injection molding is the cooling time. The plastic part needs enough time to cool down inside of the mold for it to be properly released. This limits the number of products produced by a mold in a set time and therefore also increases the manufacturing cost [p. 655, 21].

2.6.1.1 Double injection molding

Through double injection molding there can be two different materials in the same product without adding additional manufacturing or assembly steps [24]. The materials are simply added in the same manufacturing mold at different points in time and the second injection uses the cooled wall of the first injection as its mold. This creates a very strong bond between the different materials if the material selection has been done correctly.

The process is fast thanks to the ability of producing two parts simultaneously with a rotating tool, as can be seen in Figure 5. It is a method which is preferred when it is desired to combine two materials in large volume production or if high precision is required.

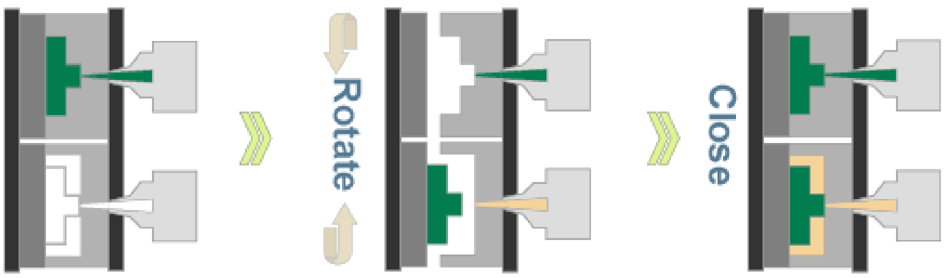


Figure 5: *The process of double injection molding.* Photo: Mony.com.tw

2.6.2 Extrusion

In extrusion the thermoplastic is pushed under pressure through an open-ended die. The opening of the die shapes the molten mass and gives it an uniform cross-section [p. 655, 21]. It is an excellent technique for producing long tubes or filaments for 3D-printing. However, the method of extrusion can also produce much more complex geometries, such as the cross section of the interlocking zip-lock bag.

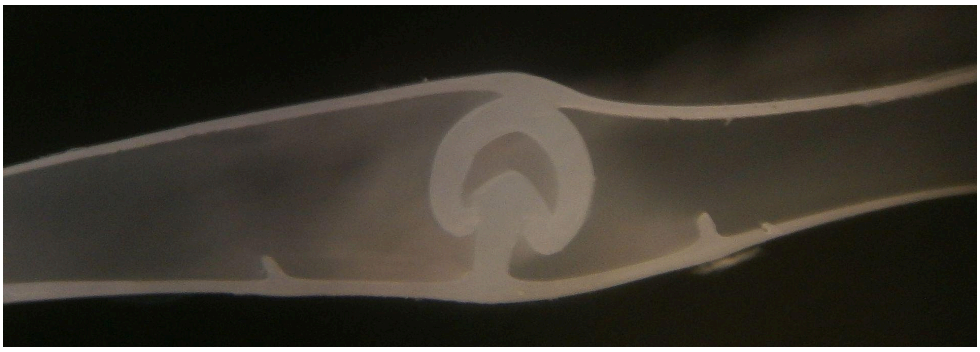


Figure 6: *Even small details with high requirements of precision can be produced with extrusion.*
Photo: Wikipedia.org

2.7 Prototype manufacturing

Prototype manufacturing processes are different to industrial processes due to the production size. For prototypes it is normally only required a few samples for testing the product, while industrial manufacturing methods are developed for thousands or even millions of the same product.

It is also very common to make many alterations along the product development, and because of this the prototype manufacturing process has to be both fast and cheap. This makes processes such as plastic injection nearly impossible for early prototypes due to the large production costs of the molds. Currently, one of the most common methods for prototyping products in plastic is 3D-printing [33].

2.7.1 3D-printing techniques

Fused Deposition Modeling (FDM)

FDM is the most common additive manufacturing method where a continuous filament is melted and extruded into layers that fuse together and harden into the desired geometry [34]. This method is cheap and rapid, however the quality layers of the extrusion will impact both surface finish and give the part anisotropic properties. If the layers are not perfectly fused in all areas, the prototype will not be waterproof. It has the benefit of a wide selection of plastic materials. [34]

Stereolithography (SLA)

SLA is a 3D-printing technique where a liquid photopolymer is fused in layers by a UV-light that is directed with high precision by mirrors, only fusing the polymer according to the desired geometry. The part is printed from the bottom and up, submerged in the photopolymer [34]. This method is quick, gives a print with high surface quality, isotopic properties and water proof walls. However, the method is limited to photopolymer materials which do not always fulfill the desired mechanical properties.

Selective Laser Sintering (SLS)

SLS is an additive manufacturing method that utilizes powder bed sintering of polymers. Polymer powder is sintered by a laser which makes the particles fuse together according to the geometry of the 3D-file [34]. SLS allows for many different materials, complex geometries and with high precision. However, this method is one of the more costly 3D-printing techniques both in equipment and operation. depending on what material is used the produced parts will be water resistant, but rarely waterproof.

2.8 Gaskets design

Both seals and gaskets are common methods of water and dust proofing electronic devices. In this report, the definition of these two terms will be in line with the book “Seals and sealing handbook” [p.7, 25].

To summarize, seals are of a design that is intended to be self energizing while gaskets are designed to be assembled with pressure against, resulting in a stored energy in the gasket. In conclusion, a seal can be assembled with much less force in comparison to a gasket.

There are two main orientations for gasket placement, radial and axial. These are illustrated in Figure 7. The red arrows are illustrating the angle of compression force that the gasket is subjected to.

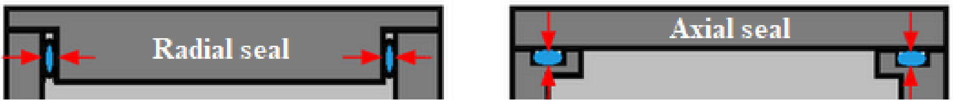


Figure 7: *Illustration of the two gasket orientations, axial and radial.* ***Figure:*** Siri Wetterstrand

2.8.1 O-rings

Elastic O-rings are the most common form of static seal. They are easy to get hold of in many sizes and are available in different materials and hardnesses. When pressure is placed on the sealing, the O-ring will move in its gland and cover the gap between surfaces, blocking liquid to reach inside the product [p.8-19, 25].

Dimensioning of the groove and placement of the O-ring is of high importance to be confident that the seal will hold. The risk of wrongful dimensioning can be extrusion damage and twisting of the gasket. Twisting can to some extent be helped by using a cross section or square section version of o-rings. Extrusion can be resolved by using a backup-ring which covers the indent that causes extrusion.

The drawback of using o-rings are that they require both post production assembly and storage, which is costly. In addition to this, they are not recommended for applications with alternating pressure since they require time for moving around to be able to seal [p.10, 25]. However, they can be used in either radial or axial orientations.

For geometries that are not circular in design, custom gaskets can be produced to any shape and cross section. The principle of how it seals remains the same as with O-rings, although it can be increasingly difficult to know how to design the groove since guidelines will be less applicable on an unstandardized geometry [p.25-27, 25].

2.8.2 Lip seals

The lip seal is ideal for the radial orientation, this is because its nature is to bend and thereby makes the assembly easier. It is common in many different applications, such as in the lids of regular kitchen jars [p.105-107, 25]. A cross sect8on of a double lip seal can be seen in Figure 9.

The lip seal is one of the most diverse when it comes to cross-section designs and is adapted depending on the application. It can be made with one lip, two or more.

2.8.3 Gasket creation through multi shot injection

A version of gasket that has become increasingly common for sealing of plastic products are the double shot injected gaskets. This is a method that is a lot cheaper than adding a separate gasket to a product. The reason for this is that it opens the possibility of completely eliminating the stage of gasket assembly as well as saving shelf space for stocking gaskets in the storage.

However, it does impact the number of materials to choose from as well as limit how complex the design of the gasket can have. It must be injection moldable and therefore keep draft angles, overhang and such in mind. Since the elastomer bonds to the hard plastic in the multi shot process, it negatively impacts recyclability compared to loose seals such as o-rings.

Figures 8 & 9: *Seal molded together with plastic component (left). Double lip seal (right).*

2.8.4 Selection of gasket material

The most common gasket materials in handheld electronic devices are the non-metallic gaskets. In this category the elastomer materials are the absolute most popular and dominating material on the market.

An example of an elastomer gasket is the silicone gasket. This is a type of gasket which has high heat resistance and is able to withstand up to 305C [26]. It also has a high environmental resistance, which means it can withstand UV-light, open flames and corrosive chemicals. Silicone is also a great moisture sealant. Additionally, it is very malleable and has the ability to be molded in any shade of color with long lasting results. However, compared to many other rubber materials the silicone is more expensive and it is less resistant to tearing forces [26].

Rubber, on the other hand, is another type of elastomer which also has resistance to both abrasion and tearing. In addition to this, it has the unique feature that it contracts when exposed to heat, the opposite to many other materials which expands experiencing a thermal increase [27]. Rubber also has the property that it can be made with different hardnesses and therefore rubber is a material with many sub materials. For example, both an eraser and an ice hockey puck is made of rubber but with different hardnesses and properties.

When selecting the elastomer for the gasket, it is important to evaluate the purpose of the gasket. Especially where the gasket will be used. Listing possible liquids, gasses and chemicals is essential to eliminate possible threats to the gasket.

It is also important to not only evaluate the environment for the gasket when mounted on a product, but also during the assembly of the product. For example, it might be required additional grease to mount a radial seal, then the material has to be able to withstand these kinds of oils even if the gasket might not come in contact with these during regular use.

The main factors to consider when selecting an elastomer material are [p.380, 25]:

- *The product's environment during the whole product lifecycle*
- *The length of the life and duty cycle*
- *The price of the material*
- *Any industry specific approvals, ex. complying to standards for food industries*
- *Environmental impact*

2.8.5 Gasket dimensioning

2.8.5.1 Squeeze formula

For the gasket to be able to seal, the material has to become energized. This happens when the gasket is squeezed against a flat surface. The general recommendation is to squeeze the gasket 20-25% of its width, and the gasket is dimensioned according to the squeeze-equation [28].

$$Squeeze\,\% = \frac{Seal\,Height - Gland\,Height}{Seal\,Height} \times 100\% \qquad \textit{(Equation 2)}$$

2.8.5.2 Gland fill

Most gaskets will have a gland for it to lay in. Both for easy assembly but also for the gasket to not squeeze further than the desired squeeze percentage. The gland is dimensioned using the gland fill equation. The recommendation for gland fill is generally around 85-90% for a static application and 80-85% for dynamic [28].

When calculating the gland fill, the assumption can be made that the seal volume is the same for both relaxed and compressed states, as long as the gasket is made out of an incompressible material.

$$Gland\,fill\,\% = \frac{Seal\,Volume}{Gland\,Volume} \times 100\% \qquad \textit{(Equation 3)}$$

2.9.5.3 Compression force

The compression force of a gasket is simply defined as the required force to compress the gasket to the desired squeeze. The direction of the compression force is perpendicular to the surface which the gasket is squeezed against [29].

The compression force for gaskets is not easily calculated through simple equations or linear methods. This is due to the gasket being closed in a loop, and therefore requires calculations related to large deformations. Instead, the compression force has to be calculated using a FEM-program or to be measured manually in a laboratory.

2.9 Interaction design

To ensure user safety, ease of access, and a positive user experience it is of importance to consider interaction design when developing the lid. A well-designed door can prevent accidents, enable effortless access, and enhance overall satisfaction with the product.

2.9.1 User experience

How a product behaves and is used by regular people, is usually referred to as user experience [p.13-15, 30]. Although the user experience itself cannot be designed, it is possible to design for a good user experience. This is done by analyzing the users behavior and to research what the user is actually looking for [p.15-16, 30]. Sometimes the user does not even know themselves what solution they want, but they usually know the problem which they want solved.

User experience is strongly correlated to design which is accessible and inclusive. This is done by either inclusive design or assistive technology, which opens the door for a user to access the full use of a product [p.17, 30].

In general there are six goals to achieve when designing for a good user experience. These are effectiveness, efficiency, safety, utility, learnability and memorability [p.19, 30].

2.9.2 Product semiotics

Product semiotics is the study of how a product conveys a message through its appearance. Shape, color and symbols together signal to the user how the product is to be handled. These unspoken signals are often referred to as affordances, which is the information which an end user will act on when attempting to open the cover [p.30, 30].

To control what affordances are signaled through the door several methods can be used. For example it is of importance to make the design user-centered which can be accomplished by understanding the needs and expectations of the end user. Having a consistent design is also important since learned behavior has more impact on consumer behavior than instructions [p.29, 30]. This can be a consistency within the product, with other similar products or for the Bosch brand.

To ensure that the affordances signaled are as desired, usability testing on prototypes can be done [p.501-503, 30].

2.10 Product development process

Good product development is crucial for both investors and the survival of the business. Product quality, product cost, development time, development capability and development cost are all factors that are closely linked to the product development and which also directly affects the profitability of a product [p.2-3, 31]. Therefore, a good product development process is also of highest importance.

The product development process is a serialized number of steps used to create a new product. Ulrich Eppinger says that you can internalize it in a similar way to the steps of a recipe for baking a cake. The product development process will be different between separate companies. Sometimes the same company will even use unique processes for their different products [p.13, 31].

However, no matter what the product development process looks like, defining it thoroughly is important since it affects factors such as quality assurance, coordination, management and improvement [p.13, 31]. Some of the key activities that are usually involved in a product development process are illustrated in Figure 10.

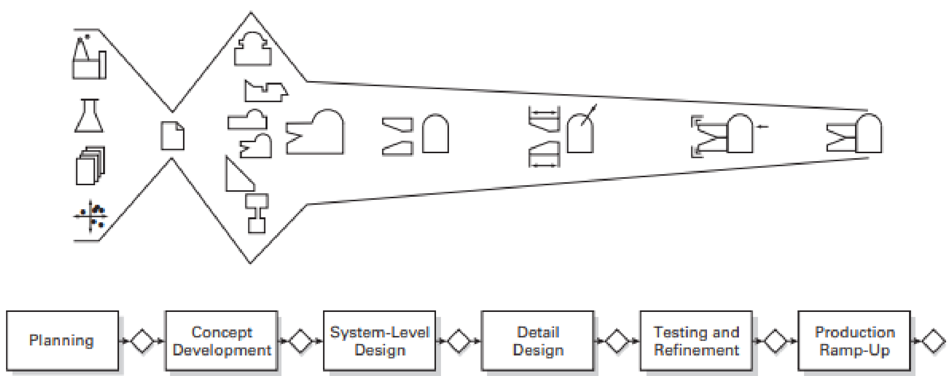


Figure 10: *The steps in the product development process [p. 14, 31].*

Photo: Ulrich & Eppinger

2.10.1 Planning

The planning phase will commence before the project starts. This activity will define the frame of the project and in this step the mission statement will be determined. The mission statement will establish constraints, the target markets for the product, business goals and key assumptions [p.13, 31].

In the planning phase you will also determine what time frame you will have for the whole project. An important part of the product development, since the development time is closely linked to the costs and profitability of the future product.

2.10.1.1 Gantt-chart

One way to plan the time requirements and timeline of a project is to use the Gantt-chart. This is a traditional tool which displays the different key activities of the project on the vertical and the projects given time on the horizontal. [p.383-384, 31] The assigned time for an activity is illustrated with a box which stretches from the start of the task to the end of the task.

There is a possibility to have overlapping tasks, and also to assign empty periods as buffer time as illustrated below in Figure 11.

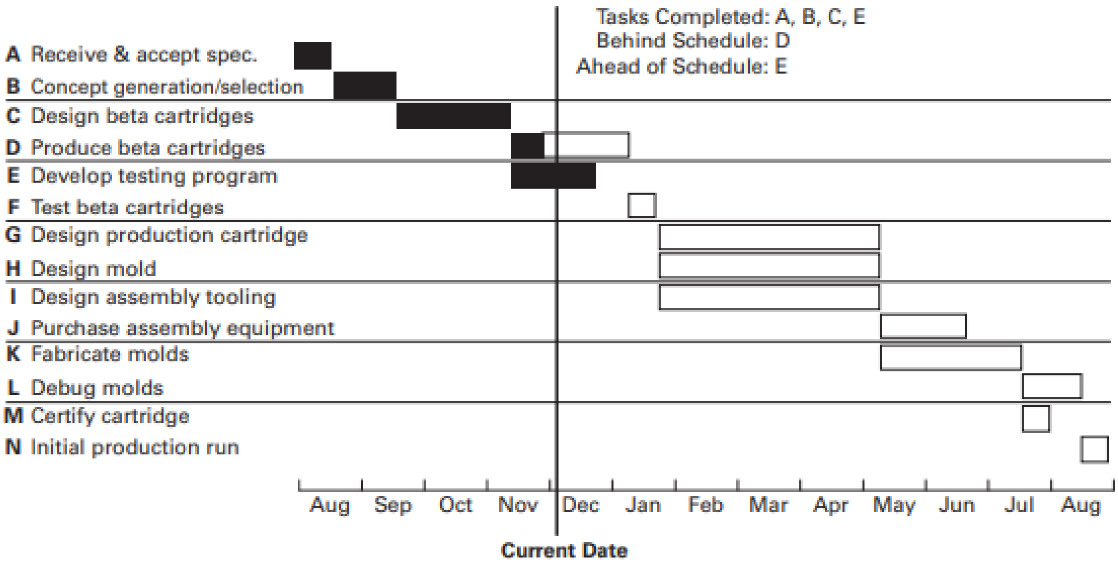


Figure 11: *Example of what a Gantt-chart could look like. [p. 383, 31].*

Photo: Ulrich & Eppinger

2.10.2 Concept development

The concept development phase includes activities such as identifying customer needs, generating product concepts and evaluating the results. The concept development is an iterative process, and it is therefore not unusual to jump between the different phases as new information or data emerges [p.74, 31], this is illustrated through Figure 12 below.

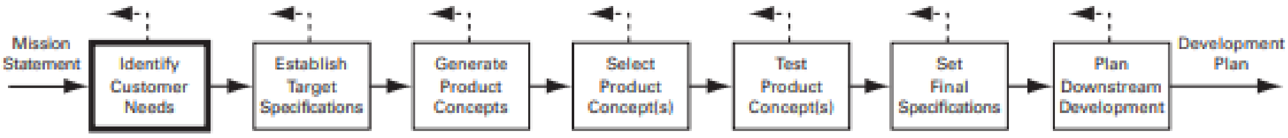


Figure 12: *The different steps in a concept development process. [p. 74, 31].*

Photo: Ulrich & Eppinger

2.10.2.1 Identifying customer needs

By identifying the customer needs, there will be a fact base for justifying the product specifications [p.75, 31]. There is no reason to implement functions and features that nobody is requesting since it would create unnecessary costs for the product. At the same time, to not detect hidden needs and wants of the user will decrease the customer satisfaction and in the long run also affect sales and profitability.

There are five steps that are generally applied when identifying the customer needs. These are; generating raw data from customers, interpreting the data as needs, organizing the needs in a hierarchy, establishing the relative importance of needs and reflecting on the results.

Step 1: *Gathering raw data from customers*

One way to gather raw data from customers is to conduct interviews [p.76, 31]. One of the team members from the development team will question the customer directly. The interview can be structured, which means that all of the questions and topics are predetermined. A common way to do this is by creating a questionnaire that can be filled in by the interviewer or by the customer directly.

The interview can also be unstructured, which means that there are no predetermined questions and the discussion flows freely in the shape of a conversation. It is also possible to have a semi-structured interview, which means that some questions are predetermined, but it is also possible for the interviewer to ask follow up questions that may come up during the interview [32].

Instead of an interview, a focus group can also be used for information gathering [p.76, 31]. This is usually done by having a moderator facilitating a two hour discussion with approximately 10 customers simultaneously. The discussion is usually observed by multiple team members of the development team and is often recorded with a camera.

Lastly, there is also the option to observe the product during use for gathering additional information [p.76, 31]. This method can reveal important details about the customer's needs, since things can be observed that wouldn’t naturally come up during an interview. Ulrich and Eppinger use the screwdriver as an example to illustrate this. The product development team might design the screwdriver only to drive screws, when the customer in fact also uses the screwdriver to open the lid of paint cans.

Step 2: *Interpret the raw data in the terms of customer needs.*

One observation or interview statement should be interpreted into one or more customer needs [p.81, 31]. Translating the raw data into needs can be difficult, and two people might translate the same customer behavior into two separate needs.

However, there are some common guidelines when it comes to defining the needs of a product [p.82-83, 31]. Firstly, the needs should be expressed in the terms of what the product has to do instead of how it does it. It is also important to not alter the need from the gathered raw data. As far as possible, you also want to express the need as an attribute of the product. This makes it easier to translate the needs into product specifications later on in the product development process.

Additionally, it is recommended that the needs are phrased positively instead of negatively. For example, the need for the product to not injure the user should be rephrased to the need for the product to be safe to use. You also want to avoid the words must and should, since organizing the hierarchy of needs is a separate step.

Step 3: *Organizing the needs into a hierarchy of needs*

When organizing the needs you will need to firstly eliminate statements that are identical to each other in meaning [p.84, 31]. Secondly, you will want to group the needs that express similar matters and pick a category name. If there are more than 20 groups or so, considering creating super groups might be necessary.

Step 4: *Establishing the relative importance of needs*

There are two main ways to establish the importance of needs [p.86, 31]. The first one is simply that the development team decides themselves the rank of the needs based on their own knowledge and personal experiences. The second way is to conduct further surveys to assess the customers perception of the different needs value.

Step 5: *Reflection of the results and process.*

In the end it is necessary to consider if all of the important types of customers have been interacted with, or if there might be groups that have been left out. There might be areas of the product that haven't been considered and as the project proceeds it might be reasonable to pursue follow-up interviews or surveys to complement the raw data and to update the needs iteratively [p.87, 31].

2.10.3 System-level design

After concept generation, the next step is to further develop the chosen concept until a high level design is defined. The system level design should include a plan for the product's design, both aesthetically and for functional components. An initial plan for material choices, manufacturing and assembly is done [p.15, 31].

2.10.4 Detail design

In the stage of detail design, there should be a final definition of the parts geometry. Simultaneously, it is appropriate to select the materials used for the product. You would also decide the tolerances for the product, and also finalize the industrial design control documentation. [p.14, 31]

2.10.5 Testing and refinement

The performance is tested during this stage as well as the product's reliability. In this stage there is also an evaluation done over the product's environmental impact. Design changes can be made depending on the results from the testing, and implementing these corrections are also done in this stage and refining the product is therefore also a part of this stage [p.14, 31].

Design of experiment (DOE) is a method that substitutes technical information with making tests to gather experimental results. The development team should use its understanding of the system to decide on what parameters to test and design the experiments around. This is a powerful tool to evaluate design when technical information is not available. Experiments have become a widely used tool to conduct valuable information in order to make robust designs. It is of importance to have wisely chosen parameters and to be aware of potential disturbing factors, so called noise, when designing the experiments. Once the experiments have been done the results should be analyzed and reflected upon. [p.316, 31].

2.10.6 Production ramp-up

The final stage of the designer's product development process is the production ramp-up. During this phase, the early production samples are evaluated. If problems are observed with the first sample, it is possible to make small design changes before going full scale on the manufacturing [p.14, 31].

3 Product development

3.1 Planning

This project follows the methodology and product development process of Ulrich and Eppinger in large. This means following the steps of planning, concept development, system-level design, detail design and testing and refinement in our planning as well. The production Ramp-up is a stage that is defined in the list of boundaries for the project and is therefore not planned for either.

One exception that is done from the standard product development process, is that it is planned for two cycles for concept generation. The reason behind this is to quickly get some reasonable suggestions on the table. This would make us be able to predict required prototyping techniques, and to refine these production methods parallely in the second round of concept generation. Using this reasoning, the prototyping method will be perfected just in time for when the project is mature enough to build prototypes.

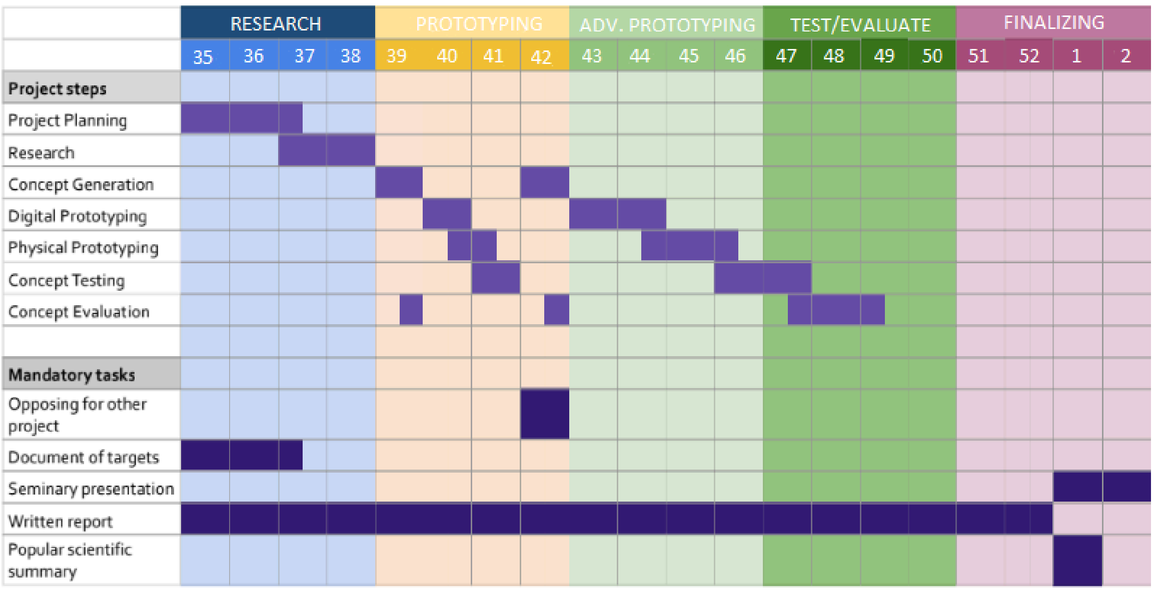


Figure 13: *The initial project plan as a Gantt-chart. Figure: Maria Bark*

3.2 First concept development phase

3.2.1 Identifying customer needs

For the first product development phase, we used the statements that were initially given by Bosch at the start up meeting of the project. These statements were also put in the document of goals to make up the targets for the whole project and can be seen in Table 1. The reasoning behind this was that Bosch should be treated as the client or customer in the initial development phase, since they are the owner of this development project.

The needs were also sorted into a hierarchy using the team members' own knowledge and experiences. Each one of the translated need statements was put on a post-it note, and after a discussion in the group they were evaluated individually. The hierarchy of the needs can be seen in the scoring Table 1, where one star (*) is of the lowest importance and three stars (***) the highest.

This was done according to the advice of Ulrich and Eppinger, since it was a recommended method for when time was scarce and the first concept development cycle being a rapid phase.

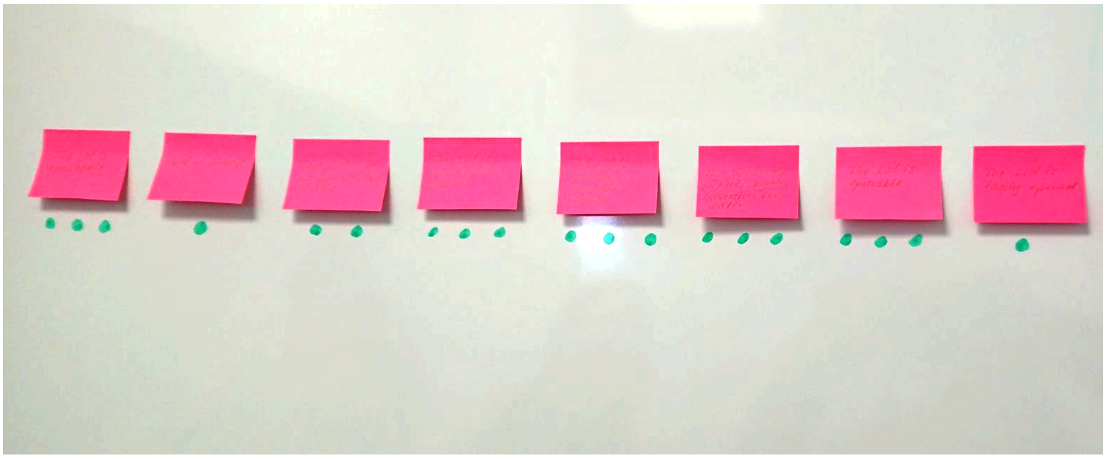


Figure 14: *Showing the methodology of sorting the needs into a hierarchy.* Photo: Maria Bark

Table 1. The first round of identified needs with decided importance.

Statement	**Needs**	**Imp.**
The lid should allow and increase the repairability of the product.	1. The lid is openable.	***
	2. The lid is resealable multiple times.	***
It should not be overly complex to open.	3. The lid is easily opened.	*
The lid should pass the IPX8 tests.	4. The lid will protect against the effects of continuous immersion in water.	***
The design has to be reasonable for industrial manufacture and assembly.	5. The lid is realizable.	***
The lid has to be suitable for a variety of products with different requirements.	6. The lid fits different products.	**
The plastic materials are to be chosen.	7. The lid is of an appropriate plastic.	**
The lid will not unintentionally open.	8. The lid is intentionally opened.	***
The lid will not take up too much space.	9. The lid is size efficient.	**
The lid is not too costly.	10. The lid is cheap.	*

3.2.2 Establishing target specifications

The need statements were translated into measurable factors such as number of reseals before failure and required minimum lid height. One of the more difficult needs to set a measurable factor to was number six, the lid fits different products. This was due to the fact that it would be impossible to test the lid on all kinds of products, and creating a list of sample products for the lid would still exclude possible use cases. In the end it was decided that a small size would increase the possibility of wide applications for the lid in addition with a subjective feeling of product compatibility.

From the ten need statements there were sixteen metrics decided, and these can be seen in the first list of metrics Table 1 and in the needs-metrics matrix Figure 15.

	Needs \ Metrics	1 Openable	2 Number of reseals before failure	3 Easy opening	4 Time to open	5 IPX8 standard test	6 Manufacturable	7 Able to prototype	8 Cost to prototype	9 Product compatibility	10 Appropriate plastic	11 Different plastics in part	12 Intentional opening	13 Minimum lid length	14 Minimum lid width	15 Minimum lid height	16 Unit manufacturing cost
1	The lid is openable	•		•	•												
2	The lid is resealable multiple times		•														
3	The lid is easily opened			•	•												
4	The lid will protect against water					•											
5	The lid is realizable						•	•	•								•
6	The lid fits different products									•				•	•	•	
7	The lid is of an approperiate plastic										•	•					
8	The lid is intentionally opened												•				
9	The lid is size efficient													•	•	•	
10	The lid is cheap																•

Figure 15: *The first needs-metrics matrix shows how different needs can be measured.*

Table 2. First list of metrics

Metric No.	Need no.	Metric	Units
1	1	Openable	Binary
2	2	Number of reseals before failure.	Numeric
3	3, 1	Easy opening	Subj.
4	3, 1	Time to open	s
5	4	IPX8 standard test	Binary
6	5	Manufacturable	Binary
7	5	Able to prototype	Binary
8	5	Cost to prototype	SEK
9	6	Product compatibility	Subj.
10	7	Appropriate plastic	Subj.
11	7	Different plastics in part	Numeric
12	8	Intentional opening	Subj.
13	9, 6	Minimum lid length	mm
14	9, 6	Minimum lid width	mm
15	9, 6	Minimum lid height	mm
16	10, 5	Unit manufacturing cost	SEK

3.2.3 Concept generation

In the first cycle of concept generation, ideas were brainstormed without having done any research in advance. This was a conscious decision made to not be coloured by existing solutions and to explore brand new options. We decided to use active brainstorming, which means going for as many different concepts as possible with as wide a range as possible.

There was no evaluation done at all whether or not the ideas were actually realistic or good ideas. Instead the mindset was that all ideas could bring something valuable to the table and even the silliest of ideas were drawn onto the white board.

Some of the more insane concepts were related to expansion and there were multiple ideas with trains or movable arms which would increase the volume of the lid. These consisted of multiple parts but were still evaluated as serious ideas.

A variety of concepts were generated by the whole design team. After this, the concepts were categorized by type of closing mechanism. All in all, there were 13 different categories of closing mechanisms. The identified concept categories can be seen in Table 3.

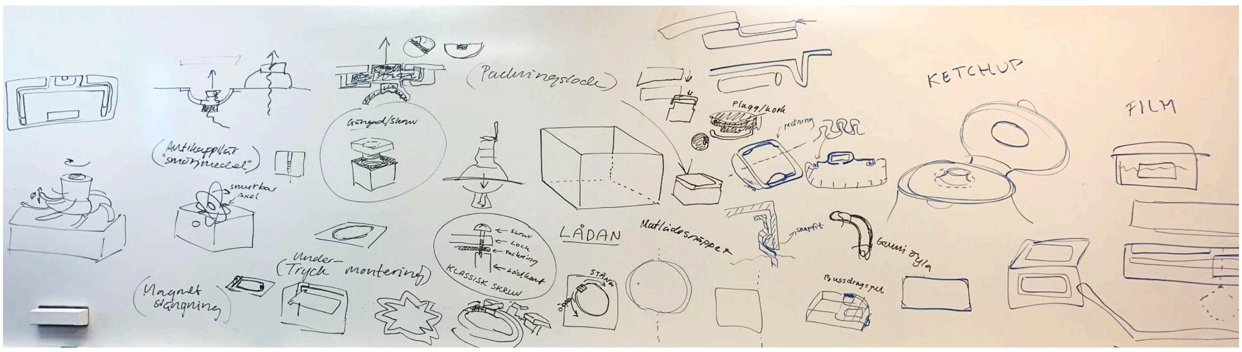
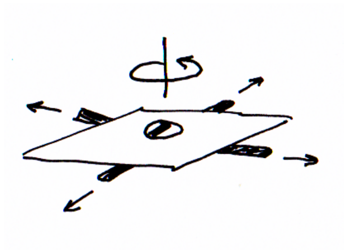
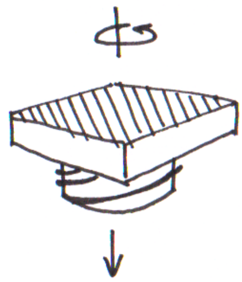
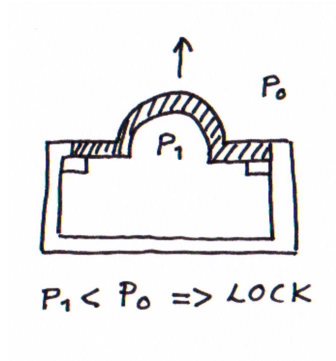
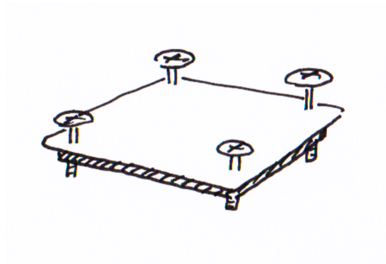
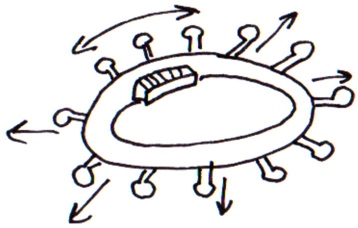


Figure 16: *The whiteboard was used to scribble down all of the ideas.* Photo: Siri Wetterstrand

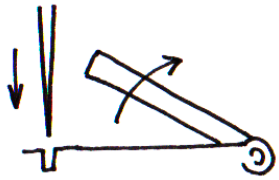
Table 3: Identified concept categories.

Nr.	Concept category	Illustration of concept
1.	***Expanding mechanism*** Arms are expanded outward by rotating a screw or a handle at the center of the lid.	
2.	***Threaded door*** The lid has a mounted screw component to its underside. Rotating the part locks or unlocks the lid depending on direction.	
3.	***Closure by negative pressure*** The pressure inside of the enclosure is reduced by partially lifting the lid and thereby increasing the volume inside. Since the atmospheric pressure is higher outside, the lid is pressured against the enclosure.	
4.	***Screw in combination with gasquet*** A lid is mechanically secured with any number of screws with a traditional gasquest in between.	

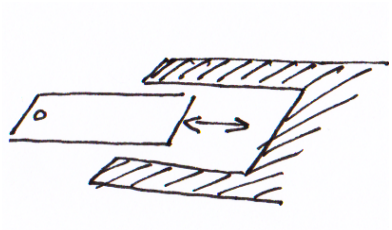
5. ***Maria's invention with pins***
The mechanism expands by pulling the gasquet zipper in one direction and retracts when the direction is altered. It secures the lid and seals at the same time.



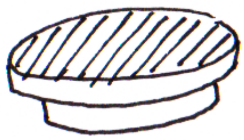
6. ***Spring lid***
By pushing a sharp tool into the mechanism, a spring is activated and pushes the lid upward. An additional gasket would be required.



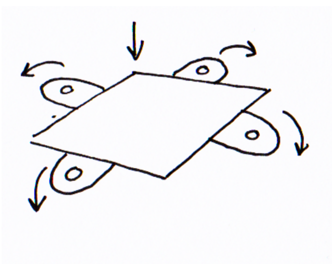
7. ***Slider***
The lid is locked by sliding it into place, a common solution for tv remotes. Is complemented by an additional gasket on the bottom side.



8. ***Plug door***
The whole lid is made of a soft material which is gasket like in nature. It seals and the material properties make the friction forces strong enough to lock in place.

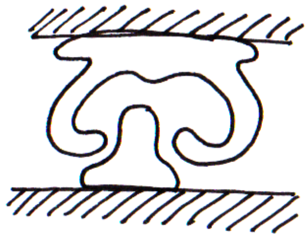


9. ***Snap-fit door***
There are flexible parts on the sides of the lid which can be snapped onto an enclosure. The mechanism is common in lunchboxes for instance, and would have an attached gasquet on the bottom side.



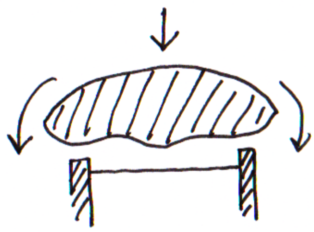
10. ***Comb gasquet mechanism***

Inspired by the ziplock bag, this mechanism would both lock and seal the lid simultaneously. This can be done by pushing the lid and enclosure together with force.



11. ***Plastic film***

The lid is made of a soft material with elastic properties. Therefore it can be stretched over the enclosure, sealing and locking simultaneously.



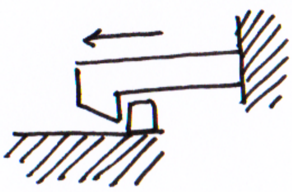
12. ***Retracting or folding mechanism***

Rotating the center of the mechanism will retract the soft arms, switching directions will extract the arms. The arms will lock the lid in place by hooking the arms into tracks of the enclosure.

Needs to be complemented by an additional gasket which is not easily placed onto the mechanism.

13. ***Lever clip mechanism***

When the lid is pushed towards an enclosure, a hook from the first part will latch onto a stop block of the second. The mechanism requires a separate gasket.



3.2.4 Concept selection

Out of the 13 categories of closing mechanisms, there were four concepts which were instantly eliminated by the identified needs. These were either not realizable or just bizarre in nature. The nine ideas which survived the instant elimination, were illustrated and low-fidelity (lo-fi) prototyped to show the basic mechanism. A few of the digitally prototyped solutions can be seen in the Figure 16.

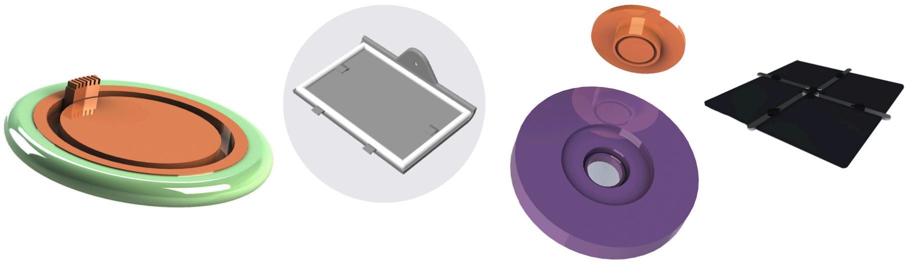


Figure 16: *The figure shows four of the nine concepts that were evaluated.*
Photo: Maria Bark & Siri Wetterstrand

The illustrations and lo-fi prototypes were presented in a meeting with our supervisor Mats-Åke Ekbladh and a group of senior mechanical engineers and industrial designers at Bosch. The meeting was done in the form of a non-structured survey, where we presented each one of the different concepts, asked some predetermined questions and then received feedback to which we asked follow up questions.

The feedback received is summarized in these bullet points:

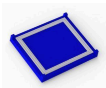
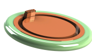
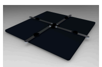
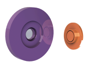
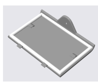
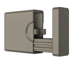
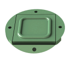
- *The corners of a gasket are critical, and are points that likely would leak.*
- *Corners are in general critical points, due to stress concentrations.*
- *The manufacturing process has to be made as easy as possible.*
- *A product has to perform a lot better, if cost is increased a little.*
- *It is important to accomplish even pressure all along the gasket.*
- *The lid should preferably be locked in place mechanically.*
- *Having the whole solution in a soft material can be problematic due to other IP-tests with 1 mm needles.*
- *The number of parts should be minimized to the best of our ability.*

Some of these statements were later used as additional need statements in the second concept development cycle. These can be found in the summarized list of need statements, Appendix A.

The nine concepts were then evaluated with the help from a concept scoring table, in accordance with the method of Ulrich & Eppinger. From the given importance for each need, which was decided earlier in Table 1, it was calculated how much weight each need had compared to the total list of needs. The weight was assigned as a percentage and put into the scoring table, see appendix M.

Each lid concept was then given a point between 1 to 5 for each need statement. The scoring was done methodically through discussion in the development team. For example, “the lid is realizable” gave a higher point if there was known manufacturing and a lower if the development team felt unsure. Another example is “the lid is of an appropriate plastic”, which was a difficult one to score since we did not have a proper material analysis done. Instead it was decided to go for the environmental perspective, where a lid that required multiple different plastic families would get a lower point since it would be less recyclable.

Table 4: The result of concept scoring to select the most promising ideas.

Description of concept:	***Illustration of concept:***	***Weighted score:***
Zip-Lock gasket		41
Maria's pin-zipper invention		28
Expanding lock mechanism		29
Self-locking plug		35
Traditional gasket + screw		38
Sliding lid		38
Snap fit cover		30
Soft material cover		27
Spring energized mechanism		30

3.3 Second concept development phase

3.3.1 Identifying customer needs

3.3.1.1 Conducting user interviews

In the second concept development phase it was decided to dig deeper into the uninvestigated needs of the final user through semi-structured interviews. To do this, without having any proper prototypes ready, it was decided to use competitors' existing lids for handheld devices, which were already on the market.

The two devices used were a computer mouse and a desktop keyboard. The brand of the mouse was Dell and had the model name of MS5320-GR . The keyboard used was a Dell Premiere KM7321W. Both of them were wireless and powered by either AAA- or AA-batteries.

Figure 18: *Shows the props used for the interviews, a mouse and keyboard.*

For the interviews, five people were selected. They were from a mixed group, representing both male and females and ages 25-61 years. The test was initiated by asking the participants to change the battery for each of the two devices. Their hands and the devices were recorded from a top view, to catch any subtle movements or signs of latent needs. The view from the video is seen in Figure 19.

Figure 19: *All of the users started to look at the bottom of the mouse.*

After changing the battery, there was a semi-structured interview with the user. Questions were prepared in advance and the questions were mainly focusing on the user experience of opening a brand new battery door. An example of a question from the interview was how the user feels about using tools when changing a battery.

If any intriguing answer came up during the interview, there were additional questions asked to find additional information and hidden needs. An example of a hidden need that was found during the interview was when a user responded that they were afraid of breaking it during the test. The developers assumed that the user meant the battery lid by saying the word it, but through a follow up question it emerged that the user meant the keys of the keyboard.

The user explained that it did not feel right putting the keys against the table, when turning the device upside down to reach the battery door. It felt even worse having to push the battery lid in with force, and putting further pressure on the keys. This was put in Appendix A as the need number 24.

The user statements were then translated into need statements. This was done in a similar manner as in section 3.2.1, when the initial needs were identified. To sort the needs into a hierarchy, both the old statements and the new statements were written on post it notes. Any duplicates were eliminated and then similar need statements were grouped with a main need statement that identified the theme.

Figure 20: *The need statements are arranged into groups before scoring.*

Each statement, as well as their group's title statement, was discussed and evaluated inside of the design team. The hierarchy was set in a similar manner to the first concept development cycle, by grading the concepts from one star (*) for less important and three stars (***) for more important.

The list was then evaluated by the project supervisor at Bosch. Some of the feedback received questioned the set hierarchy points related to user experience, the opinion was that UX was weighed in too heavily since the lid is estimated to be opened approximately five times.

However, the argument can also be made that since the lid concept is meant to be used for a wide range of products, it also has to take into account different user cases. Perhaps the ones where the door is opened more frequently. Simultaneously, the analysis done of the sustainability movement indicates that the users right to repair is growing worldwide. Allowing easy repair for the user themselves is not required by law today, but might very well be in the future.

Therefore, it was decided to continue with the list of need statements and their hierarchy with only minor changes. The summary of all user statements, as well as their corresponding need statements and hierarchy is found in Appendix A.

3.3.1.2 Expert interview

To dive deeper into the requirements and needs for the gasket, an additional interview was conducted. For this interview we talked with two senior employees at the Bosch office in Germany. One of them was having expertise in the field of elastomeric materials and the second one in gaskets and their design.

The interview was conducted as a semi-structured interview, as some questions were prepared in advance and other questions were added freely as the discussion commenced. The questions related mainly to gasket dimensioning and gasket design, but the discussion in whole became closely linked to material choice as it became evident that this was one of the main determining factors.

In general, they still advised us to start with the design and then evaluate which material would be appropriate. Another advice was to use multi-layered seals, since sink-holes or other defects in the plastic could cause leaks of the seal if there was only one barrier. The further away the seal layers are from each other, the smaller the risk that the seal will leak. They also told us that the holy grail for this application would be to create a radial seal which seals by compression but remains manufacturable and cost efficient.

The advice regarding designs for axial and radial seals is summarized in Table 5, and is relevant for gaskets that are under static pressure for a long period of time.

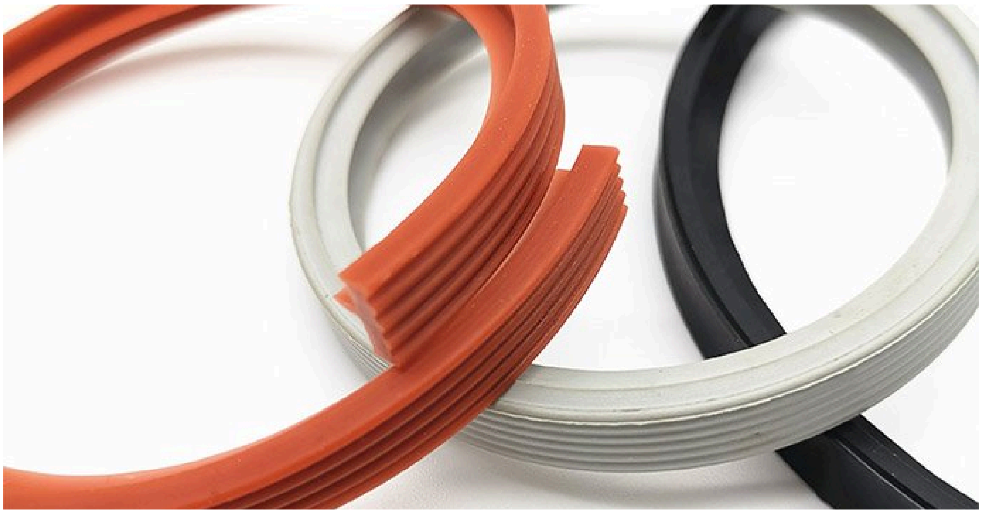


Figure 21: *Radial seals with multiple layers of parallel lips.* Photo: d-tk.com

Table 5: Advice and guidelines for gasket design

<table>
<tr><th></th><th>Radial seal</th><th>Axial seal</th></tr>
<tr><td>Recommended materials</td><td colspan="2">Silicone because of its general ability to resist compression sets. Especially important when using a bending seal.

TPE plastics, cheap and can be manufactured with 2K.

LSR gives good properties and enables many different cross sections to be used</td></tr>
<tr><td>Inappropriate materials</td><td>TPE plastics, due to compression set in seals from static pressure and bending.

Silicone, because it is both more expensive to purchase and to manufacture.</td><td>N/A</td></tr>
<tr><td>Appropriate cross sections</td><td>Cross sections which seal by bending over.

Lamellar or lip shaped seals, due to increased sealing ability when water applies pressure against the lip.</td><td>Cross sections which seal by compression.

Rectangular or circular seals because of its ability to evenly compress.</td></tr>
<tr><td>Inappropriate cross sections</td><td>Rectangular, because it is either impossible or difficult to assemble products without additional grease.

Only using one lamel/lip, vulnerable if there are any sinkmarks or imperfections in the gasket.</td><td>Seals which might compress unevenly.

Such as a triangle, if it partly bends due to axial pressure.</td></tr>
<tr><td>General benefits</td><td>Easy to create even pressure over the whole seal.

Generally simple assembly.</td><td>Less prone to compressionset.</td></tr>
<tr><td>General disadvantage</td><td>Lip seals can fold the wrong way.

Compression set is not calculated for bending seals. A bending seal has to be tested, there is no material property data for this ability.

Manufacturing cross sections of lamellar or lip design is prone to imperfections and puts high demands on the manufacturer and equipment. Limiting the material options.</td><td>Difficult to create even pressure over the entire seal.

Requires enough space around it to be able to expand in the gland and avoid extrusion..</td></tr>
</table>

3.3.1.3 Design rules of thumb

Documents of design guidelines regarding seal design were provided by Bosch. Listed below are some key takeaways that are based on research, experience and gathered knowledge across the company.

Key take-aways:

- Do not design seals with a cross section that become weaker once pressure is applied from the expected direction.
- Allow for some compression set and thermal expansion to occur without failure of the gasket.
- Avoid sharp corners against the elastomer.
- Tension should not exceed 50% of elongation at break.
- Appropriate choice of elastomer material and properties are vital.

Common reasons that the seal interface fails:

- Thermal expansion and shrink
- Swelling caused by fluids
- Extrusion of the gasket
- Compression set
- Temperature changes the rate of relaxation of the gasket material

3.3.2 Concept generation

In the second iteration of the design phase, it was decided to divide the construction into two categories - one of the design of the closing mechanism and one of the seal. This, to find the best possible options of both categories. The most suitable options will then be morphed in the final concepts.

From the first round of concept scoring three possible closing designs were chosen to proceed with. These concepts were “zip-lock”, “screws and gasket” and “slider”. The focus now was to generate different concepts that fell under the umbrella of these categories.

3.3.2.1 Concept generation of closing with screws

For the screw mounting solution, it was decided to try to minimize the number of screws. Because of this, there were different solutions created which also contained a supporting ridge, sliding into the lid’s surrounding material and replacing one of the screws. It was decided that this idea was treading into the territory of the sliding mechanism, which also had been chosen from the first round. This led to the elimination of the sliding mechanism as an individual concept, and instead it was integrated and combined in the screw mounting concept category.

The interviews with users of electronic handheld devices also steered us in the direction of trying to eliminate the use of tools or allowing the use of a wide range of tools to open a concept.

This was because many of the individuals answered they disliked the idea of needing a tool to open a battery lid and that they generally tried to avoid the use of tools if they had the chance. From this, the idea spawned that it could be possible to create custom screwheads which had increased usability and reduced the requirement of using a traditional tool.

The different lid designs, as well as different potential designs for custom mounting screws were brainstormed individually and on the whiteboard within the project group. Some of the early screw-head concepts can be seen in Figure 22.

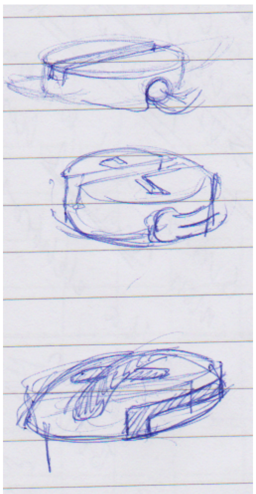


Figure 22: *Custom screwheads.*

3.3.2.2 Concept generation of closing with ziplock

For the ziplock concept it early emerged a brand new problem which turned out to be difficult to solve. During the first supervision meeting in the new concept generation phase it was realized that the concept as such would have production difficulties.

This is because a ziplock is created through the production method of plastic extrusion. It works very well for parts with long lengths and a continuous cross-sections, such as tubes, rods or ziplocks. However, this method does not work at all if the length of the part is closed in a loop without loose ends. The elimination of loose ends, and the requirement of a loop would be required for the ziplock concept to be able to close and seal around a rectangular hole.

It was discussed with our supervisor whether or not it would be realistic to use plastic injection with this type of geometry. However, it turns out that plastic injecting is quite unsuitable for the ziplock geometry. This is because the ziplock's geometry in nature has large overhangs to be able to hook onto the connecting surface. This means that it is a high chance of damaging the part when trying to pull it up from the mold in production.

If the ziplock geometry was made out of a length with loose ends, it could have been possible to use some sort of slider within the ziplock. But, our geometry was closed in a loop and because of this the slider would have no place to slide out. Because of this reason, the ziplock concept was canceled.

Instead it was discussed if there could be some other solution, somewhat similar to the ziplock in the sense that it closed and sealed at the same time. Through the brainstorming which is seen in Figure 23, a new closing concept emerged - the radial seal with snap fit levers.

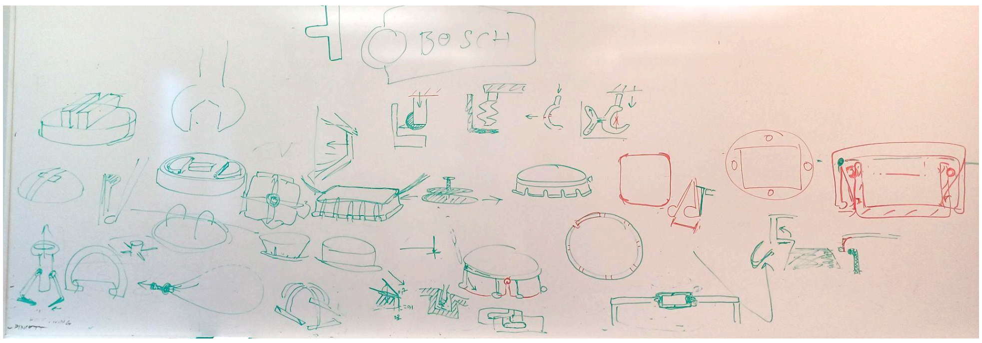


Figure 23: *Brainstorming new solutions with elements from the scrapped idea of ziplock.*

3.3.2.3 Radial seal with snap-fit levers

In this concept the aim was to achieve a radial seal where the gasket will not be subjected to shear stress or bending when closing or opening the door. This would allow the benefit of equal pressure that a radial seal provides, while minimizing the risk of compression set which is a down side with conventional designs of radial seals.

The design is made up of a rib holding the gasket in place, and levers that will snap the door in place. In addition, the surrounding of the door has a little bump that will make the levers avoid coming in contact with the gasket while sliding in place. Once in place the pressure on the gasket will be the same concept as in a conventional radial seal.

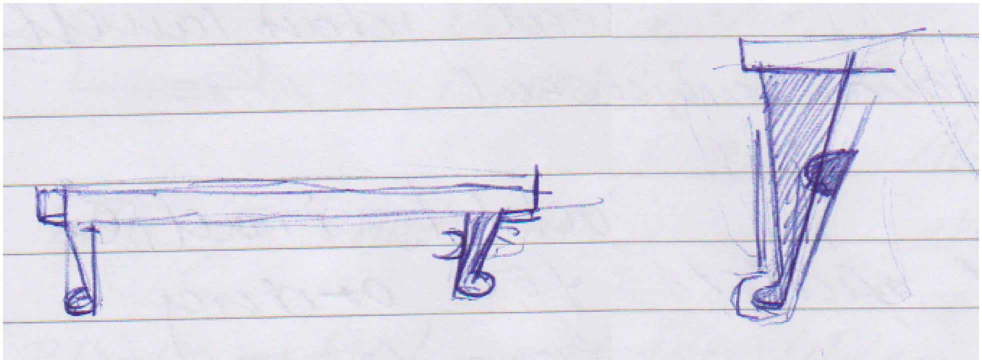


Figure 24: *Early cross-section sketches of the Wetterbark seal.*

A drawback of this concept is that it will require some space in depth into the product.

The concept started out as a simple snap fit lever that would be guided outwards in assembly, avoiding impact on the gasket. However this design was faulty because of the lever being under stress when in place - which is not preferable because of increased risk of material fatigue.

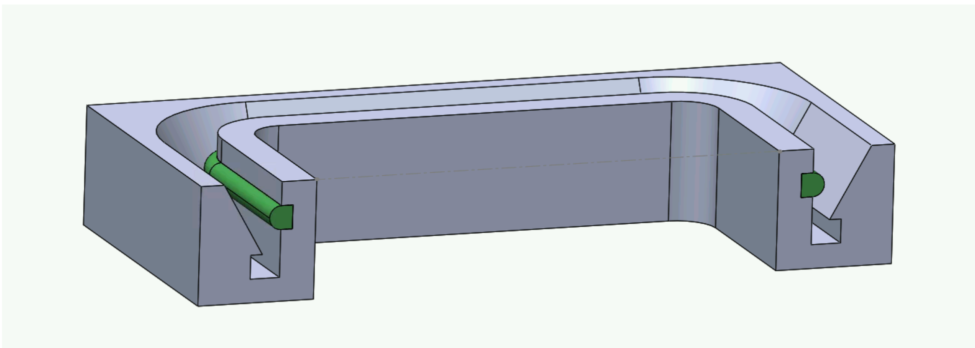


Figure 25: *First iteration in CAD of the mechanisms surrounding.*

In the next version the lid was designed to no longer keep the plastic walls under constant pressure. This design however was not preferable since it cannot be placed on the same level as the product. Therefore, the design was changed to keep the levers inside the product.

This is where a more interesting design started to form. The new levers allowed for the lid to be mounted, and snap into place without damaging the seal. A big difference and benefit when compared to the traditional radial seal mounting.

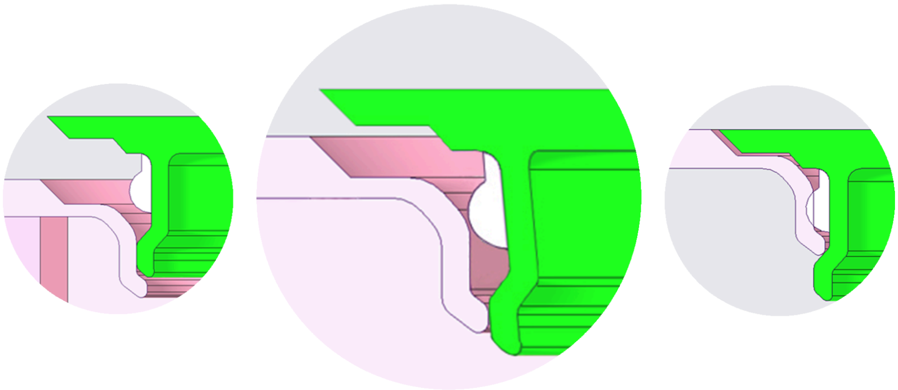


Figure 26: *The lever creates space for the gasket during assembly and snaps the lid into place.*

However, the assembly needed improvement. It was also a fear that the gasket would leak because of the slits, not allowing for equal pressure all over the seal. To assure a working concept, four versions of the same idea were developed. These were named radial seals, and got index R1-4, which can be seen in Figure 27. In the next phase, they was benchmarked against one another.

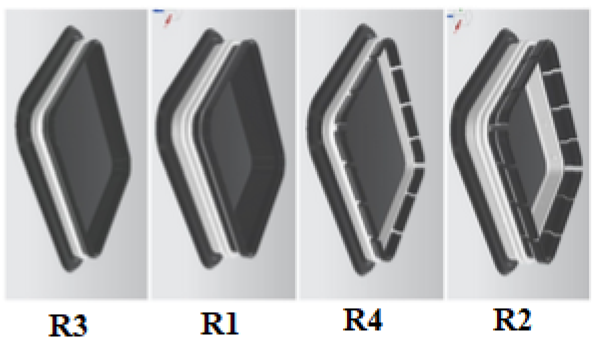


Figure 27: *Different versions of the same concept, slitted in different ways.*

The first version, with the gaps running all the way from the bottom to the lid surface is the easiest to assemble and is the most prone to not apply shear stress to the gasket. However, it does come with the disadvantage of the seal not being backed with a hard surface on the entire seal area. This concept was decided to be prototyped in order to see if this will cause leaking or not.

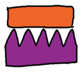
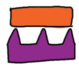
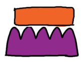
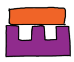
The second version is much like the first, with the exception of an added surface in the gaps where the seal is added. This will ensure an even pressure, however it is expected to add more stress concentrations in corners as well as a slightly higher assembly and disassembly force.

The third version does not use any gaps above or on the surface of the seal. This is expected to significantly heighten both assembly and disassembly. This high force could potentially damage the lid or the surrounding product. The upside with this design is expected to be less difficult to produce, demanding lower precision on tolerances and contact adhesion between the two plastics. It is also expected to have a high reliability since there are fewer weak spots that could become damaged or produced with imperfections that will cause leaking.

3.3.2.4 Concept generation of gasket design

Since the new concept for radial seal would work in a similar manner as to the axial seal, they would be able to use the same gasket design. The goal was to completely avoid lip seals, since these are prone to problems. The designs for cross-sections are summarized in Table 6. O-ring and D-ring were also added.

Table 6: *Different concepts of cross-sections generated for gasket designs*

1		7			
2		8			
3		9			
4		10			
5		11			
6		12		13	

(Purple = Hard material, Orange = Soft material)

3.3.3 Concept selection

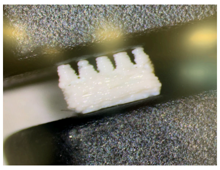
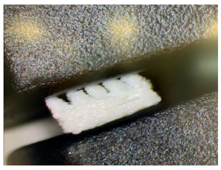
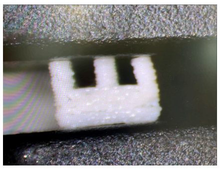
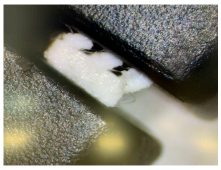
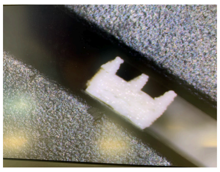
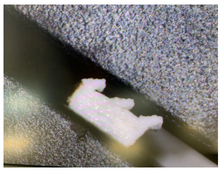
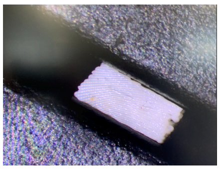
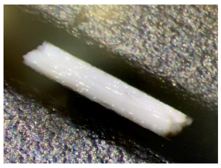
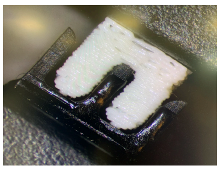
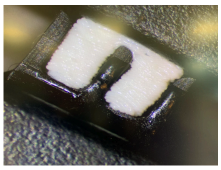
3.3.3.1 Selecting gasket concepts

Since it was found that most literature available regarding gasket design is mostly related to gaskets that are manufactured and assembled separately to the hard plastic part, and not 2K injected as this project is aiming towards, it was decided that in addition to this literature some experiment would be of help. Therefore, cross sections of a softer gasket material (TPU, shore hardness A82) and corresponding hard plastic materials were 3D printed to see how the cross section behaves when pressure is applied.

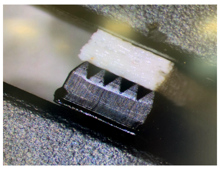
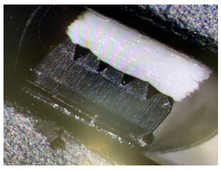
The gasket cross sections were put in a screwclamp and studied under a microscope to compare the difference in relaxed state compared to under pressure.

Figure 28: *Set up with screw clamp under a microscope to study gasket deformation.*

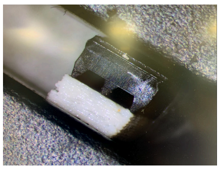
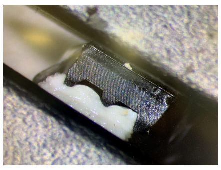
Table 7: Photos taken in microscope during gasket stress test

Description:	Relaxed state:	After deformation:
1. Sinus curve lip		
2. Square block lip		
3. Lip with radius		
4. Chamfered lip		
5. Square		
6. Interlocking		

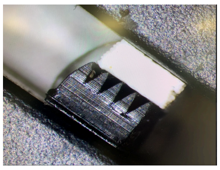
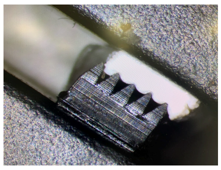
7. Zig-zag against square gasket

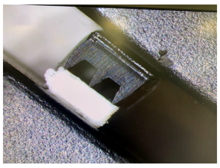
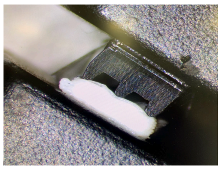
8. Chamfered lip against square gasket

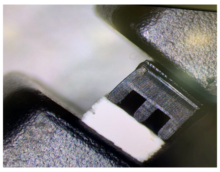
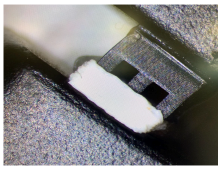
9. Sinus curve against square gasket

10. Sinus curve with distance against square gasket

11. Block lip against square gasket

The conclusion from this simple experiment was that the contact surface should not be too small since it causes either high concentrations of stress where the gasket meets hard plastic, or causes bending in the gasket. Both of which should be avoided since stress ages the gasket and bending in an uncontrolled manner makes the gasket performance unpredictable.

Gasket 8 was eliminated from further testing due to its aggressive tendency to eat into the soft material. The interlocking gasket was eliminated as well, because of white micro cracks in the black material, indicating that there was excessive stress caused by limited space for the white gasket to expand.

Gasket concepts 5, 7, 9, 10 and 11 were further evaluated in a water submerge test. The D-ring and O-ring were also evaluated further, but since they are traditional seals their behavior was not observed under a microscope.

For the water test, the five remaining gaskets were made as CAD-models of lids which can be seen in Figure 29. For this, the squeeze formula was used to estimate how much the plastic should push into the soft gasket. With the rule of thumb of a 25% squeeze, and a soft rubber gasket with a thickness of 2 mm, the container was designed so that 0.5mm would need to be compressed for the lid to close.

The five lids and one container were then 3D-printed using the Anycubic mono 2 printer. The soft gasket was bought off the shelf, and was a 2 mm rubber gasket which was manually cut to fit inside the container to simulate the soft 2k surface of a container.

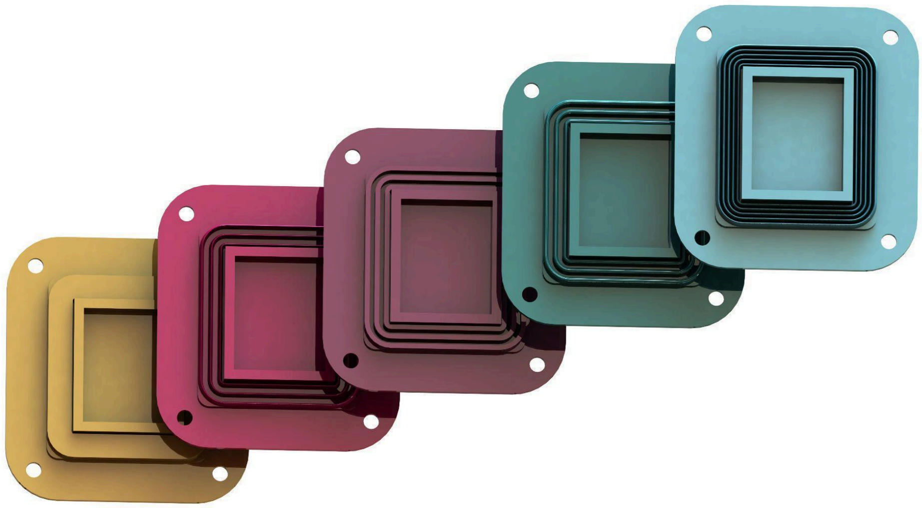


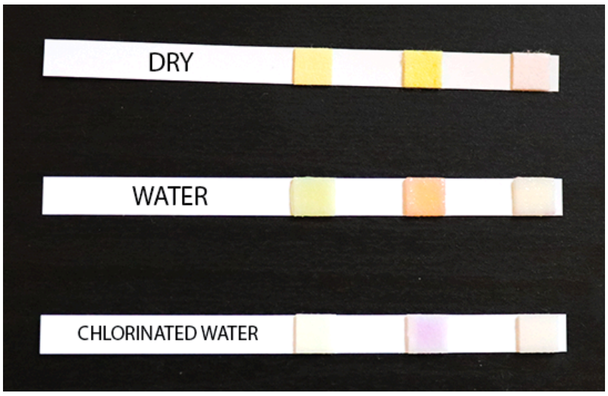
Figure 29: Render of the five axial gaskets which proceeded into water testing.

3.3.3.1.1 *The importance of temperature for resin 3D-printing*

Some problems arose when printing the lids because of their strong attachment to the build plate. It was nearly impossible to remove them from the metallic surface. After some discussion about this with the supervisor, it became evident why this most likely had happened.

Because of the toxic fumes created when 3D-printing, 3D-printing was only done outside of office or living areas. An appropriate space was found for this, but the temperatures there were only 16-18 C when heated to the max. However, the resin bottles were stored in a location with 25C.

The conclusion was made that the temperature shock of the 18C build plate and 25C resin caused the print to attach like welding to the plate. Because of this, it was decided to dismount the build plate and store it inside together with the resin bottles when not printing. This would cause less damage to the future prototypes.



To be able to detect water leakage in the containers, it was first evaluated if only a visual check would be enough. However, there could be small moisture that wouldn't be easily detectable and because of this it was decided to use test strips.

The test strips used were easily available and bought off the shelf. They had three different squares which indicated Chlorine in ppm, pH-value and total alkalinity. When the test strip came in contact with regular water from the tap, the pH-square became slightly orange. However, the strip quickly dried up and turned back to the same yellow it had before as dry.

Because of this, it was decided to do the submerge tests in water that was slightly chlorinated. This would not only cause the color to be more distinguishable as purple, but when the strip dried up it would impossibly turn back to yellow. Instead, the chlorinated water would bleach the squares to white.

The squares were cut from the strip to fit into the printed container, and the full setup can be seen in Figure 30.

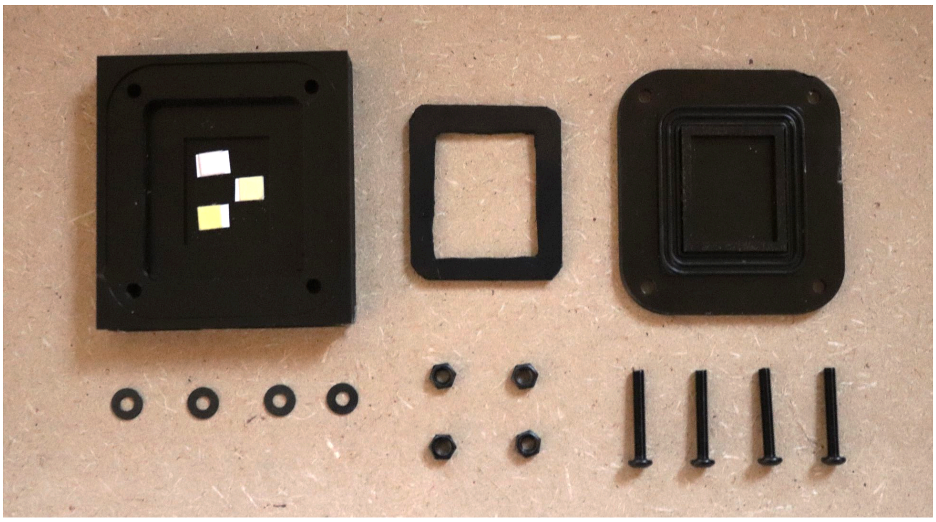


Figure 30: *Jar with test assembly.*

The testing device, a gasket lid assembled with a container, was submerged in chlorinated water for 30 minutes.

It was placed inside of a jar diagonally, not only because of space limitations, but the diagonal placement would also decrease the risk of air pockets protecting the device from leakage.

From the five testing assemblies, there were only two which remained sealed for the whole 30 minutes. The other three did not show liquid inside of the container, but had purple on one of the squares which indicated leakage. The result is found in Table 8.

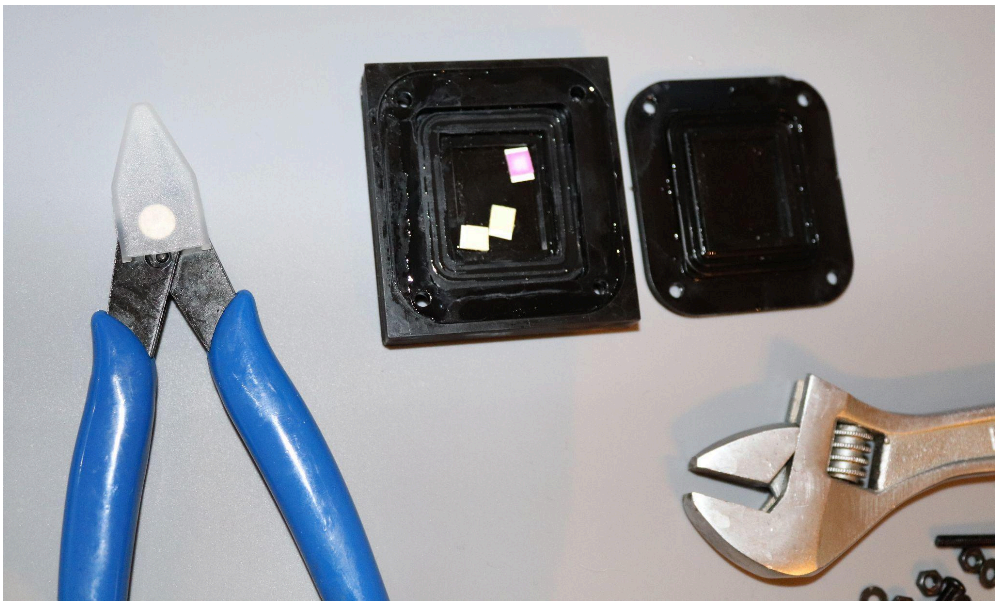


Figure 31: *Shows an opened test with a purple marker indicating leakage.*

One result which was unexpected was the leakage of the soft rectangular cross section. This is one of the most traditional solutions and should therefore have been waterproof. However, it is possible that it was designed with too much width, hindering it from completely compressing due to lack of force from the small screws. Because of this, and the fact that this solution only had approximately ¼ of a square coloured purple which only indicated a slight leak, it was decided to continue with this concept to the second round.

For the second round of testing, the two concepts that didn't leak and the concept with a slight leak were tested with a 1mm gasket. If it worked it would potentially save space for the final design. The design of the lids remained the same but the container was adapted and reprinted to allow for a 25% squeeze with only a 1 mm thick gasket, which means an overlap of non-compressed parts of 0.25 mm.

Like in the first submerge test, the assembly of lid, gasket and container was submerged for 30 minutes. The results from the test can be seen in the column for chlorinated, Table 8.

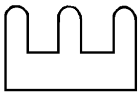
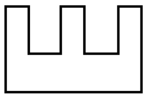
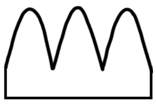
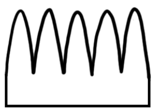
After the test, there was some debate in the team about how it was possible that all of the three leaks were purple even though none of them had any observable droplets of liquid inside of the container. The test squares either absorbed one hundred percent of the leaked liquid, or there was some other explanation to it.

From the discussion, it emerged a theory that chlorine vapor might affect the test results just as much as contact with chlorinated water. To test this, a test square was mounted on the inside of the glass jar's lid, without any contact to the chlorinated water. A timer was set for 30 minutes, but within five minutes we had a result in a bold purple square. It was therefore confirmed that the testing method was not only testing positive for contact with chlorinated water, but also for the chlorine dispersed in the container's air.

Because of this, it was decided to do a second round of testing. This time, a new set of testing squares was acquired. These were much more expensive, but reacted to the contact of liquid only, by swapping color from white to red when wet. They also had the benefit of only needing regular tap water to react, and keeping the color when drying up.

The second tests using the new test squares showed that all of the concepts were watertight, for both 2 mm and 1 mm soft surfaces. However, the first tests with the chlorinated water still indicated some sort of weakness for the concepts A, B and C since chlorine vapor was able to get inside of the enclosure with the testing square. Because of this, it was decided to still only continue with the concepts D and E for further evaluation.

Table 8: Results from liquid submerge tests of custom gasket designs.

Seal:	Cross-section:	Description:	Chlorine:		Water:		Pursue?
			2 mm	1 mm	2 mm	1 mm	
A		*Three blocks with rounded corners*	**Leak**	**N/A**	**Seal**	**Seal**	**No**
B		*Three blocks*	**Seal**	**Leak**	**Seal**	**Seal**	**No**
C		*Sinus wave with inverted minus*	**Leak**	**N/A**	**Seal**	**Seal**	**No**
D		*C gasket with increased frequency*	**Seal**	**Seal**	**Seal**	**Seal**	**Yes**
E		*One block*	**Slight leak**	**Seal**	**Seal**	**Seal**	**Yes**

3.3.3.1.2 *Material selection for screws*

After about four cycles of testing and a total of two hours in the chlorinated water, the screws had become oxidized enough for the lids to be nearly impossible to open.

Although the product most likely wouldn't come in contact with chlorine, the matter of material selection for screws was noted for the upcoming section of setting final specifications.

Except for the less traditional cross sections which were studied in the microscope, more traditional ones were evaluated as well. The first one was the classical O-ring. Although this is a gasket which is already very well tested out in the industry, additional tests were done in order to set proper dimensions for this application.

To do this, five different gasket dimensions were bought off the shelf. However, only two of the five dimensions were initially modeled into a lid and container. The two had the largest and the smallest thickness among the five, and the reasoning was that if both were to be sealed in the test, the smallest would be selected and the other three would not be modeled. If the test showed that the thinnest gasket were leaking, the larger thicknesses would then be tested.

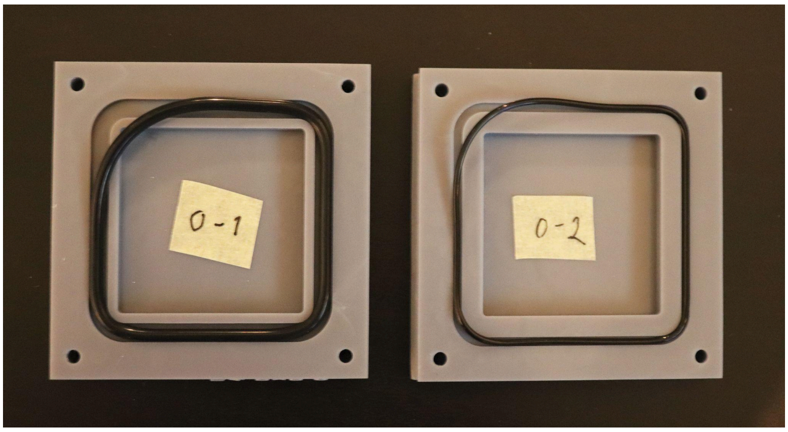


Figure 32: *The two 3D-printed containers and O-ring dimensions*

The test was done in pure water as the chlorinated water test could give a false positive for leaks. The submersion lasted for 30 minutes. Both gaskets were water proof and because of this the smallest dimension was selected to save space for the final product.

Table 9: Results from water submerge test of different O-ring dimensions

O-ring dimensions: *(Diameter x thickness)*	**Result:**	**Pursue?**
54,2 x 3,0 mm	Seal	**No**
60,0 x 1,5 mm	Seal	**Yes**

Another traditional gasket is the U-shaped gasket. This one would also have a shape appropriate for 2k-molding. To test this gasket, a custom gasket had to be molded out of silicone.

Waxing the mold turned out to be the most successful method for the silicone to release from the mold. To simplify it even further, a two piece mold was 3D-printed. This was created to further improve the removal of the gasket from the mold.

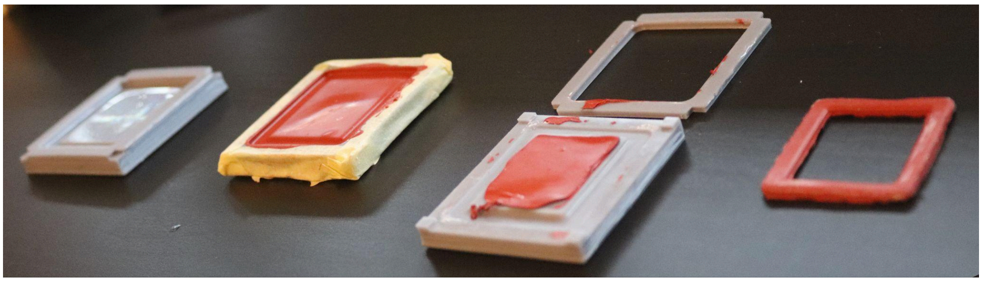


Figure 33: *Shows the process of custom gasket creation in silicone.*

The first silicone to be tested was the high temperature silicone which could withstand from -50C to 250C. To be able to pour the silicone into the 3D printed gasket mold, it was slightly diluted with mineral spirits. It was then left overnight in the mold, before it was removed and put into a lid and container assembly. The process of molding the gasket can be seen in Figure 33.

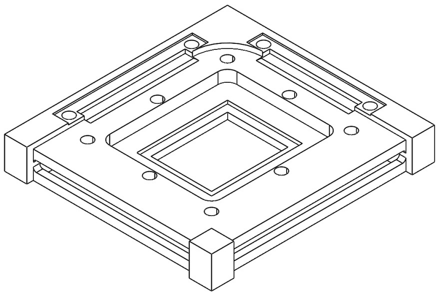
The first gasket was tested in water in a similar manner as the O-ring, submersion for 30 minutes. The test was successful but this gasket was instantly eliminated anyway. This was due to the strong fumes and smell from the residue of mineral spirits inside of the gasket, it was too much of a health hazard and inconvenience to continue using this prototyping method.

Table 10: Results from water submerge test of custom U-gasket

Name:	**Shore hardness:** *(ISO 868)*	**Result:**	**Pursue?**
High temperature silicone, Biltema	35	Seal	**No**
Gjutsilikonet	60	Seal	Yes

3.3.3.2 Selecting locking points for axial gaskets

The locking points for axial gaskets were tested in a similar manner as the gasket cross sections. There was an assembly made of a lid and container with a water test marker inside. The assembly was put in a bucket with a water level of approximately 25 cm for 30 minutes, thereby slightly increasing the pressure compared to the previous jar tests.



It was decided that six different locking points were to be tested. The gasket used for the test was gasket D, but the results would be applicable to the other axial gaskets as well.

To minimize the number of printed parts, a special container was developed. This container, also known internally in the project as the Multihole, could fixate all the six different variants with one single container design.

The gasket D was tested together with a 1 mm rubber gasket, and the assembly started to leak when it was mounted to the Multihole in lock L3. It was sealed in mount number 1, indicating that there might have been a bend of the lid when mounting on the short sides to the container.

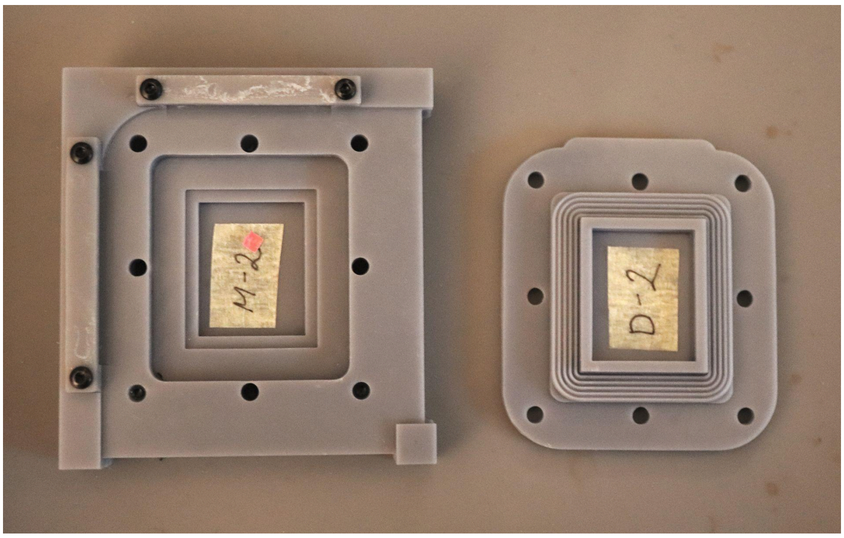
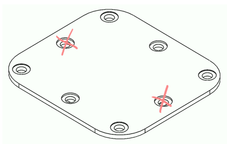
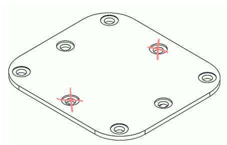
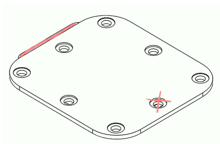
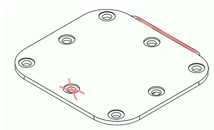
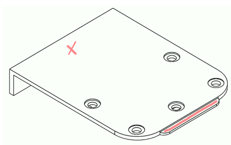
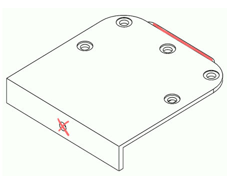


Figure 34: *Red marker indicating a water leak for gasket D in mount 2.*

To minimize the risk of future leaks, it was decided to only proceed with the mounts on the longest side of the lid. This would decrease the odds for the lid to bend and to let water inside of the container. The results can be seen in Table 11.

Table 11: Results from water submerge test of custom U-gasket

Lock:	Illustration:	Description:	Result:	Pursue?
L1		*Two screws on the shortest sides.*	**Seal**	**No**
L2		*Two screws on the longest sides.*	**Seal**	**Yes**
L3		*One screw, one bar on the shortest sides.*	**Leak**	**No**
L4		*One screw, one bar on the longest sides.*	**Seal**	**Yes**
L5		*One screw on a bent edge, one bar on the. Both on the shortest sides.*	**Seal**	**No**
L6		*One screw on a bent edge, one bar on the. Both on the longest sides.*	**Seal**	**Yes**

3.3.3.2 *Observed compression set in solution D*

After testing all of the combinations of the locking points, a problem suddenly emerged. The solution of a hard cross-section against a soft material, named D, had left marks into the soft sealing material. In other terms, there were visible signs of compression set.

The compression set was slightly visible with the naked eye, but was significant when evaluated more closely in a digital microscope.

Although the solution still did not leak in the tests, the risk would be overwhelming that the seal would start to leak over time as the sealing material is compressed even further. The reasoning was that if this was the observable indents after a few cycles of 30 minute fixations, imagine the additional compression set after a few years inside of a product.

Because of this, it was decided to not pursue solution D as a sealing concept any further.

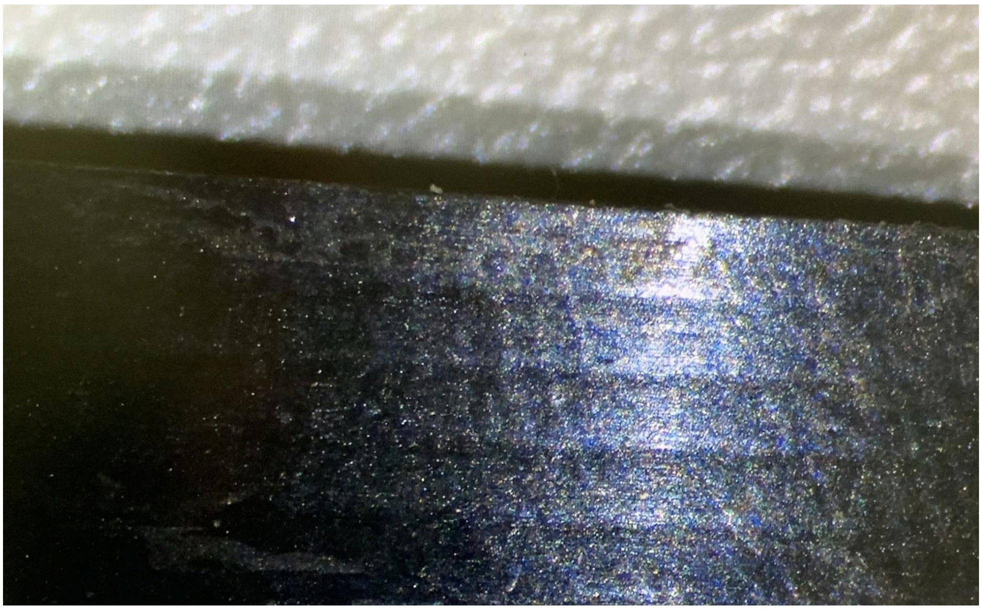


Figure 35: *The microscope showed indented marks in the black sealing material.*

3.3.3.3 Selecting screw head design for axial gaskets

To select screw designs it was decided to do a user test. The reason for this was that it was unclear whether or not the users thought it was better to be able to use a wide array of tools to unscrew the same screw or if it was better to use one traditional tool. It was also necessary to confirm if a larger head of the screw was preferable or if the users had a neutral, or even negative, opinion about this.

For the test two traditional screws were selected in M2 and M3 sizes. In addition to this, three custom screwheads were designed and 3D-printed. These three were all designed with multiple tools in mind.

Then, a total of 20 different traditional tools and household items were selected as references for the test. Some of the tools used for testing can be seen in Figure 36 and a complete list of them with their corresponding index can be seen in Appendix J.

Figure 36: *Some of the tools and household items used for testing*

Five test users were then asked to evaluate how many of the 20 tools they thought could be used for each one of the total of five screws. They were not allowed to try any of the tools on the screw, only to visually evaluate whether or not a tool was appropriate. If the user did not note that screw 5 had movable parts, the first guess of the number was noted and, after being told about the feature, the second guess was noted down as well. The results can be seen in table 10.

Then, for each one of the screws they were asked to pick the best suited tool among the 20 tools to unscrew each screw. They were not allowed to try the tool in advance, only to visually evaluate and once the tool was selected they were not allowed to switch tools. If the selected tool could not open the screw, for example because of size, the attempt was noted as a failed attempt. The selection of tools and unscrewing were video filmed from above.

Finally, after unscrewing all five screws with the tools they had picked, they were asked to pick one favorite screw. The results from the tests can be seen in Table 14.

Table 12. Estimated number of utilizable tools for screw concepts.

	User 1		***User 2***		***User 3***		***User 4***		***Avg.: (Tools)***		***Avg.: (%)***	
Screw 1	3		1		3		6		3,25		16,25%	
Screw 2	3		1		2		3		2,25		11,25%	
Screw 3	17		10		20		19		16,5		82,5%	
Screw 4	17		9		16		18		15		75%	
Screw 5	14	16	10	11	14	16	17	18	13,75	15,25	68,75%	76,25%

Table 13. Results from unscrewing screw with the selected tool.

		User 1	***User 2***	***User 3***	***User 4***	***Success Rate:***
Screw 1	***Tool:***	T3	T4	T4	T4	*N/A*
	Result:	Fail	Pass	Pass	Pass	75%
Screw 2	***Tool:***	T3	T4	T3	T3	*N/A*
	Result:	Pass	Fail	Pass	Pass	75%
Screw 3	***Tool:***	T8	T5	T15	T5	*N/A*
	Result:	Pass	Pass	Pass	Pass	100%
Screw 4	***Tool:***	T18	T8	T13	T5	*N/A*
	Result:	Pass	Pass	Fail	Pass	75%
Screw 5	***Tool:***	T14	T20	T20	T13	*N/A*
	Result:	Pass	Pass	Pass	Pass	100%

The results from the user testing were evaluated in Table 14 through the factors of perceived percentage of useful tools, success rate for opening with the first selected tool and number of user’s favorites.

It was noted that screw no. 3 had the best performance overall, with 100% success rate combined with a 82,5% perceived percentage of useful tools. In addition to this, it was noted that it was two users' favorite concept. Because of this, screw no. 3 was selected as a concept to pursue further.

Screw no. 5 had similar traits, a 100% success rate as well as one user’s favorite. It was also ranking high in perceived useful tools and because of this it was also moved further to next rounds.

Screw no. 1 was the third concept to pursue further. The reason behind this was that it was one user’s favorite and although it did not perform well in the created test, it is a traditional concept and an industry standard choice.

Table 14. Comparison between evaluated testing factors for screws.

	Screw 1	***Screw 2***	***Screw 3***	***Screw 4***	***Screw 5***	
Perceived percentage of useful tools	16,25%	11,25%	82,5%	75%	68,75%	76,75%
Success rate for opening with first selected tool	75%	75%	100%	75%	100%	
Number of user’s favorite	1	0	2	0	1	
Pursue?	*Yes*	*No*	*Yes*	*No*	*Yes*	

3.3.4 Setting final product specifications

3.3.4.1 Axial concepts

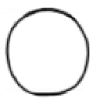
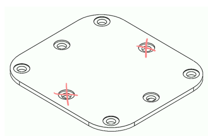
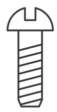
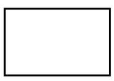
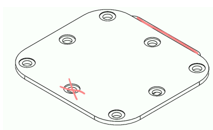
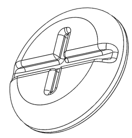
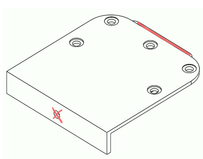
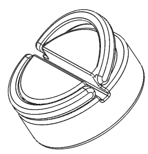
From testing it emerged parts which were to be pursued further and combined into the final concepts. Combining the winning parts was done through discussions within the team and together with the supervisor.

It was decided that the lid with two screw locking points was to be used together with two traditional screws and the o-ring. The reason for this is to keep the first lid as traditional and restrictive as possible. This one would also be working as a reference in further tests.

The flat lid with extended edge and one screw was to be combined with the screw with a modified plastic screw head together with a flat gasket. This is because the steel would work quite well with the direction of the gasket compression force and the size of the required force to compress the flat gasket for 25%.

Finally, the bent lid with an extended edge and one screw was to be combined with an U-shaped gasket. The screw for the final concept would be a bayonet screw entirely made out of plastic to increase usability and recyclability. These were combined because the plastic screw would work better together with the bent lid, as the same time as the U-shaped gasket would generate less force for the screw to plasticize.

Table 15. Summary of generated axial concepts from pursued elements.

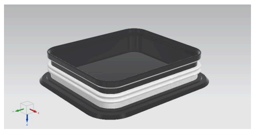
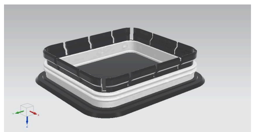
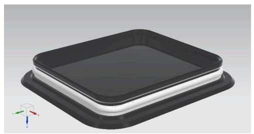
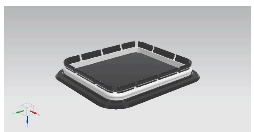
Name:	Index:	Seal:	Locking points:	Screw:
Axial 1	**A1**			
Axial 2	**A2**			
Axial 3	**A3**			

3.3.4.2 Radial concepts

The dimensions for the gaskets were designed for a 20% squeeze of the sealing gasket. Space around each protuberance was set to allow for the deformation when sealed against.

The compact versions, R3 and R4, were designed with one sealing surface to allow for a space efficient cover. The larger versions, R1 and R2, were designed with double sealing surfaces to create abundance in case one seal surface for some reason fails. This, in alignment with the design guidelines from the experts that were interviewed.

Table 16. Summary of generated radial concepts from pursued elements.

Name:	Index:	Seal:	Final design
Radial 1	**R1**		
Radial 2	**R2**		
Radial 3	**R3**		
Radial 4	**R4**		

3.3.4.2 Material selection

3.3.4.2.1 Current material selection

For the current Bosch e-bike computer, there are already material choices in place. In the hard plastic details a PC/ABS alloy, and the sealing elastomer is a TPU. These materials are a common choice for these kinds of products and manufacturing methods

TPU is a common material to use in a 2K injection because of flowability and adhesion. However, it is not as resistant to chemicals and UV-light as a silicone rubber. The silicone is on the other hand more expensive than the TPU, one reason for this is that scraps generated during the manufacturing process can't be recycled for silicone but it can for TPU's. The same is true for the classical rubber materials, they are difficult to recycle. It also has a very poor resistance to oils and greases which would lead to the product's failure in future chemical tests.

Lastly, it is difficult to change the material from PC/ABS when the surrounding material of the lid's environment would likely remain the same. It would create visual changes between environment and lid, they would for example very likely have different shine or texture to them. It is also possible that they would not respond the same to external loads, creating cracks in the product.

Because of this it was decided to continue with PC-ABS for the hard surfaces and TPU material for the soft seals. This applied to all of the seven concepts. For threaded inserts and the metallic threads for screws it was decided to go with SS, stainless steel. This would avoid corrosion to the metal as had been witnessed earlier during the initial water intrusion tests. Metal was only used in concept 1-2.

Figure 37: *PC/ABS was selected for all of the concepts. Figure: Indiamarkt.com*

3.3.4.2.2 Possible material selection in the future

In future products when an entirely new material can be chosen, while the requirements of the product remain the same, a more sustainable PC-ABS could be chosen.

For example there are grades of varying percentages of post consumer content. Compounds that could be further benchmarked to the grade in place are for instance, EvoSource PC/ABS 5366 9005 and MGG PC/ABS 7600 or 6700, which all have 100% post consumer content. If a lower percentage of recycled content is preferred to assure consistent properties, there are even more alternatives to choose from. For instance, Chi Mei PC-540 G60 rPC/ABS Recycled PC/ABS alloy which has 70% recycled content or Bayblend® FR3008 R65 which has 65 % recycled content. [43]

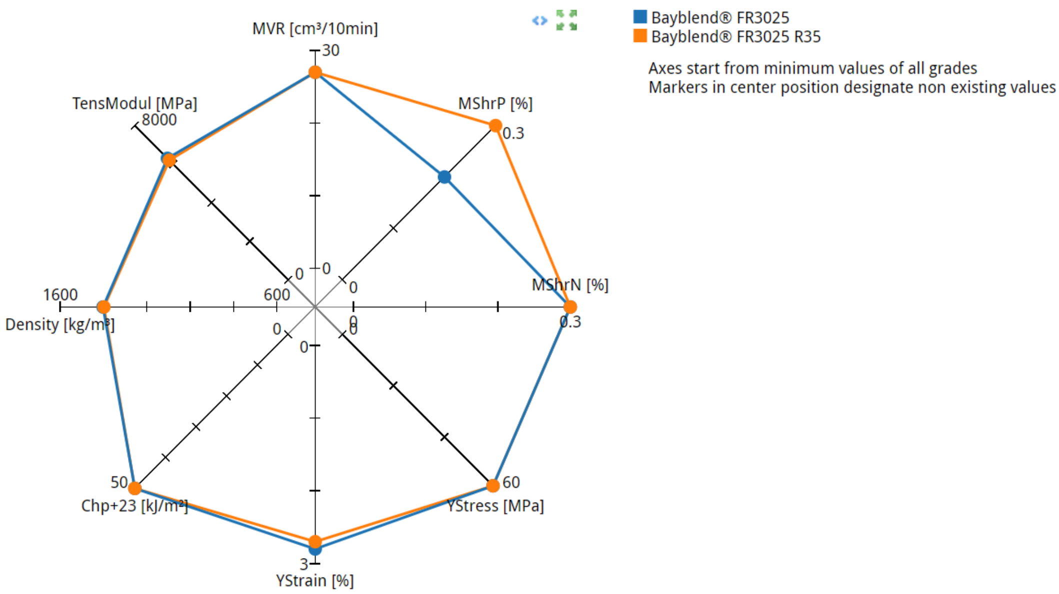


Figure 38: *Chart comparing virgin PC-ABS to 35% post consumer PC-ABS.* *Data from Campusplastics.com*

In the chart above, two versions of the same PC-ABS grades are compared. Both are Bayblend FR3025, where the blue line is an entirely virgin compound while the orange has 35% recycled content. As seen in the chart the properties of the materials are incredibly similar, where the main differences are minor variations in parallel mold shrinkage (MshrP) and yield strain (YStrain).

Figure 38: *PC/ABS before & after recycle processing.* Figure: mgg-recycling.com

The availability of recycled TPU is more sparse, although the science in this field is moving at a fast pace and recently the first grade of chemically recycled TPU was launched by Novoloop, with a recycled content of 35% while still performing as a virgin material. These grades are still mainly used in experimental ways but could be an alternative to look further into in the coming years. For this project, the main concern is to make the elastomer properly bond to the PC-ABS. Therefore, a TPU such as AD-45A-NT-1-32 PC/ABS which is developed especially for adhering to PC-ABS is selected.

3.3.4.3 Selection of production method.

For convenience, the production method of 2K-molding was selected for all of the concepts except for the axial concept number 1. This concept had an O-ring which would be inconvenient to 2K-mold, and instead the O-ring would be separately assembled.

Using the 2K-molding production method for the other concepts would eliminate this step of assembly for the gasket and therefore also save time and money. This is also a method which is already used within the company and because of this there is already a lot of experience and routines in place which would be beneficial for the production of the product.

4 Detail design

The dimensioning of walls for all lid designs was set at 1.6mm. Because of the rule of thumb of any supporting ridges being around 50% of the wall thickness, these were dimensioned to be 0.8mm thick. Following this rule improves producibility and minimizes the risk of sink marks and other imperfections.

4.1 Axial gasket lids

For all of the axial gasket lids, the top surface was given a slight curve of R = 800mm. This was to increase the resistance to bending and to prevent leakage. All of the vertical surfaces were given a slight draft of 1.5 degrees to simplify removal from the plastic injection mold. Sharp corners were also eliminated for this reason, and the smallest corner radius for all concepts was 0.25mm.

4.1.1 Concept A1

Axial concept 1 used an O-ring for sealing and because of the previous test results it was dimensioned with a diameter of 1.5mm. The gland depth for this O-ring was calculated with a 22% squeeze according to the Bosch expert's recommendations. Using equation 3, the gland depth for Concept A1 was set as 1.17mm.

$$O - ring\ squeeze\ \% = \frac{(O{-}ring\ diameter) - (Gland\ depth)}{(O{-}ring\ diameter)} * 100 \quad \textit{(Equation 3)}$$

The width of the gland was calculated with equation 4 and 5. This resulted in the O-ring section area to be 1.78mm^2. With a recommended gland fill of 80%, the gland area would be 2.20mm^2.

$$O - ring\ section\ Area = \pi r^2 \qquad \textit{(Equation 4)}$$

$$Gland\ Fill\ \% = \frac{O{-}ring\ Area}{Gland\ Area} * 100 \qquad \textit{(Equation 5)}$$

Knowing that the gland depth should be 1.17mm and that the gland area should be $2.20mm^2$, the gland width was calculated simply through equation 6. The gland width was calculated to be 1.89mm.

$$Gland\ area\ =\ Gland\ depth\ *\ Gland\ width \qquad \textit{(Equation 6)}$$

The lid was modeled in SolidWorks with these measurements. An edge was also modeled to give the O-ring an even squeeze along the whole loop. The top surface was also slightly bent in two directions for this reason, avoiding a bend in the lid for even pressure along the O-ring.

The holes in the lid were dimensioned to fit the M3 screws used in the previous user test. Small indents were created to make the screws sink into the lid and somewhat even to the rest of the surface for aesthetic reasons.

Figure 39: *Lid design of concept A1 which is mounted with screws and O-ring.*

4.1.2 Concept A2

Axial concept two has a gasket thickness of 1mm just like in the previous tests. This concept does not have a gland in the same sense as concept A1, but it uses a supporting ridge to allow for even pressure all along the gasket. The height of the supporting ridge was calculated with the squeeze percentage formula, equation 3 using a 22% squeeze. The supporting ridge was therefore dimensioned to be 0.78mm in height.

The lid was dimensioned both to look proportional and aesthetic together with the customized plastic headed screw. The screwhead was printed in multiple different sizes and through discussions in the group it was decided that the screwhead with 15mm in diameter had a good balance between usability and space efficiency. The height of the screw head was set to be 3 mm to be able to both fit in a threaded metal part inside and a groove for inserting tools.

The thickness of 3mm was quite large and looked a little bit weird when sticking up over the lid surface, because of this it was decided to make a container for the screwhead. This container would go down into the product to make the surface look even from the outside. However, the container also created a local gland which could interfere with the gasket expansion.

Because of this, the gasket width was dimensioned using the Gland fill formula, equation 5. The width of the local gland, between the supporting ridge and screwhead container was 2mm. Using the upper limit of a 90% gland fill resulted in a gasket which could have a width of 1.40mm which could be a reasonable dimension to remain watertight. See equation 7 for W_{Gasket} dimensioning.

$$W_{Gasket} = \frac{Gland\ Fill\ \% \times W_{Gland} \times H_{Gland}}{100 \times H_{Gasket}} \qquad \textit{(Equation 7)}$$

Figure 40: *An illustration of the local gland and it's smallest width* W_{Gland}

4.1.3 Concept A3

Gasket number three was made with a squeeze of 22% and since the concept does not have any gland, the dimensioning of the gasket could be set completely freely. It was decided that the gasket was to have the same height as the gasket of concept A2. Since the cross-section is a semi-circle, the radius would therefore be 1mm and this would result in the width of 2mm. The supporting ridge was because of this set to have the same height as in Concept A2, 0,78mm.

The shape of the lid was created with a radius between the top part and side part. The reasoning behind this is that it would increase the stress resistance as well as simplifying the release from the plastic mold during manufacture.

The screw was modified to the previous screw concept to reduce the number of parts and because it was difficult to fit two axes when the screw was scaled down. Because of this the two loops were switched to one loop. There had also been some feedback that it was tiresome to screw for an eternity, and because of this the screw was converted into a bayonet screw which also only had to be turned 90 degrees to be opened. The bayonet screw also opened up for the possibility of creating the lid with one single material family.

During testing it also became evident that the users did not understand that the loops were foldable, because of this there was a signifier added to the top of the new loop. This would indicate that the loop was graspable in some way.

In a similar manner as in concept A2, the lid had a designated screw container to allow for the screw to have a continuous surface with the lid. The bayonet screw was created partly hollow to maintain an even thickness of the walls. To hide the inlets for the hooks of the bayonet screw in the lid, the screw was created in the shape of a mushroom. This way the top part of the screw would cover the holes in the lid for aesthetic purposes.

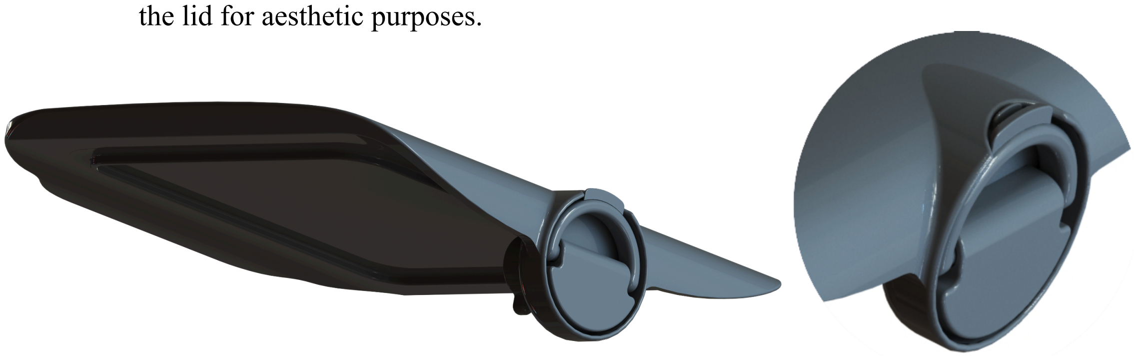


Figure 41: *A rendered figure of the A3 concept and the bayonet screw.*

5 Testing and refinement

5.1 Plastic flow analysis

Simulating the plastic's flow during the plastic injection process was done in the CAD-software Solidworks. The selected material for simulating was a general ABS-PC material for the lid. For the gasket a general TPU material was chosen, with similar properties as the one already used by Bosch in similar contexts. Both were evaluated to give an estimation good enough for this early stage simulation.

The simulations were run with all of the parts individually, even if the intention was that they would be molded together through 2k-injection in the final product. The reasoning behind this decision was that this is a very early stage evaluation, and that a wall of a mold would emulate a wall of a part closely enough for them to be simulated in separate simulations. Because of this, lids and gaskets were simulated separately and plastic headed screws were simulated without the threaded insert of metal.

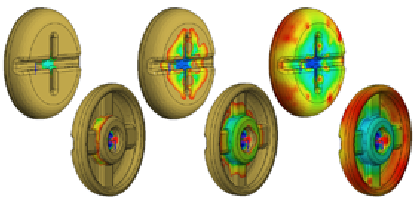


Figure 42: *Moldflow analysis of Concept A2's screwhead without metal insert.*

The total cycle time was calculated based on the individual molding as well, and because of this the real cycle time is likely to be lower than the estimated one. The reason behind this is that it wouldn't be necessary to open the mold in between injections in real production.

The opening time of the mold was set to 5 seconds for all concepts except for concept A2 which was set to 7 seconds. The reason for this was that it was roughly estimated to take two additional seconds for a robotic arm to put a new threaded insert into the mold for the plastic headed screw.

All of the results from the moldflow analysis are summarized in Appendix E and Appendix D.

5.1.1 Axial concepts

The injection location was decided to be in the center on the bottom side of all the axial lid concepts. The reason for this was that the plastic's surface quality might be affected in this place and that this spot offered a symmetrical infill without being too visible.

For the gaskets they were set on the side of the gasket, instead of the top, to prevent hypothetical sink marks on the contact surface of the gasket. Because of the geometry of the gasket, a closed loop, it was impossible to avoid confluence lines at the opposite side of the injection location, but it was decided that these lines would not affect the sealing properties of the gasket if the plastic injection machine was properly operated.

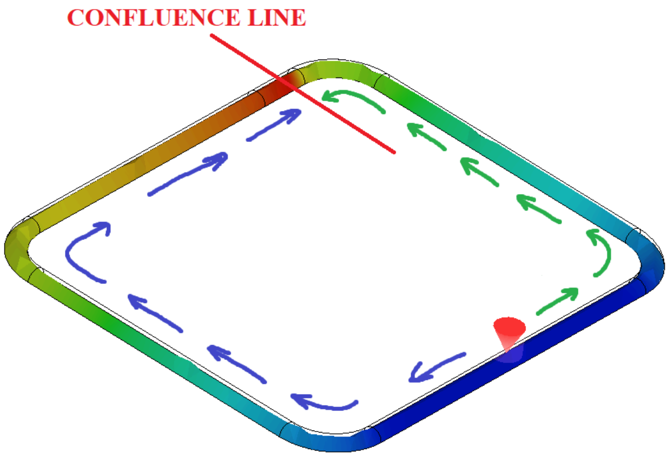
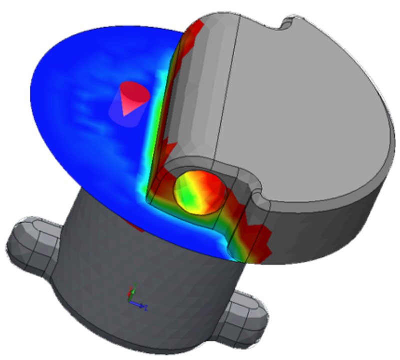


Figure 43: *Shows the flow directions and confluence line of Concept A3's gasket.*



All of the axial concepts managed to do a successful moldflow except for the bayonet screw of Concept A3. This part refused to fully refill with either one or two infill locations. It was thought that this was due to the geometry of the screw, and because of this reason the design was refined to fill easier.

The sharp edge was eliminated and the thickness was increased which can be seen in Figure 44.

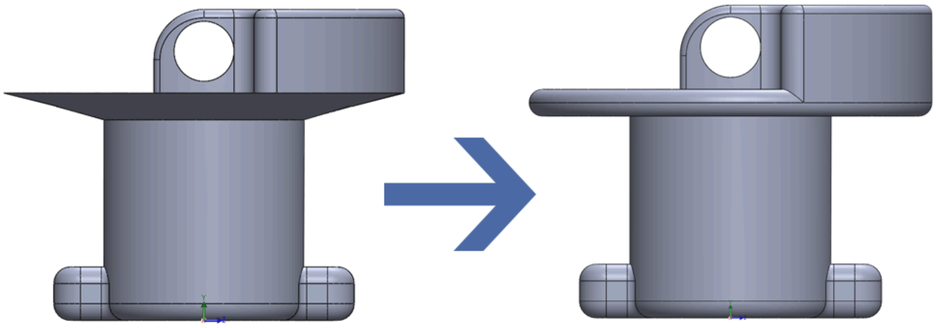


Figure 44: *The alterations made to the bayonet screw for increased moldability*

The alterations made to the bayonet screw of Concept A3 increased the moldability of the screw dramatically. The mold flow simulation went from a partly unfilled screw to an infill of 100%.

The required injection pressure was somewhat similar to all of the different axial lid concepts. Ranging around 20MPa, since the maximum limit is around 200MPa for modern plastic injection machines, this was well below the top limit for all of the axial concepts. For smaller parts, such as screws, the required injection pressure was slightly higher but still well within the limits.

5.1.2 Radial concepts

The radial concepts were simulated in a similar manner as the axial concepts. All of the lids were molded successfully with injection pressures within acceptable limits.

There were however some difficulties simulating the thicker gasket concepts. One of them only had a partial infill and one of them refused to simulate. The fact that they had the same geometry as the thinner gaskets, raised the question that there might have been some issue with the import of the files from Creo into Solidworks Plastic.

No solution to this was found, but the assumption can be made that they would have similar cycle times as their thinner siblings in real life, if the machine was operated correctly. This assumption is made on the fact that it is more difficult to inject a thinner geometry than a thick one and that the thinner lids had similar cycle times as their corresponding thicker versions.

5.2 Compression force stress simulation

All of the lids will experience stress due to the force required to compress the gaskets according to the squeeze formula. If the lid's resistance to this stress is too weak, this will result in bending deformations in the lid, sealing failures or even material breakage.

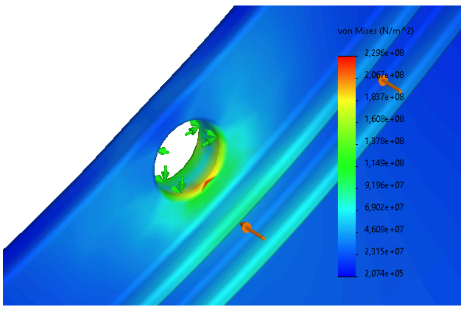
To avoid this and to confirm that the lids have been dimensioned properly, it was decided to run stress simulations on the lids. However, the compression force is not easily calculated and since most of the concepts have custom designs these numbers are impossible to find in tables.

Instead, the compression force was roughly estimated using a scale. Having the 3D-printed prototypes of the lids, and their corresponding gaskets, this was quite effortless. The lid was simply pushed against the weighing scale until the gasket was fully compressed, the supporting beams in the 3d-printed assured that they wouldn’t compress further than the desired squeeze percentage. When this happened, the weight was noted down and multiplied by the gravitational acceleration to get the compression force.

The compression force ranged from around 4 kg to 6 kg for all of the concepts. To get some safety margins, it was therefore decided to run all of the simulations with a compression force of 70 N, or approximately 7 kg.

All of the results are fully summarized in Appendix F.

6.2.1 Axial concepts



The first simulation only flagged a very small part on the inside of one of the holes for Concept A1. The fact that the lid is symmetric and only one of the holes was marked, raised some suspicion it was due to the large polygon size. The size was reduced and the red area disappeared.

Practical reasons led to the decision of simulating the stresses of the lid and the screw separately for A2 and A3. The simulation of the lid was done first for both of them, and then the screw’s share of the compression force was estimated through length measurements in the CAD model and simple force equations.

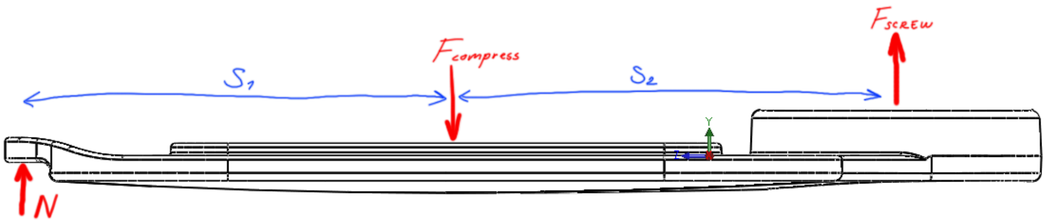


Figure 45. *Dissection of forces for lid concept A2*

$$(\uparrow):\ N + F_{SCREW} - F_{COMPRESS} = 0$$

$$M(N);\ S_1 \times F_{COMPRESS} - (S_1 + S_2) \times F_{SCREW} = 0$$

$$S_1 = 29.30\ mm$$

$$S_1 + S_2 = 57.7\ mm$$

$$F_{COMPRESS} = 70\ N$$

$$\Rightarrow F_{SCREW} = 35.55\ N$$

The result of the simulation of stress effects with the distributed compression force on the screw can be seen in Figure 46. The simulation shows that the proposed dimensioning on the screw does not cause any zones with too high levels of stress.

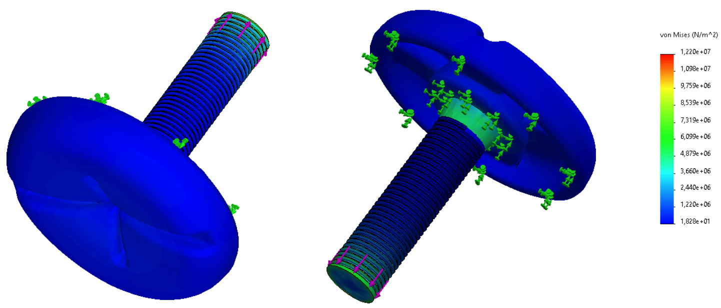


Figure 46. *Shows the results from the stress simulation of screw assembly 2.*

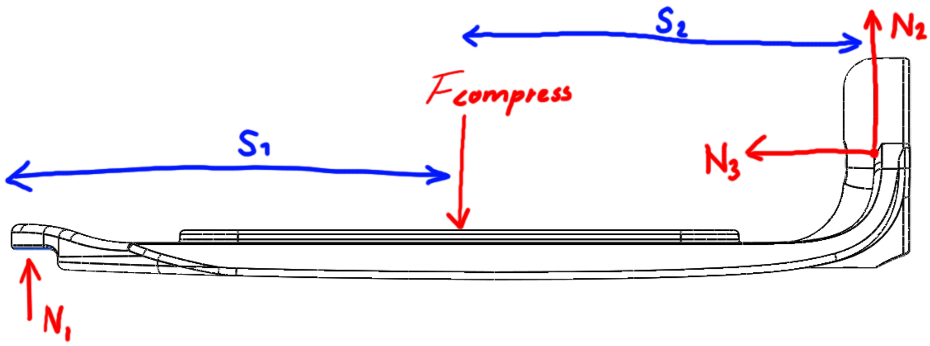


Figure 47. *Dissection of forces for lid concept A3*

$$(\uparrow):\ N_1 + N_2 - F_{COMPRESS} = 0$$
$$(\rightarrow):\ N_3 = 0$$

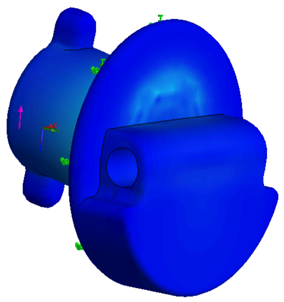
$$M(N);\ S_1 \times F_{COMPRESS} - (S_1 + S_2) \times N_2 = 0$$

$$S_1 = 17.9\ mm$$

$$S_1 + S_2 = 54.47\ mm$$

$$F_{COMPRESS} = 70\ N$$

$$\Rightarrow\ N_2 = F_{SCREW} = 23.00\ N$$



The result of the simulation of stress effects with the distributed compression force on the bayonet screw can be seen in Figure 48. Note that the direction is radial in this scenario.

The simulation shows that the top material might be a little bit too thin, but since there are no red or yellow areas it should be fine to continue without any further refinements.

Figure 48. *Result for bayonet screw.*

6.2.2 Radial concepts

Simulating the assembly of the radial seals was, because of the necessary bending and squeezing of materials, too complex for the simulation programs at hand to perform. Therefore, the compression force was estimated to be similar to the compression force of the axial seals which is an assumption that can be made because of the same shore hardness and a similar amount of deformed volume on the gaskets. Simulations were then performed of how the stress is distributed once in assembled state, which will be the stress situation for the majority of the covers' lifespan. The same force, 70 N, was therefore chosen and simulated similarly as the axial seals but in radial direction.

In the following figures, on the left side the analysis illustrates the stresses in the material, and the color is a representation of when the maximum allowed stress is reached according to Von Mises stress theorem. On the right side the simulation measures the displacement, where red is the most displacement and dark blue is the least.

However, the simulations below are to be considered a worst case scenario since the compression force will be applied both from the surrounding product and the lid. In the simulated situation, the entire force is assumed to be absorbed by the lid. It was also later shown, with a more successful simulation, that the assembly force of the radial concepts was only about 40 N.

For all versions the highest stresses are found in the transition that connects the brim to the bottom lid surface. The largest displacement is, as expected, in the middle of the long side of the brim.

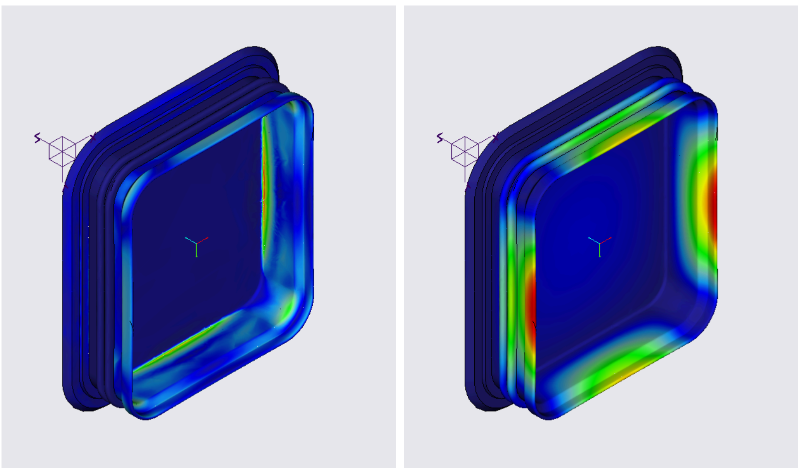


Figure 49. *Stress respectively displacement of radial concept R1.*

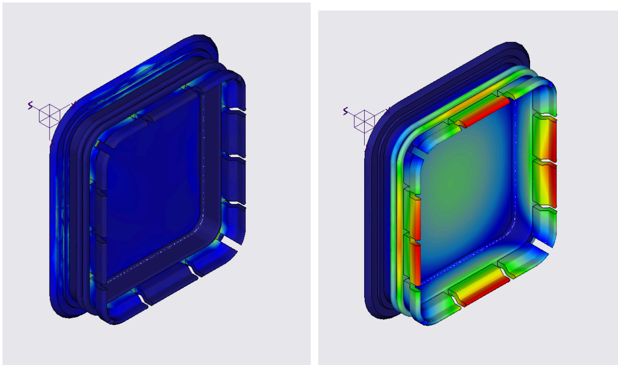


Figure 50. *Stress respectively displacement of radial version R2.*

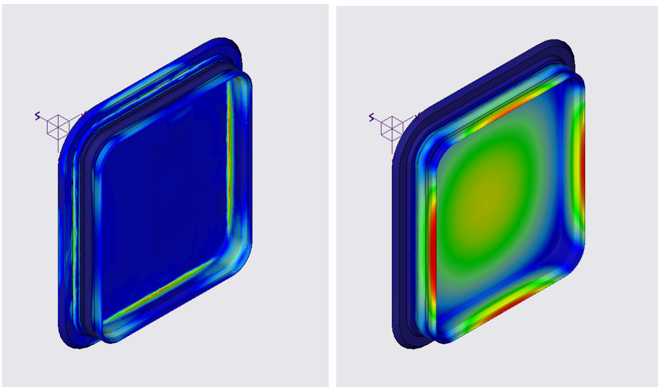


Figure 51. *Stress respectively displacement of radial compact R3.*

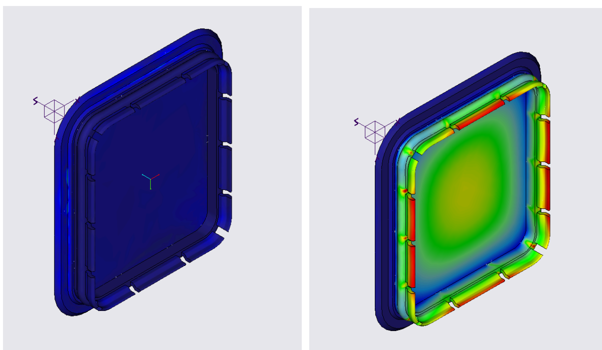


Figure 56.*Stress respectively displacement of radial compact R4.*

5.3 IP-classification test

Figure 57. *Indicative testing.*

5.3.1 Indicative testing

A simple water ingress test was conducted at 15 cm of depth for 15 minutes.

The prototypes were placed on the bottom of a water filled box with the help of mugs to prevent floating. After the tests the prototypes with leakage were reprinted to increase the chances of favorable results of the professional water ingress test.

5.3.2 Water ingress protection testing

Further water ingress testing was conducted at Sigma Connectivity with the assistance of experienced test engineers and utilizing professional test equipment.

Unfortunately, not all concepts could be evaluated in this test because of failure of the prototypes. The prototypes ordered from the manufacturing workshop were made in a brittle plastic, resulting in complete or partial failure for some of the prototypes when closing the lid. Another problem was the tolerances between the surrounding product and the lid, which was difficult to control since the lids were manufactured in a workshop while the surrounding product was printed in our own printer. This resulted in one of the lids not being able to fit into the surrounding. In Figure 58 the prototypes that were tested are shown.

The first test was made by weighting the prototypes before and after submerging them in water, 1 m of depth for 30 minutes, and comparing the weights to identify how much water has penetrated the prototype. This creates a pressure of 10.76 kPa and is a test that qualifies for IPx7.

According to the test engineer a general rule of thumb is that 0.02 grams increase of weight is the limit before a leak should be suspected. However this depends on if the product has many other ridges and corners where water can gather. In professional tests the samples are left sealed for 24 hours to dry before weighing the second time, but because of our limited time in the test laboratory this was not possible for us to do. Instead, the prototypes were dried with tissue and pressurized air to the best of our ability before weighing.

Figure 58: *Testing setups for the different concepts.*

Table 17. *Results from water ingress protection testing at Sigma.*

Number in figure	**Index**	**Description**	**Weight before [g]**	**Weight before [g]**	**Difference [g]**
1	R2	Radial, ribbed	26.01	30.61	+ 4.6
2	A2	Multitool	57.69	59.05	+1.36
3	A1	O-ring	43.20	44.15	+0.95
4	A3	Bayonette	71.91	72.63	+0.72
5	R3	Radial, compact	18.92	19.01	+0.09
6	R1	Radial	19.94	20.27	+0.33
-	BM	Benchmark product, Garmin	148.48	148.64	+0.16

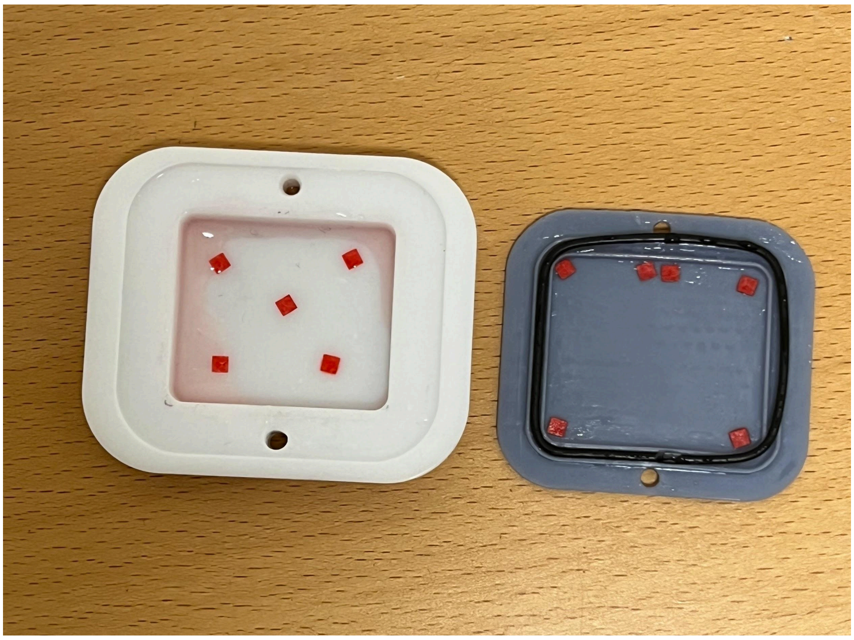


Figure 59: *Concept A1 failed the 30 min water submerge test.*

When opening prototypes one, two, three and four they had visible water ingress. Because of this significant leakage they were not suitable for more advanced testing. Prototype 5 and 6 were candidates for the "bubble testing" and the surroundings were drilled into to allow for a valve. Unfortunately prototype six broke during this step and only prototype 5 could be tested.

The test was conducted by submerging the prototype in water while slowly increasing the internal pressure.The internal pressure was increased until slightly above 1100 millibars which was when bubbles started to appear on one of the sides of the lid. This pressure is the equivalent of 0.1 bars above the surrounding pressure.

The test engineer explained that when testing a final product, they usually aim to reach 0.4 bars above the surrounding to indicate a good selling interface. However, since this product is only an early prototype 0.1 bars should be considered a positive outcome and indicates that the concept holds promise. In addition, most products that are tested today are sealed with some sort of adhesive, which is where this rule of thumb is applied.

It should also be considered that this test is mostly to find the leaking points, since the simulated situation is inverted to a real situation where the surrounding pressure is higher. On the tested prototype the leaking spot was noticed, and when opening the lid it was clear that the seal had a manufacturing defect in the corresponding inner wall and seal which likely was the cause of failure.

5.3.3 Supplementary tests

In order to evaluate the prototypes that either failed or could not be tested with professional equipment at Sigma Connectivity, a new batch of prototypes were made and a tube was purchased to create a test environment with a one meter water column. A similar test to the one at Sigma was executed on the improved prototypes. Unfortunately, the prototypes made by our own printers turned out to not have good enough quality and therefore the test came out inconclusive.

Table 18 - The results from IP-classification tests

Concept:	**Axial lid with O-ring**	**Axial lid with bayonet**	**Axial lid with screw and lever**	**Radial lid**	**Radial lid, compact**	**Radial lid with gaps**	**Radial lid, compact with gaps**
Indicative submerge (15 min)	minor leakage	leakage	leakage	-	minor leakage	no leakage	breakage, small leakage (prototal) no leakage
Submerge (30 min) at Sigma	Leakage 	Leakage 	Leakage 	OK 	OK 	Leakage 	-
Submerge (30 min) supplementary test	Leakage	-	-	Leakage	Inconclusive	-	-
Result:	Leakage	Leakage	Leakage	OK	OK	Leakage	inconclusive

5.4 User testing

User testing was also done to determine the users different opinions about the lids. It was also done to determine if it was easy or difficult to open and how much time it took to assemble and disassemble the lids for a beginner who didn't know how to open it.

Concepts R1-4 were evaluated together in Table 16 and 17, this is because these questions were related to the lid's closed appearance and all of them looked the same while closed.

The user testing was done as a structured interview with 4 test users. They were asked pre-determined questions and were then asked to open all of the lids while being video filmed. However, one of the test users gave up during the test due to too many questions. This user has been weighed in for some questions, but not all of them.

To open the lids they had access to all of the tools as in the screw concept testing, all of them are listed in Appendix J. The tables below give the opinion of the average users, calculated from the answers from the 4 users.

The full answers are filled into Appendix I and Table 16, 17, 18 and 19 are a summary of these results.

Figure 60: *Testing setup with tools and plastic batteries during the user testing.*

Table 19 - The users average ranking (1-5) of first impression to the concepts

	Impression	Openability	Quality	Design	Able to change battery	Security	AVG.
Concept A1	3.5	3.25	2	3.5	2.75	2.25	2.8
Concept A2	4.67	4.67	3.67	4	3.67	3.67	4.1
Concept A3	2.67	2	2	2.67	1	1.67	2.0
Concept R1-4	3.33	4.33	3	4	4	4.33	3.83

Table 20 - The users average estimated number of usable tools

Concept:	*A1*	*A2*	*A3*	*R1-4*
No. of tools	1.33	33	20/H	5
Percentage	1.3%	33%	100%	5%

When asked about their first impression of the concepts in different categories, it was quite surprising how badly Concept A3 performed. It was a concept which was developed especially for good user experience, and still it performed worst in first impression of all the concepts. It scored especially low in openability and battery changeability.

Another surprise was that the Concept A3 was difficult for the users to open. One user gave up in fear of breaking the product and another user accidentally broke the plastic bayonet screw. A third user managed to open the bayonet after some struggle but was surprised that it was not a regular screw.

When ranking the concepts again after opening, there were two lids which exceeded the ranking from the first impression and two which met the expectations. Even in this category, the Concept A3 was performing remarkably badly and although it was ranked initially low it performed even worse in reality and did not meet the users expectations. Concept R4 and R5 were also performing a little worse than the initial expectations. This could be because some users were surprised by the large force required to open and close these two concepts. One of the users also started off by opening the lid by hand, but eventually had to surrender and switch to a screwdriver and uttered a few words of disappointment over this since she did not like tools.

Figure 61: *Concept A3 was a large disappointment in many ways.*

Table 21 - Average information gathered from video of lid opening

Concept:	*A1*	*A2*	*A3*	*R1*	*R2*	*R3*	*R4*
Able to open?	100%	100%	33%	100%	100%	100%	100%
Time to open	71.33s	50.33s	N/A	31s	34s	14.67s	12.33s
Used tools to open	1.67	1	1.33	1.33	1.33	1	1

Table 22 - Users average opinion of lid before and after opening (1-5) .

Concept:	*A1*	*A2*	*A3*	*R1*	*R2*	*R3*	*R4*
Before	2.8	4.1	2.0	3.83	3.83	3.83	3.83
After	3.33	4.33	1.67	2.33	3.33	3.67	4.67
Reality compared to expectation:	Better	Similar	Worse	Worse	Worse	Similar	Better

6 Production ramp-up

6.1 Cost estimation

The evaluation of costs per unit is a very simplified calculation. The price will be estimated based on costs for material, cycle time in the plastic injection machine and storage of loose parts directly linked to the concepts. Additional production labor costs, overhead costs or equipment costs are not included in this simplified estimation of production cost.

Although tooling and molds is generally the largest expense, it will be seen as an investment and will not be distributed or amortized as a cost per unit. Instead this will be evaluated as a separate metric, since production volume is unknown.

The estimated costs are only a roughly estimated value for comparing and evaluating concepts, not for indicating the final retail price of the lid.

6.1.1 Material cost

Material cost was estimated by measuring the volumes in the different CAD-files. By then investigating the density and cost per gram of the selected material per part, the cost per part could be calculated. The values collected for the different materials are summarized in Table 23, while the summary of the costs per part and concept are summarized in Table 24. Cost for the plastic materials was given to us by our supervisor, the steel price was estimated based on current market rates.

Table 23 - Material density and cost

Material	**Density** [g/mm^3]	**Cost per gram** [SEK/kg]
PC-ABS	0,001150 [35]	53,14
TPU	0,001470 [36]	92,31
SS	0,008030 [37]	0.0338 [38]

Table 24 - Estimation of material cost from weight

	Part	CAD- Volume [mm3]	Selected Material	Part weight [g]	Estimated part cost [SEK]	Total cost [SEK]
Concept A1	Lid	6020.16	ABS-PC	6.92	0.37	0.4438
	Gasket	275.29	TPU	0.40	0.04	
	Two screws	*N/A*	SS	0.5	0.0169	
	Two insert threads	*N/A*	SS	0.5	0.0169	
Concept A2	Lid	6758.60	ABS-PC	7.77	0.41	0.475
	Gasket	220.47	TPU	0.32	0.029	
	Screw head	297.12	ABS-PC	0.34	0.02	
	Screw threads	*N/A*	SS	*0.25*	0.008	
	Insert threads	*N/A*	SS	*0.25*	0.008	
Concept A3	Lid	6827.74	ABS-PC	7.85	0.42	0.478
	Gasket	254.91	TPU	0.37	0.034	
	Bayonet screw	399.14	ABS-PC	0.46	0.024	
Concept R1	Lid	3319.72	ABS-PC	3.82	0.203	0.261
	Gasket	430.93	TPU	0.63	0.058	
Concept R2	Lid	3974.57	ABS-PC	4.57	0.2428	0.3118
	Gasket	511.73	TPU	0.75	0.069	
Concept R3	Lid	3392.61	ABS-PC	3.90	0.207	0.236
	Gasket	220.80	TPU	0.32	0.029	
Concept R4	Lid	4668.95	ABS-PC	5.37	0.2853	0.42
	Gasket	1015.60	TPU	1.49	0.138	

6.1.2 Machine costs related to cycle time

Cycle times were calculated through the injection molding simulation in Solidworks, and can be found in Appendix D. The cost of the machine rate is assumed to be around 100 USD per hour [39], or 0.2829 SEK per second. For the partly failed simulations of 5 and 7 they were assumed to be similar to 4 and 6 with correct machine settings because of similar volume. They are marked (*).

Table 25 - Cost of injection molding machine

Concept	*A1*	*A2*	*A3*	*R1*	*R2*	*R3*	*R4*
Time [s]	17.81	32.62	59.9	15.75	15.75*	15.08	15.08*
Cost [SEK]	5.03	9.23	16.95	4.46	4.46	4.27	4.27

6.1.3 Machine operator salaries

A portion of the part's cost will come from the machine operator's salary. It is assumed that the machine operator has a salary of 300 SEK/h, a reasonable salary for a Swedish machine operator. It is then expected that the worker can operate five different machines simultaneously, leading to the salary costs to be 60 SEK/h, or 0.0167 SEK/s, per machine.

Furthermore, it can be expected that the machine will be shut off around 15% of the time. This is due to changes of tools etc, when the machine is off but the operator is active, which means that the approximated cycle time has to be increased by 15% to calculate the cost of salary per part more accurately.

Table 26 - Cost of operating the injection molding machine

Concept	*A1*	*A2*	*A3*	*R1*	*R2*	*R3*	*R4*
Time [s]	17.81	32.62	59.9	15.75	15.75*	15.08	15.08*
Time + 15% [s]	20.48	37.51	68.885	18.1125	18.1125	17.342	17.342
Cost [SEK]	0.297	0.545	1.00	0.263	0.263	0,252	0,252

6.1.4 Summarized production cost per unit

The material costs, costs related to production cycle time and operator costs are summarized in Table 24, and also filled into the Appendix G. It is assumed that around 10% of the lids will break during manufacturing, and therefore the sum of all the expenses is multiplied with this expense to get a more realistic estimate.

Furthermore the company will most likely add additional costs to cover their operational expenses. These will cover storage of parts, office space, industrial facilities, electricity, bank services, accounting and everything else for the business to operate properly. A common way to measure this is through the Operating Expense Ratio (OER) [40].

$$OER\,\% = \frac{Total\ operating\ expenses}{Gross\ revenue} \qquad (Equation\ 8)$$

An ideal range for OER is generally between 60% to 80% for a functional business. In this scenario it is assumed to be 70% and this fee is multiplied onto the sum of costs for material, machine and operator. The total in Table X is the sum of costs of material, machine and operator multiplied by the waste factor and OER.

Table 24 - Summary of costs per concept unit measured in SEK

Concept:	***A1***	***A2***	***A3***	***R1***	***R2***	***R3***	***R4***
Material	0.4438	0.475	0.478	0.261	0.3118	0.236	0.42
Machine	5.03	9.23	16.95	4.46	4.46	4.27	4.27
Operator	0.297	0.545	1.00	0.263	0.263	0.252	0.252
Sum:	5.7708	10.25	18.428	4.984	5.035	4.758	4.942
Operative cost (70%)	4.04	7.175	12.9	3.49	3.52	3.33	3.4594
Waste (15%)	0.856	1.54	2.7642	0.7476	0.76	0.71	0.74
Total:	10.68	18.97	34.09	9.22	9.315	8.8	9.14

6.1.5 Price of tooling per concept

The price of tooling for the different concepts have been approximated by our supervisor at Bosch, and can be seen in both Table 25 and additionally as an individual metric in Appendix G. The O-ring does not require a custom tool to be bought since it would most likely be bought off the shelf from an external supplier.

Lid concept R1-4 would need a tool with four sliders, which increases the expense for the tool. These tools would approximately cost 130000 EUR each, which is around 1.4 million SEK. The concepts A1-3 can be produced with much simpler molds, estimating them to be around 120 000 SEK. The molds for the custom screws are estimated to have a price of 50 000 SEK [41].

Table 25 - Cost of tooling per concept [SEK]

	A1	A2	A3	R1	R2	R3	R4
Lid	120 K	120 K	120 K	1.4 M	1.4 M	1.4 M	1.4 M
Screw	N/A	50 K	50 K	N/A	N/A	N/A	N/A
Total:	120 K	170 K	170 K	1.4 M	1.4 M	1.4 M	1.4 M

6.1.6 Cost per unit depending on production volume

The cost per unit varies largely between concept A1-3 and concept R1-4 depending on the production volume. The price per unit (P) is calculated with Equation 9, it consists of the base cost (B) from table 24, the tooling cost (T) from Table 25 and is depending on the production volume (V).

$$P(v) = B + \frac{T}{V} \qquad (Equation\ 9)$$

Because of the low base and tooling cost of Concept A1, it will be the cheapest option for low production volumes. Concept A2 and A3 can never be cheaper. Because of concept R1-4 having the same tooling cost, concept R3 will become the cheapest concept if volumes are large enough. Concept R1, R2, R4 can never be the cheapest option. Costs of Concept A1 and R3 are plotted in Figure 62.

Using this equation, it can be determined when the production volume becomes large enough for the cheapest option to go from concept A1 to R3. Turns out that the production volume needs to be larger than 680 851 units for the R3 to become the cheapest option.

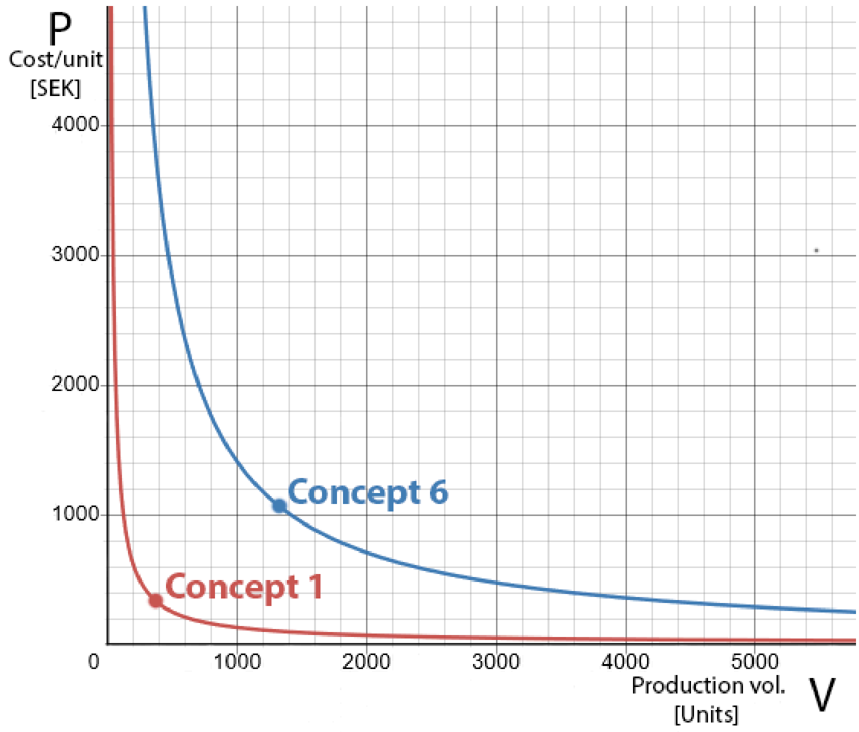


Figure 62: *Cost per unit for Concept A1 and R3 for low production volumes.*

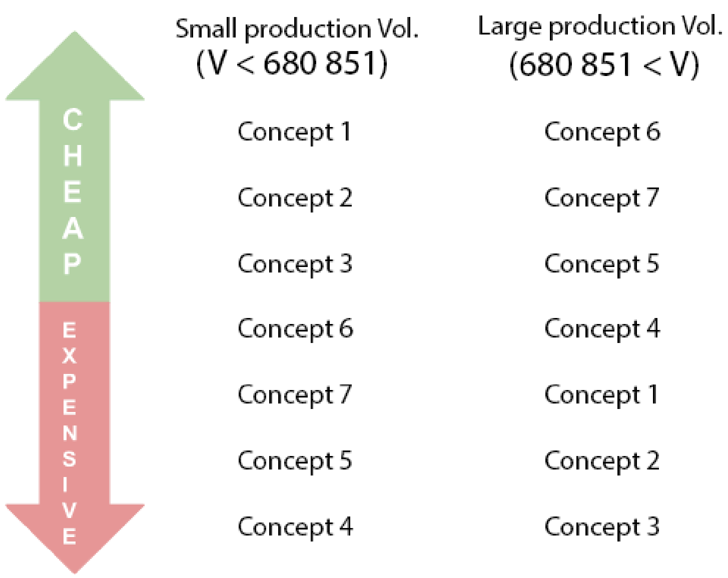


Figure 63: *Concepts ranked based on cost depending on production volume..*

7 Evaluation

To evaluate our concepts, it was decided to use the metrics which had been previously specified for the identified needs. It was also decided to use a handheld electronic device with similar certifications which this project's lids aimed for. The selected product was a Garmin Etrex Venture, which can be seen in Figure 64.

The metrics were filled in with the help from previous tests. Both stress simulations, user testing and the water submerge tests went into Appendix G to be benchmarked against this already existing product. Values that performed better than the benchmarking battery lid were marked with green and red means worse.

Some of the fields were marked with yellow, these were decided to be irrelevant for benchmarking in this scenario. For example, the measurements. The hole to be covered was set at the beginning of the project and had different dimensions than the benchmarking product which was selected at the end of the project. For this reason, the measuring metrics were irrelevant to compare against.

Figure 64: Shows the electronic device which was used for benchmarking

Concept A1 and A2 performed worse than the benchmarking concept in the category of feedback. Screws have the drawback of the user never knowing when the screw has been tightened hard enough. The bayonet screw can only be folded back up if it is in the correct position and thereby gives you both a sensory and a visual feedback. The concepts R1-4 have the benefit of the audial feedback.

When it comes to the number of materials all of the developed concepts performed better than the benchmarking concept. This was because the hard part of the lid in the benchmarking concept seemed to be made out of two different hard plastic materials. One for the outside and one for the inside, while ours only had one hard lid material.

The concepts use different types of tools to open them. Some of them use tools while others are opened by hand. Whether it is good or not, in terms of evaluation, depends on the scenario of which the lid is applied. There are some products which it is desirable for only trained professionals to swap the battery, while there are others which can cause frustration for the users if they can't change batteries themselves.

As mentioned during the user evaluation Concept A3, which was especially niched towards user experience to increase the repairability, was performing horribly in the user tests. This also led to the subjective metrics to shine red for this concept. Combined with the fact that this was one of the more complex and expensive solutions, led to the conclusion of this concept being a big loser among the seven.

In general it can be said that R1-4 performed very well in the evaluation. This is due to the strength of both feedback, few materials and general versatility. They also performed well in the water tests and R3 & 4 was evaluated especially strongly, with Concept R3 being the cheapest to produce.

8 Result

Figure 67: *Renders of the seven concepts.*

Above are the seven final concepts that were prototyped and evaluated. The radial sealed concepts, illustrated on the lower row in the image, have resulted in a patent application which has been filed and which is currently pending.

9 Discussion

9.1 The product development process

In general the product development process went well and it was a good choice to use the Ulrich & Eppinger process. The modification to do the stage of concept development twice was also a positive aspect, since the first rough development process allowed us to go in blindly and to freely explore alternative solutions.

To not dig into system-level design was also a good choice, since it was not really applicable to the product development since we didn’t design the container.

9.1.1 Planning

The project started off with creating a Gantt-chart for the whole project. This Gantt-chart should probably have been iterated the moment that we decided to go for the Ulrich and Eppinger method, since the initial chart was created before we had decided this. The Gantt-chart was discarded, instead we chose agile work.

We set up a logbook with tasks to be done and questions that needed answers. The next week we summarized what was left of the previous week's work, if it still needed to be done and planned the new week accordingly.

During the start of the project we spent quite a long time researching a lot of different topics which we thought could be useful for the project. However, after finishing the project we can say with certainty that there were only a few things which we actually used in the report, and that there were many more which we had to add as the project continued. To optimize the time used for research, we should have waited until the project was more mature and only researched the things we had particular questions about.

It also became clear that we estimated the time consumption wrong for ordering parts from an external supplier. As we had become used to 3D-printing most parts ourselves, and being able to hold new iterations of the lid’s the same afternoon as we had designed it, it came as quite a shock that it would take almost a month to receive our professionally crafted prototypes.

9.1.2 Concept development

During the whole project we used an approach of open brainstorming. This was quite a good approach, drawing large quick sketches which we could discuss and make alterations to. We also had regular meetings with our supervisors from both Bosch and Lunds University which allowed for quick feedback and fast iterations.

During the concept development we also had the approach that no ideas were bad ideas, allowing ourselves to really explore even the wildest ideas. Although some of them do not seem to lead anywhere, the early concepts of expanding lids led us on the track for a great idea that eventually also led to the patent application in the end.

9.1.3 Detail design

In detail design we selected materials and dimensioned the lids and gaskets. This was done with the help from experts within their fields. We also used some of the previously researched materials, but came to the conclusion that many things also boils down to experience and a feeling for what works. Because of this we decided to bring in alot of expertise and take a lot of advice.

9.1.4 Testing and refinement

There were some issues during the testing and refinement stage. It was desired to do simulations of required closing force for the concepts R1-4, but did not manage to make the program do these correctly. It is probably because Solidworks and Creo are not designed to simulate this type of material bending motion combined with movement. Instead, it was decided to only do the stress testing with the forces caused by the compressed gaskets. This was after all the state the concept would stay in most of the product's lifecycle.

9.1.5 Production ramp-up

For this stage, it would have been great if we had saved the numbers from previous mold flow analyses regarding injection pressure. This could have been used as a base for more accurately estimating the tonnage of the machine used in production, and thereby also the cost per unit. However, we managed to discuss it somewhat with our Bosch supervisor and came to a conclusion of an average which we could use instead. It was determined that this was good enough as a pilot study.

9.2 Potential sources of errors

For practical reasons the user testing groups were kept rather small. Although this also increased the quality of the interviews and the amount of information which could be extracted, it also opened the door for individual preferences which could shape the results with disproportionate strength. This could be tackled by adding additional test users with an even wider range of backgrounds, opinions and experiences.

The initial water ingress testing had a little bit of the same issue, as the testpool was not that big. The tests were only performed once each. To increase the credibility of the tests, the water submersion time could have been prolonged and the same tests could have been repeated to confirm the results and strengthen the drawn conclusions.

It is normally around 10 samples of the same product which is tested in the laboratory. In this project we only had resources to produce one sample of each design, and this increased the risks of a good concept looking disproportionately bad if the only sample had manufacturing defects.

The prototypes did not have the same materials as indented for the final product. Some of the seals were prototyped in silicone instead of the TPU for practical reasons, and some of the PC-ABS parts were built with either 3D-printing resin or nylon. Differences in material properties could have affected both water ingress testing and user tests as the materials would have behaved and been perceived differently than the intended materials.

The O-ring for Concept A1 was home made, being glued together with a silicone glue to the custom length. This could have caused the leaking in the water tests, and this is strengthened by the fact that it was watertight during the concept selection test when we used an off the shelf O-ring with standard length.

Since all of the tests were performed on prototypes, and not the final products, any leaks could have been because of the prototype quality instead of the design. For instance, there could have been uneven surfaces in the silicone seals which we molded by ourselves. There were also sometimes air bubbles in the 3D-prints which could have caused leaks in between the printed layers although we thoroughly screened for this in the microscope.

Lastly, there have been rough estimations in some of the calculations. This rings especially true for the financial approximations of cost per unit. The price depends largely on production country, volume and individually negotiated contracts. The prices estimated should therefore be taken more as a value for comparing concepts, rather than an actual price.

9.3 Future work

There have been some things discovered during the work of this project which could have been interesting to investigate further, but which had to be put aside to finish the project within the given timeframe.

One of these things could be to dig further into the material selection of the concepts. It could especially be interesting to evaluate if there are recycled PC-ABS or TPU materials which could be worthy to consider without adding additional costs or reducing the quality of the product.

It could also be interesting to investigate deeper into the sustainability aspect of the lid. For instance, performing a complete life cycle analysis of the different concepts could provide valuable insights which one is truly better for the environment.

To take the concepts into a real product, it would be necessary to calculate the required tolerances for the different parts. This would also give an additional preciseness of the costs for the concepts. As higher requirements would increase costs, and because of this it would be desirable to aim for as large tolerances as possible in the future.

As a part of this, it would also be relevant to consider the compression set for different tolerances. This is because it perhaps would be possible for different tolerances to leak, even if the dimensioning still fell within the limits for the squeeze formula, due to the compression set..

Finally, it would be of high value to produce samples of the suggested concepts with the intended materials and manufacturing methods. This could with higher certainty indicate which concepts that can both pass the tests in the laboratory and which are appreciated by the end users.

9.4 Conclusion

The aim for this project was to create a concept for a lid which increased the repairability for a project. Seven lid concepts have been developed, some more successful in the evaluation than others. Concept 6 is the strongest champion among these, performing well in all of the tests and obliterating the benchmarking product Garmin Etrex Venture.

We can clearly see that it paid off to keep the doors open for new and innovative ideas, even late into the project. Thanks to the second development cycle we could find the Concepts R1-4 which became testwinners in the evaluation.

We can also conclude that traditional solutions remain strong. Concept A1 with the traditional O-ring and two screws performed quite well, as is expected with a classical concept which will stand against the ages. It performed especially well financially in low production volumes.

It was also evident that it is difficult to predict which concepts would be popular amongst the users. Concept A3 which we thought would easily score highly in the user tests, and thereby motivate a higher cost, was crushed by the radial lids with their simple but very elegant closing maneuver.

All in all, we are happy with the result, and even though this is a pilot study we have high hopes that concept R3 might make it into an actual Bosch product one day.

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Appendix A

Table A.1 - Summary of needs and their hierarchy

No.	Importance	Need statement	Comment
1	*	**The lid gives a good first impression**	
2	*	The lid looks easy to open.	
3	*	The lid breathes quality	
4	**	The lid appears to be professionally designed	
5	**	**The lid is easily located.**	
6	*Future work*	The lid placement is traditional.	*Out of scope*
7	*	The lid is distinguishable from the rest of the product.	
8	***	**The lid is only intentionally opened.**	
9	**	**The lid communicates its features.**	
10	***	The lid informs you how it is opened.	
11	**	The lid communicates that the battery is changeable.	
12	***	The lid is easy to understand.	
13	**	The lid gives you feedback when it is closed.	
14	*	The lid is perceived to look watertight.	
15	*Future work*	**The lid provides easy access for what is within.**	*Out of scope*

16	**	**The lid instills faith.**	
17	**	The lid instills self confidence in the user.	
18	*	The lid encourages the user to open it themselves.	
19		The lid is enjoyable to open.	
20	**	The lid feels secure.	
22		The lid is enjoyable to close.	
23	*	The closing mechanism feels strong enough to be watertight.	
24	* (!)	The lid can be opened without fearing damage to the rest of the product.	*Latent need*
25	***	The lid instills trust in the user for the product.	

26	***	**The lid is resilient.**
27	**	The lid protects against particles. (IP5)
28	***	The lid is sturdy.
29	***	The lid can withstand multiple attempts closing it the incorrect way.
30	**	The lid can withstand rapid temperature changes.
31	***	The lid can withstand surface impact.
32	**	The lid can withstand chemical load.
33	***	The lid can be resealable multiple times.
34	***	The lid can withstand -10°c to +50°c
35	**	The lid protects from waterjets
36	**	The lid protects from splashing water
37	***	The lid will protect against immersion in water

38	***	**The lid is realizable**
39	**	The lid is efficient for industrial assembly
40	*	The lid size is efficient

41	**	The lid is easy to manufacture
42	**	The lid is cheap
43	**	**The lid is sustainable**
44	**	the lid promotes recycling
45	***	the lid is of an appropriate plastic
46	*	**The lid is easily maneuvered**
47	*	the lid is easily gripped
48	**	the lid can be handled by the inept
49	***	**The lid is opened/closed with ease**
50	***	The lid is easily opened
51		The lid is somewhat familiar in design
52	*	The lid is predictable
53	*	The lid can be opened by hand
54	*	The lid is opened without traditional tools
55	**	The lid is quick to open
56	***	The lid is openable
57	***	The lid is easy to close
58	***	**The lid fits different products**

Appendix B

Table B.1 - Complete list of metrics

Metric no.	Need no.	Metrics:	Units:	Importance:
1	1, 2, 3, 4, 25	Perceived impression	*Subj.*	1.6
2	2, 5,7,10,16, 17 18	Perceived openability	*Numeric*	1.5
3	3, 4	Perceived quality	*Subj.*	1.5
4	4, 3	Perceived design	*Subj.*	1.5
5	5, 1, 2, 7	Locatable	*Binary*	1.25
6	8, 20, 31	Number of drops before accidental opening	*Numeric*	2.667
7	9, 5, 7, 14, 20, 23	Perceived watertightness	*Subj.*	1.5
8	11, 9	Perceived battery changeability	*Subj.*	2
9	12, 9, 10, 11, 13, 25, 52, 51	Easy to understand	*Subj.*	2.5
10	13	Gives feedback	*Binary*	2
11	19, 22	Enjoyable	*Subj.*	0
12	20, 23, 25	Perceived security	*Subj.*	2
13	24	Safe opening	*Subj.*	1
14	26, 27	IP5X standard test	*Binary*	2.5
15	26, 28	Maximum compr. force	*N*	3
16	29, 28, 26, 33	Number of reseals before failure	*Numeric*	3
17	30, 45, 34	Maximum temperature	*°C*	2.5
18	32, 45	Materials theoretically withstands chemicals from chemical test	*Binary*	2.5
19	29	Maximum force on weakest part	*N*	3

20	35, 36	Waterjet resistance	*Binary*	2
21	36	Splashing water resistance	*Binary*	2
22	37, 36, 35	Water immersion resistance	*Binary*	2.33
23	38, 39, 41, 45	Manufacturable	*Binary*	2.5
24	38, 39, 41, 45	Estimated assembly time	*s*	2.5
25	30, 45, 34	Minimum temperature	*°C*	2.5
26	38, 40	Minimum lid length	*mm*	2.5
27	38, 40	Minimum lid width	*mm*	2.5
28	38, 40	Minimum lid height	*mm*	2.5
29	42, 40, 45	Tooling costs	*SEK*	2
30	42, 40, 45	Cost to manufacture one unit	*SEK*	2
31	43, 44	Recyclable	*Binary*	2
32	43, 44, 45	Number of different materials	*Numeric*	2.33
33	46, 47, 48, 57	Easy maneuvering	*Subj.*	1.33
34	49, 50, 53, 54,56	Tool class	*Tool class*	0
35	55, 49	Time to open	*s*	2.5
36	58, 38, 40	Applicability to different products	*Subj.*	2.33

Appendix C

Table C.1 - Complete needs-metrics matrix

METRICS

NEEDS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
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NEEDS

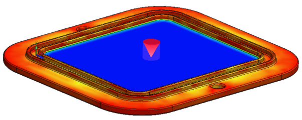
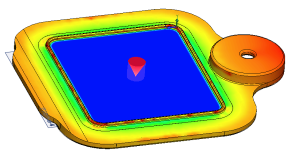
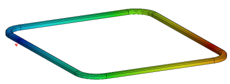
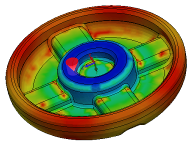
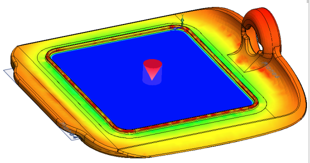
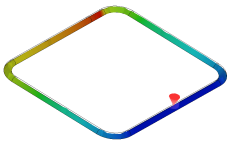
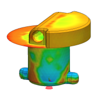
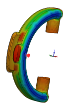
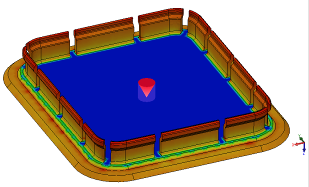
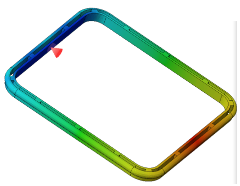
Appendix D

Table D.1 - Summary of plastic flow analysis

Concept	Sub-Part	Filling time (s)	Cooling time (s)	Mold open time (s)	Cycle time (s)	Total cycle time (s)
Concept A1	**Axial lid 1**	1.33	11.49	5.0	17.81	**17.81**
	Gasket 1	*N/A*	*N/A*	*N/A*	*N/A*	
Concept A2	**Axial lid 2**	1.34	13.17	5.0	19.51	**32.62**
	Gasket 2	0.16	2.66	0	2.81	
	Screw 2	0.40	4.90	7.00	10.30	
Concept A3	**Axial lid 3**	1.42	12.85	5.00	19.27	**59.9**
	Gasket 3	0.08	2.08	0	2.17	
	Screw 3 v. 1	*Fail*	*Fail*	*Fail*	*Fail*	
	Screw 3 v. 2	1.50	28.47	5.0	34.97	
	Ring 3	0.24	3.24	0	3.49	
Concept R1	**Radial lid 4**	0.53	5.99	5.00	11.52	**13.75**
	Gasket 4	0.12	2.12	0	2.23	
Concept R2	**Radial lid 5**	0.57	6.07	5.00	11.65	**N/A**
	Gasket 5	*Fail*	*Fail*	*Fail*	*Fail*	
Concept R3	**Radial lid 6**	0.57	5.87	5.00	11.44	**13.08**
	Gasket 6	0.09	1.85	0.00	6.64	
Concept R4	**Radial lid 7**	0.45	5.95	5.00	11.41	**N/A**
	Gasket 7	*Fail*	*Fail*	*Fail*	*Fail*	

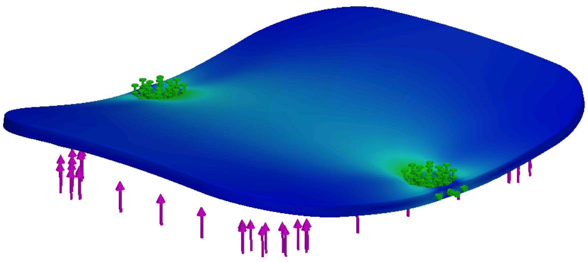
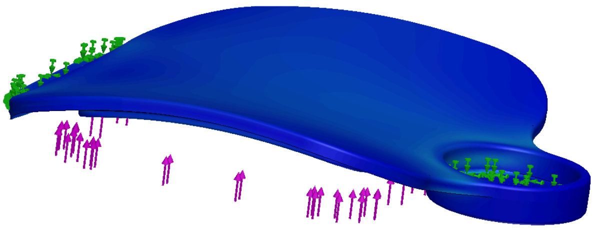
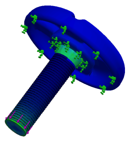
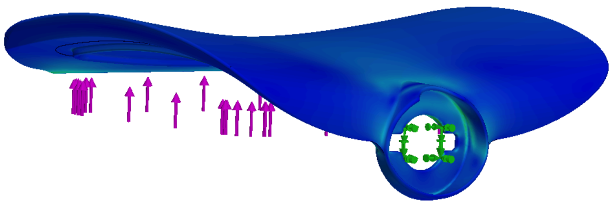
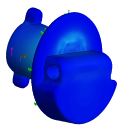
Appendix E

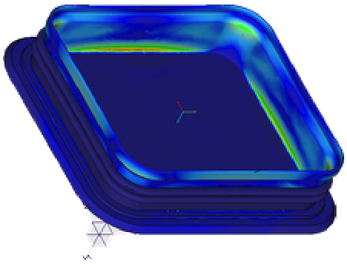
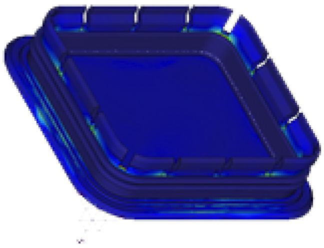
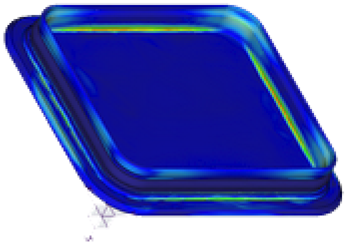
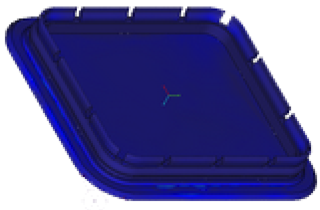
Table E.1 - Moldflow on parts in Solidworks

Concept no.	Results			OK?
	Lid	Gasket	Screw	
A1		N/A	N/A	YES
A2				YES
A3			 	YES
R1-4			N/A	YES

Appendix F

Table F.1 - Compression Force Stress Analysis Results

No:	Results	OK?
A1		YES
A2	 	YES
A3	 	YES

R1		YES
R2		YES
R3		YES
R4		YES

Appendix G

Table G.1 Final evaluation made on created concepts

No.	Metric	Unit	CB	A1	A2	A3	R1	R2	R3	R4
1	Impression	*Subj.*	9	5.6	8.2	4	7.7	7.7	7.7	7.7
2	Perceived openability	*Numeric*	10	7	9.3	5.3	6.7	6.7	6.7	6.7
3	Perceived quality	*Subj.*	8	6.5	9.3	4	8.6	8.6	8.6	8.6
4	Perceived design	*Subj.*	10	4	7.3	4	8	8	8	8
5	Locatable	*Binary*	Y	Y	Y	Y	Y	Y	Y	Y
6	Number of drops before accidental opening	*Numeric*	>5	>5	>5	>5	>5	>5	>5	>5
7	Perceived watertightness	*Subj.*	7	4.5	6.7	3.3	8.7	8.7	8.7	8.7
8	Perceived battery changeability	*Subj.*	7	7	8	5.3	8	8	8	8
9	Easy to understand	*Subj.*	8	7	8	5.3	8	8	8	8
10	Gives feedback	*Binary*	Y	N	N	Y	Y	Y	Y	Y
11	Meeting expectations	*Binary*	Y	Y	Y	N	N	N	Y	Y
12	Perceived security	*Subj.*	8	5.5	7.3	2	8	8	8	8
13	Safe opening	*Subj.*	6	5.5	7.3	2	8	8	8	8
14	IPX8 standard test	*Binary*	P	F	F	F	F	F	P	P

15	Maximum compr. force	*N*	*Unk.*	FW	FW	FW	FW	FW	FW	FW
16	Number of reseals before failure	*Numeric*	>5	>5	>5	>5	>5	>5	>5	>5
17	Maximum temperature	°C	Unk	FW	FW	FW	FW	FW	FW	FW
18	Materials theoretically withstands chemicals from chemical test	*Binary*	Y	FW	FW	FW	FW	FW	FW	FW
19	Maximum force on weakest part	*N*	*Unk.*	FW	FW	FW	FW	FW	FW	FW
20	Waterjet resistance	*Binary*	Y	FW	FW	FW	FW	FW	FW	FW
21	Splashing water resistance	*Binary*	Y	FW	FW	FW	FW	FW	FW	FW
22	Water immersion resistance	*Binary*	Y	F	F	F	F	F	P	P
23	Manufacturable	*Binary*	Y	Y	Y	Y	Y	Y	Y	Y
24	Estimated assembly time	*s*	3	2	2	3	1	1	1	1
25	Minimum temperature	°C	Unk.	FW	FW	FW	FW	FW	FW	FW
26	Lid length	*mm*	65	57	69	59	49	49	49	49
27	Llid width	*mm*	48	52	56	57	44	44	44	44
28	Lid height	*mm*	8	3	5	14	6	11	6	11
29	Tooling cost	*SEK*	Unk.	120 K	170 K	1.4 M	1.4 M	1.4 M	1.4 M	1.4 M
30	Cost to manufacture one unit	*SEK*	Unk.	11	19	34	9	9	8	9
31	Recyclable	*Numeric*	3	3	3	8	8	8	8	8

32	Number of different materials	*Numeric*	4	3	3	2	2	2	2	2
33	Easy maneuvering	*Subj.*	Y	Y	Y	N	Y	Y	Y	Y
34	Tool class	*Tool class*	H	TT	T	H	T	T	T	T
35	Time to open	*s*	7	71	50	NA	31	34	15	12
36	Applicability to different products	*Subj.*	6	8	7	6	8	8	8	8

Table abbreviations:

FW = Future work
Unk. = Unknown
NA = Not Applicable

Tool classes:

H = By hand
TT = Traditional tool
T = Tool

Appendix H

H.1 Structure for final user interviews

Question 1:

Rank the seven lids (1-5) for:
a) Impression
b) Openability
c) Quality
d) Design
e) Perceived battery changeability
f) Security
g) Waterproofness

Question 2:

How many of the 20 tools do you think can be used to open each of the seven lids?

Question 3:

Open the lid, with one of the 20 tools or by hand, and change the battery.
This step is video recorded.

Question 4:

What did you think about opening the lids?
Rank them from 1-5, where 1 is less good and 5 is more good.

Appendix I

Table abbreviations:

C1-7 = Concept Number
U1-10 = Usernumber
I1 = Openability
I2 = Quality
I3 = Design
I4 = Perceived battery changeability
I5 = Security
I6= Waterproofness

I.1 Ranking the different first impressions

Table I.1.1 - The users ranking (1-5) of first impression of Concept A1.

	U1	U2	U3	U4	**AVG.**
I1	5	2	4	3	3.5
I2	3	3	4	3	3.25
I3	2	2	3	1	2
I4	5	2	4	3	3.5
I5	2	3	3	3	2.75
I6	2	3	2	2	2.25

Table I.1.2 - The users ranking (1-5) of first impression of Concept A2.

	U1	U2	U3	U4	**AVG.**
I1	N/A	5	5	4	4.67
I2	N/A	5	5	4	4.67
I3	N/A	4	4	3	3.67
I4	N/A	5	4	3	4
I5	N/A	4	3	4	3.67
I6	N/A	3	4	4	3.67

Table I.1.3- The users ranking (1-5) of first impression of Concept A3.

	U1	U2	U3	U4	**AVG.**
I1	N/A	3	2	3	2.67
I2	N/A	2	2	2	2
I3	N/A	1	3	2	2
I4	N/A	3	2	3	2.67
I5	N/A	1	1	1	1
I6	N/A	1	2	2	1.67

Table I.1.4- The users ranking (1-5) of first impression of Concept R1-4.

	U1	U2	U3	U4	**AVG.**
I1	N/A	4	3	3	3.33
I2	N/A	4	5	4	4.33
I3	N/A	4	4	3	3
I4	N/A	5	3	4	4
I5	N/A	3	5	4	4
I6	N/A	4	5	4	4.33

I.2 Estimating the number of usable tools/ease of opening

Table I.2.1 - The users estimation of usable tools (1-20 or Hand).

	U1	*U2*	*U3*	*U4*	AVG.
A1	N/A	1	2	1	1.33
A2	N/A	13	12	8	33
A3	N/A	20/H	H	H	20/H
R1-4	N/A	7	3	5	5

I.3 User's feelings after opening the lid

Table I.3.1 - The user's ranking of concepts after opening the lids. (1-5)

	U1	*U2*	*U3*	*U4*	AVG.
A1	N/A	3	4	3	3.33
A2	N/A	4	5	4	4.33
A3	N/A	1	2	2	1.67
R1	N/A	2	2	3	2.33
R2	N/A	3	4	3	3.33
R3	N/A	4	3	4	3.67
R4	N/A	5	5	4	4.67

I.4 Information gathered from video recording

Table I.4.1 - User's success rate of opening the lid. [P/F]

	U1	U2	U3	U4	AVG.
A1	N/A	P	P	P	100%
A2	N/A	P	P	P	100%
A3	N/A	F	P	F	33%
R1	N/A	P	P	P	100%
R2	N/A	P	P	P	100%
R3	N/A	P	P	P	100%
R4	N/A	P	P	P	100%

Table I.4.2 - Required time to open the lid. [s]

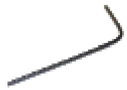
	U1	U2	U3	U4	AVG.
A1	N/A	89s	55s	70s	71.33s
A2	N/A	49s	57s	45s	50.33s
A3	N/A	Fail	75s	Fail	N/A
R1	N/A	36s	25s	32s	31s
R2	N/A	61s	17s	24s	34s
R3	N/A	20s	9s	15s	14.67s
R4	N/A	17s	7s	13s	12.33s

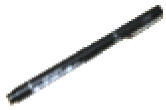
Table I.4.3 - Number of attempted tools to open the lid.

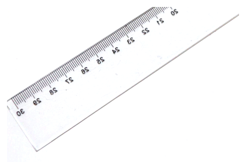
	U1	U2	U3	U4	AVG.
A1	N/A	1	2	2	1.67
A2	N/A	1	1	1	1
A3	N/A	1	1	2	1.33
R1	N/A	1	1	2	1.33
R2	N/A	2	1	1	1.33
R3	N/A	1	1	1	1
R4	N/A	1	1	1	1

Appendix J

Table J.1 - Complete list of available tools for user tests

Index:	Tool name:	Figure:
T1	Allen key #1	
T2	Allen key #2	
T3	Allen key #3	
T4	Allen key #4	
T5	Table spoon	
T6	Hair comb	
T7	Fishing knife	

T8	Teaspoon measure	
T9	Pen	
T10	Scissors	
T11	Access card	
T12	Philips screwdriver	
T13	Flat screwdriver #1	
T14	Flat screwdriver #2	

T15	Wooden butter knife	
T16	Cheese slicer	
T17	Tweezers	
T18	Ruler	
T19	Pocket multitool	
T20	Wrench	

Appendix K

Table K.1: The different qualifications for IP-classifications [18].

First digit	**Intrusion protection against foreign objects**	**Second digit**	**Moisture protection against water**
0	*No protection*	0	*No protection*
1	*≥ 50 mm diameter*	1	*Vertically falling drops*
2	*≥ 12,5 mm diameter*	2	*Vertically falling drops when capsule assumes ingress of 15°*
3	*≥ 2,5 mm diameter*	3	*Spraying water*
4	*1,0 mm diameter*	4	*Splashing water*
5	*Dust protected*	5	*Water jets*
6	*Dust proof*	6	*Powerful waterjets*
N/A	*N/A*	7	*Temporary immersion in water*
N/A	*N/A*	8	*Protected against the effects of continuous immersion in water*
N/A	*N/A*	9	*High pressure and temperature water jets*

Appendix L

L.1 Work distribution

The work distribution in the project was equally split between the team members. Both Siri Wetterstrand and Maria Bark have been involved in all activities to the same degree and worked the same amount.

L.2 Timeplan

The project was going according to the plan in the beginning, then we had some small issues with part deliveries which resulted in the project being pushed into the Christmas break. However, the project was finished in time anyways.

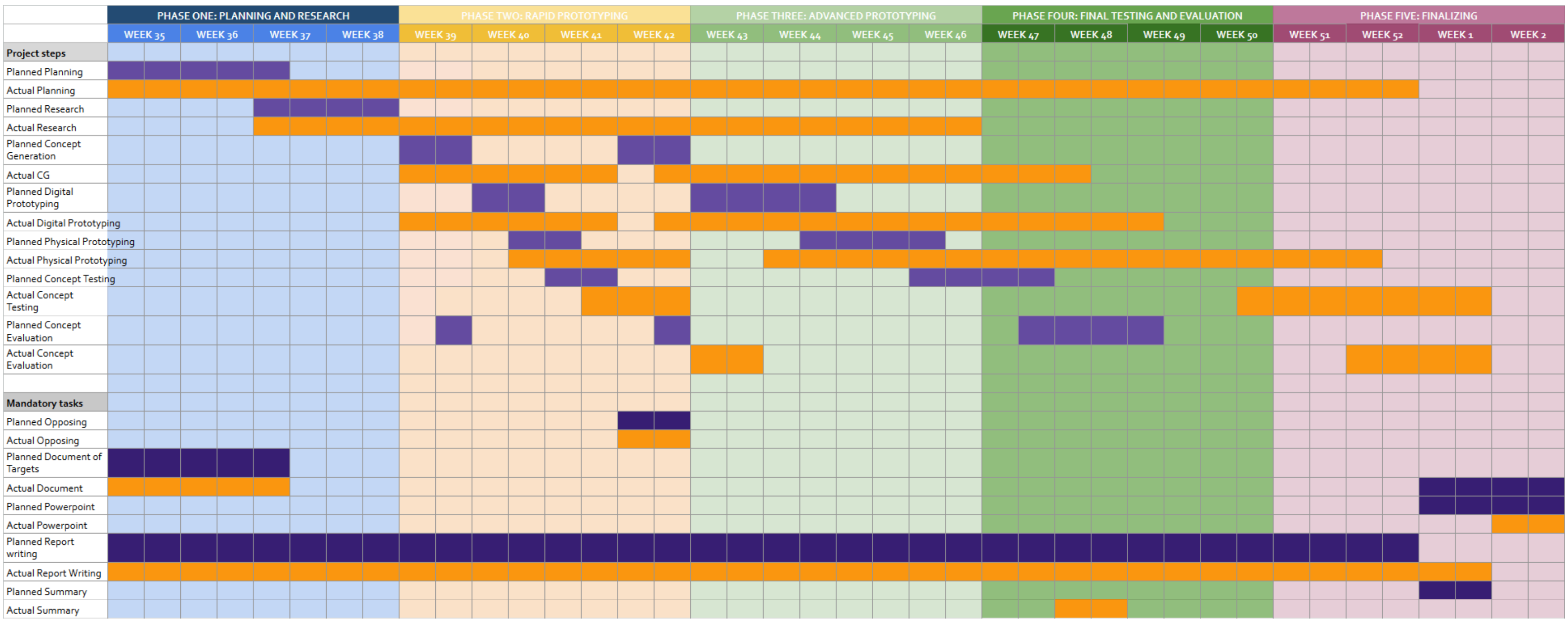


Figure 65: *The original plan (Purple) and the actual project (Orange).*

Appendix M

Importance	Need statement	Weight	Ziplock score	Maria zipper	Hasp/lås expander	Pluggish	Traditionell skruv	Slider	Snapfit	Mjuk baksida	Fjädring i låset
***	The lid is realizable	13.04%	4	2	3	4	5	4	3	2	2
*	The lid is cheap	4.35%	4	2	1	4	3	4	3	3	2
**	The lid is of an appropriate plastic	8.70%	2	1	3	2	3	3	3	2	2
***	The lid is intentionally opened	13.04%	4	4	4	2	5	3	4	3	4
***	The lid is resealable multiple times	13.04%	5	5	5	5	4	5	3	3	4
***	The lid will protect against immersion in water	13.04%	4	1	1	4	5	3	4	4	3
***	The lid is openable	13.04%	5	3	5	4	3	5	3	2	4
*	The lid is easily opened	4.35%	4	5	4	4	2	4	2	2	3
**	The lid size is efficient	8.70%	5	2	2	3	3	3	3	4	3
**	The lid fits different products	8.70%	4	1	1	3	5	4	2	2	3
		SUM:	41	26	29	35	38	38	30	27	30

Figure 66: *Scoring matrix for concept selection in the first iteration.*