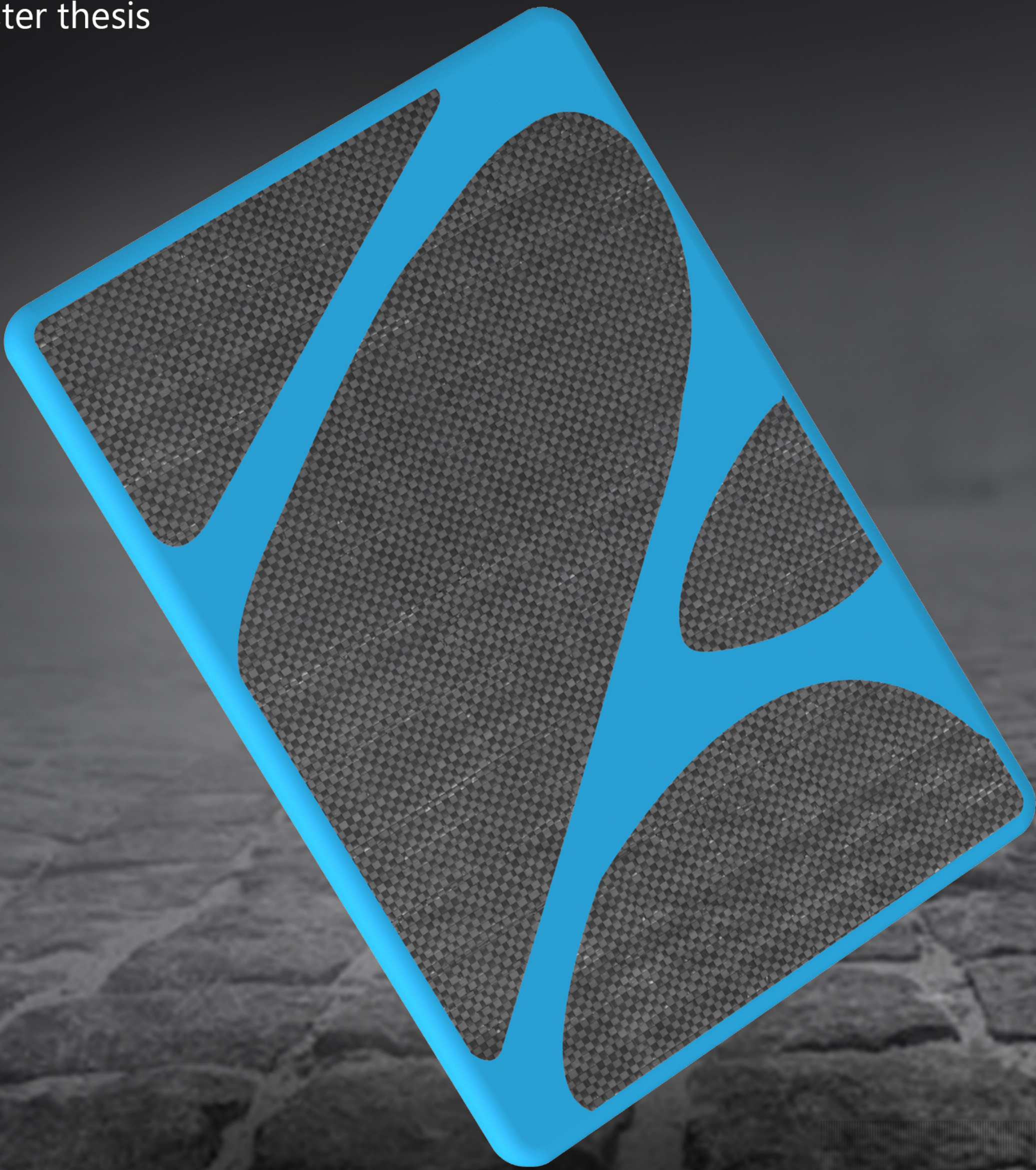
# Designing a recyclable impact resistant tablet cover

Master thesis



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# Gecko Dynamic:

# Designing a recyclable impact resistant tablet cover

# Executive Summary


This thesis looks into the application of self-reinforced polypropylene (SRPP) in a tablet cover for the company Gecko Covers.

Gecko Covers is a company that provides protection for devices in the form of covers and sleeves. They are performing at their best in the tablet market. Gecko would like to enter the impact resistant tablet cover market using an impact cover that is both impact resistant and stylish. Their product style is characterized by the usage of contrast in both material texture and color, simple shapes and an attention to detail. Based on a market analysis, the tablet user on the go is selected as target group. These people carry their tablets with them wherever they go. To differentiate from the current competitors in this tablet market segment, Gecko has to focus on reducing the environmental impact of the new cover by e.g. making it recyclable.

The most important material properties for the impact cover are high toughness, low density and a minimum ductile-to-brittle temperature of -20 °C. Not only does SRPP meet these requirements, it is also recyclable as it is only made out of a single type of thermoplastic. The manufacturing process of producing laminates out of woven SRPP influences the material properties such as impact resistance. Literature research shows that a combination of hot compaction and film stacking improves the impact resistance of the SRPP laminate the most. The values of the other parameters which influence the material properties of the laminates were determined through trial and error. To evaluate the SRPP laminates, a bending fatigue test and an alternative Izod impact test were conducted. In the end, the laminates with a compaction temperature of 170 °C, a pressure of 1,73 bar, an active heating time of 5 min and 1 PP film layer in between the SRPP fiber layers are the toughest and most ductile.

The focus of the design was on a minimum viable product. A back structure inspired by those of suitcases, the screen edge, the corners and the regular edges of the cover were all taken into account. In order to validate that the shape is manufacturable from SRPP, a proof of concept was made with a mold. Furthermore, this proof of concept was tested via a drop test to get more information about the actual performance of the SRPP layer and to determine which orientation results in the highest impact resistance. The drop test showed the importance of the screen edge, which was missing from the proof of concept as it cannot be made out of SRPP. The test also showed that the SRPP lacked damping. To add the screen edge and improve the damping of the product, the back structure and an additional inner layer are injection molded with PP. The final design was inspired by natural Voronoi structures which creates a contrast in material texture and color, matching the current style of Gecko Covers (see figure 1).


Figure 1: Gecko Dynamic.

# List of abbreviations

| | |
|---|---|
| DBTT | Ductile-to-brittle temperature |
| FGP | Functionally graded polymer |
| HFRP | Hybrid fiber reinforced polymer |
| MT | Metric Ton |
| MVP | Minimum viable product |
| NFRP | Natural fiber reinforced polymer |
| PC | Polycarbonates |
| PE | Polyethylene |
| PET | Polyethylene terephthalate |
| PLA | polylactic acid |
| PMMA | Polymethyl methacrylate |
| PP | Polypropylene |
| PVC | Polyvinyl chloride |
| SRP | Self-reinforced polymer |
| SRPE | Self-reinforced polyethylene |
| SRPET | Self-reinforced polyethylene terephthalate |
| SRPP | Self-reinforced polypropylene |
| TFRC | Tranditional fiber reinforced composites |
| TPU | Thermoplastic polyurethane |
| UAG | Urban Armor Gear |
| USP | Unique selling point |

# Acknowledgements

This graduation project would not have been possible if it wasn't for all the support that I received along the way. I would like to thank the following people:

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My graduation bird is finally taking flight.

# Table of contents

**1. Introduction** **12**

**Part 1: Current situation** **15**

**2. Stakeholders** **16**
**3. The company: Gecko Covers** **20**
3.1 Brand identity 21
3.2 Product portfolio 22
3.3 Unique selling point 26
**4. Potential competitors** **28**
4.1 Impact cover market 29
4.2 Differentiation strategy 33
**5. Target group** **36**
5.1 Perception impact resistance 37
5.2 User characteristics 49
**6. Design criteria** **57**

**Part 2: Material Exploration** **60**

**7. Material selection** **61**
7.1 Material requirements 62
7.2 Reinforced polymers 64
7.3 Self reinforced polymers 68
**8. Material tinkering** **70**
8.1 Material variables 71
8.2 Making laminates 1 75
8.3 Making laminates 2 80
**9. Material evaluation** **84**
9.1 Fatigue bending test 85
9.2 Izod impact test 93

Part 3: Application 98

**10. Form ideation 99**
10.1 Inspiration 100
10.2 Directions 102
**11. Concept detailing 108**
11.1 Proof of concept 109
11.2 Drop test 112
11.3 Style 118
**12. Embodiment 125**
12.1 Final concept 126
12.3 Evaluation 130

**Discussion & Recommendations 131**
**References 132**

The Appendix is included separately and consists of:

A. Orginal design brief
B. Current market analysis
C. User test guide
D. User test transcripts
E. Questionnaire results
F. Technical drawings iPad 10,5”
G. Original bending cycles data
H. Adjusted setup Izod impact test
I. Results brainstorm Gecko Covers
J. Technical drawing mold
K. Structure ideation
L. Technical drawings back design

# 1

# Introduction

The aim of this chapter is to introduce the scope and goal of this graduation project

Figure 2: Falling tablet (Gizmoslip, 2018).

## Introduction

Smart devices such as tablets and smartphones are becoming thinner and sleeker (Leiva-Gomez, 2017). This results in better portability and increased user comfort, but simultaneously makes the products less durable. For the tablet specifically, the large glass display is the most fragile part (Williams, 2019). Many consumers therefore add protection by the means of a tablet cover. These users can be divided into two groups: the people who favor aesthetics over function and vice versa. This results into the book cover, which is thin and fashionable, versus the rugged cover, which is bulky but protects the device better (see figure 3). There is no alternative type of tablet cover available.

Gecko Covers, the partner company in this project, wants to enter the tablet impact covers segment by providing a stylish impact cover. They are known for their covers and sleeves for tablets, smartphones, eReaders and laptops. However, they perform best in the tablet market which is why they would like to enter a new tablet cover segment.


Figure 3: Examples book cover (left) and rugged cover (right).

## Design brief

Before the start of this graduation project, a design brief was set up to determine the goal, scope and planning for the project. The original design brief can be seen in appendix A. After some initial research, the following problem statement was defined:

*How to design an affordable tablet cover that is high impact resistant and recyclable, but still slim and stylish. The product should distinguish Gecko Covers from its competitors and fit in their current product line.*

Based on a brief analysis of the competitors which is elaborated in chapter 4 (competitors) and initial impact material research (see chapter 7 for all the research), it has been decided to focus on developing a reinforced polymer which is high impact resistant. With this new material an impact tablet cover will be designed while considering recyclability.

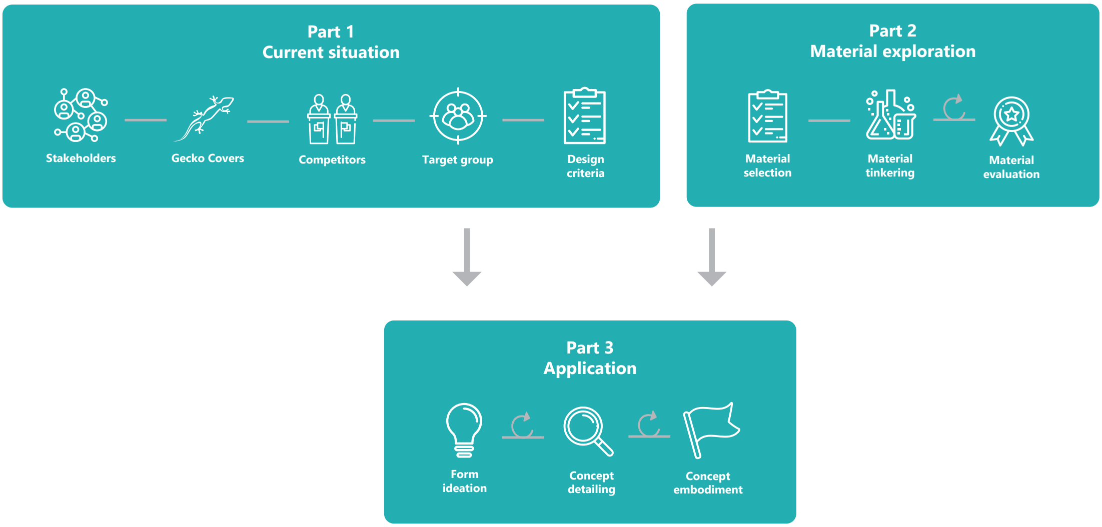



Figure 4: Applied design process.

**Process**

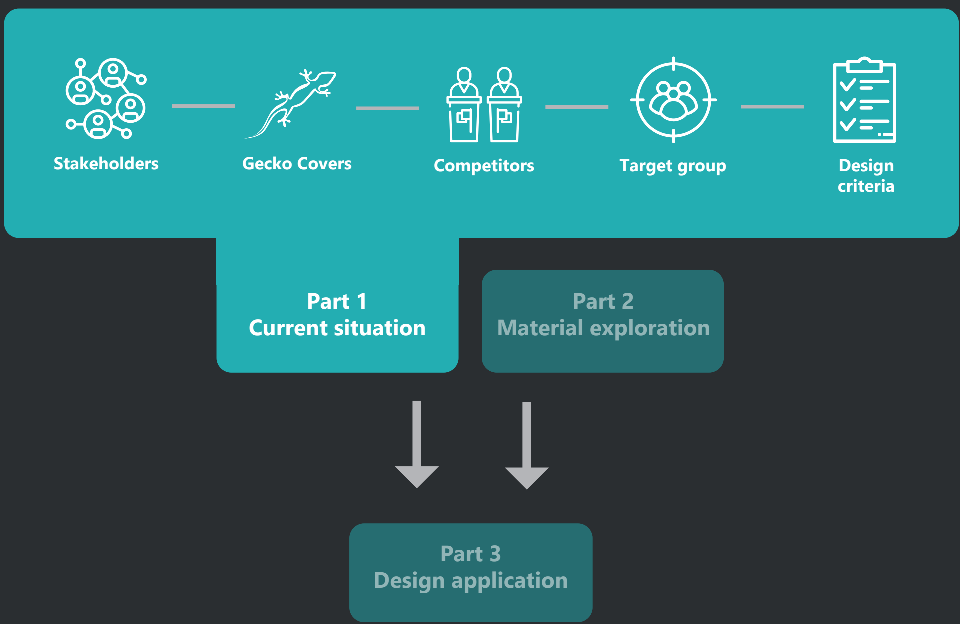
Figure 4 shows the process that was used during this project. Because the focus of this project is both on the design of the cover and the development of the new material, the process was a bit different compared to other design projects. It mainly consisted of three parts: an analysis of the current situation, a material exploration and the application of the findings of parts 1 and 2 in the design process.

Parts 1 and 2 were done in parallel, as they were not related to each other and were needed as input for the ideation on how to use structure and shape to improve the impact resistance of the material. Some parts had iterative steps, such as the material tinkering and concept detailing. These can be recognized by the circular arrows. To remind the reader of the different parts and the relation between them, there will be an introduction of the part before the corresponding chapters will be presented.

Each chapter will end with take always that are presented in a grey box. These are the main conclusion from the chapter, along with some aspects that were taken into account during the process.

# Part 1
# Current situation

To find the stakeholders that must be considered, an stakeholder analysis was done (chapter 2). The most important stakeholders are then selected and further looked into, which are the company Gecko Covers (chapter 3), the competitors in the impact tablet market (chapter 4) and the target group (chapter 5). Based on the overall findings, the design brief is reformulated and design requirements are defined in Chapter 6.



# 2

# Stakeholders

In this chapter, the different stakeholders are identified through a product life cycle. Then the influence which the stakeholders have on the product and vice versa are analyzed. Lastly, the most important stakeholders are selected.

Figure 5: Puzzle pieces (Alpha Coders, n.d.).

**Relevant stakeholders**

A product life cycle analysis has been used to get an overview of all the factors and stakeholders currently involved with the tablet cover (see figure 6). The product life cycle consists of eight phases with certain stakeholders connected to each phase. However, it does not show which stakeholders are more important than others. To establish that, the influence of each stakeholder in relation with the product was further analyzed (see figure 7).

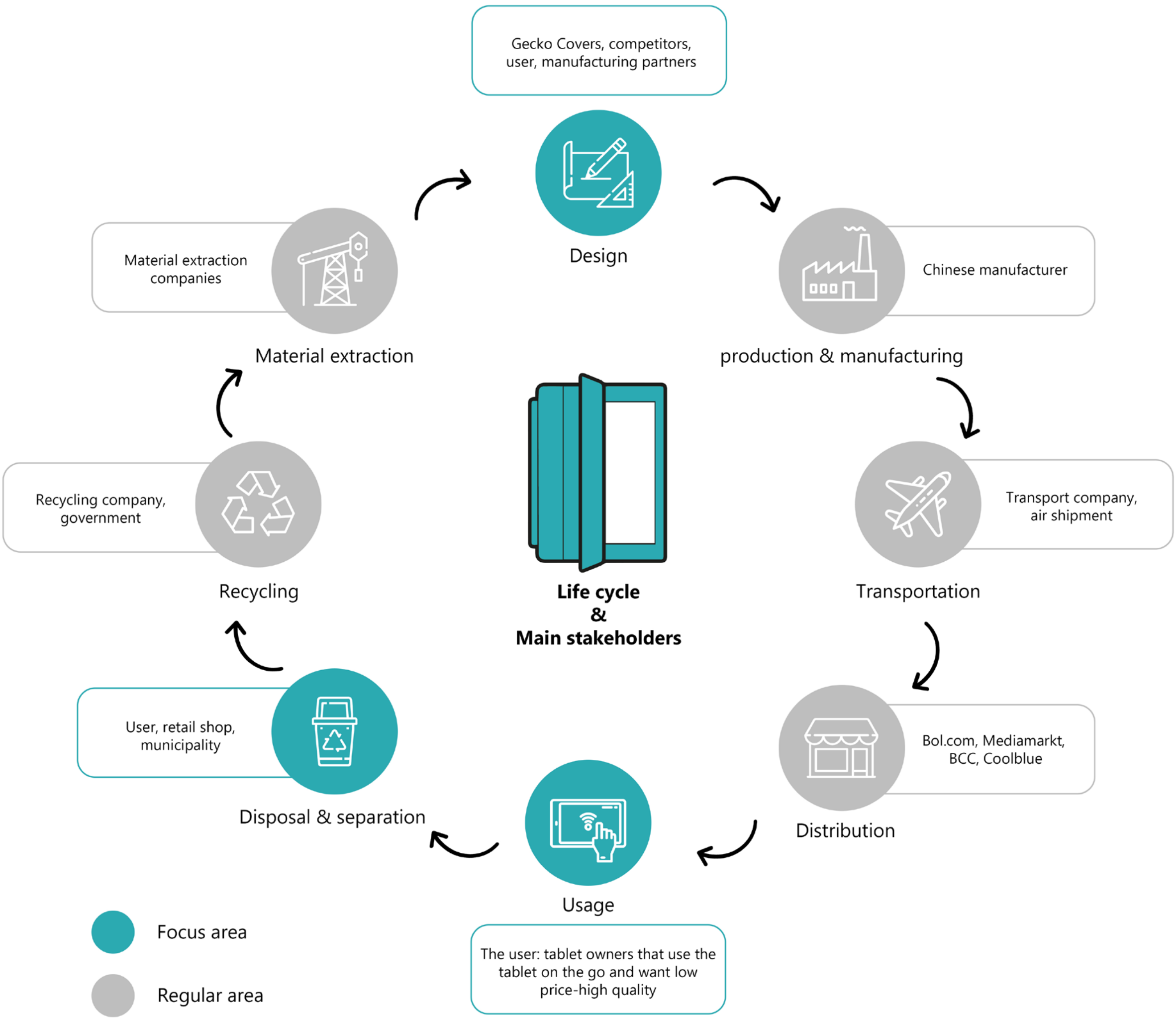



Figure 6: Life cycle analysis.

The stakeholders are divided into one of the following groups:

- *Main stakeholders*
  The main stakeholders have a direct influence on the product and the product has a direct influence on the stakeholders. An example is the company Gecko: they decide how the product will be designed and the product enables them to enter a new market.
- *Influencer*
  The influencers have a direct effect on the product, but the product has no effect on these stakeholders. The competitors influence the market segment the new product will target, but the product will not directly influence the competitors.
- *Affected*
  The decisions made concerning the product will influence this type of stakeholder, but not the other way around. For example, the choices made in material and manufacturing will influence the manufacturing partner as they will produce the product. However, the current manufacturers do not limit the production options, as partnering with a new manufacturing partner is also an option.
- *Big corporates/organizations*
  Lastly there are stakeholders that have no direct influence on the product and are mostly bigger corporates or organizations. Examples are the government, which can make rules concerning recycling that will indirectly influence Gecko, or the material extraction companies that mine the materials regardless of the application of it.

The influencers and main stakeholders are the most important as they have a direct influence on the product (dark blue). The affected stakeholders will be important in a later stage of the project, when concept details need to be thought out. They are direct stakeholders, but irrelevant at the moment (light blue). The big corporate or organization stakeholders influence the product indirectly and are therefore irrelevant (grey).

When looking back at the life cycle analysis, the direct and relevant stakeholders are located in the main focus areas which are highlighted. The design phase is the whole project, as a new product will be designed and embodied. The usage area is important as Gecko is targeting a new market with a new target group which needs to be further analyzed. The last highlighted phase is the disposal & separation area. This area does not contain relevant stakeholders, but because sustainability, recycling and reducing impact are all actual and important topics, it has been selected. Also, it is expected that it can be used to help Gecko distinguish themselves from competitors. To gain more information on the relevant stakeholders, a more in-depth analysis of the company, the competitors and the target group will follow in the next chapters.

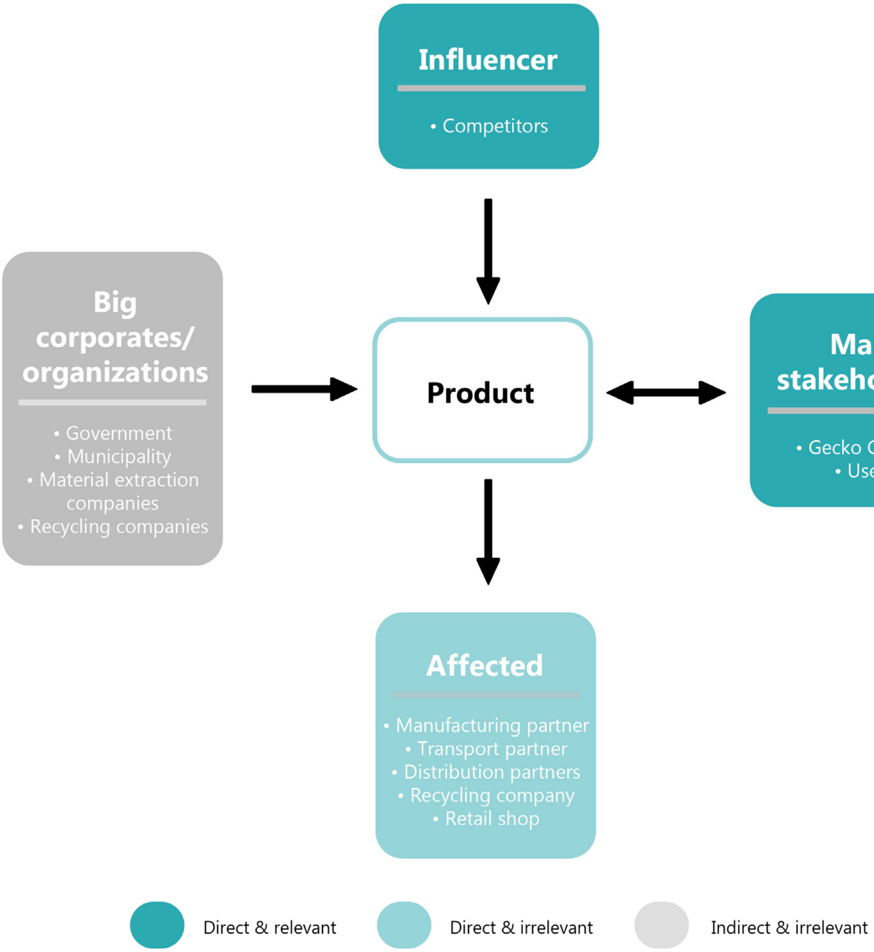



Figure 7: Stakeholder influence overview.

*Note: This figure is not based on any theory or existing model.*

The main focus areas of the project will be the design, usage and disposal & separation phases of the product life cycle. The main stakeholders are the company Gecko Covers and the user, as the product has a direct influence on them and vice versa. However, some choices will influence other product life cycle phases with the corresponding stakeholders, such as production and manufacturing partners. These are called affected stakeholders and are important in a later stage of this project. Lastly, influencer stakeholders are the competitors who are already in the impact cover market and determine the market segment that Gecko Covers will target with the new product.

# 3

# The company: Gecko Covers

This chapter focuses on the partner of the project, Gecko Covers. Firstly, the brand identity is analyzed to determine which brand characteristics need to be conveyed. Then the product portfolio is analyzed to see how the new product can fit in and what style it should have. Lastly, by comparing Gecko with the current competitors the brand USP is determined.

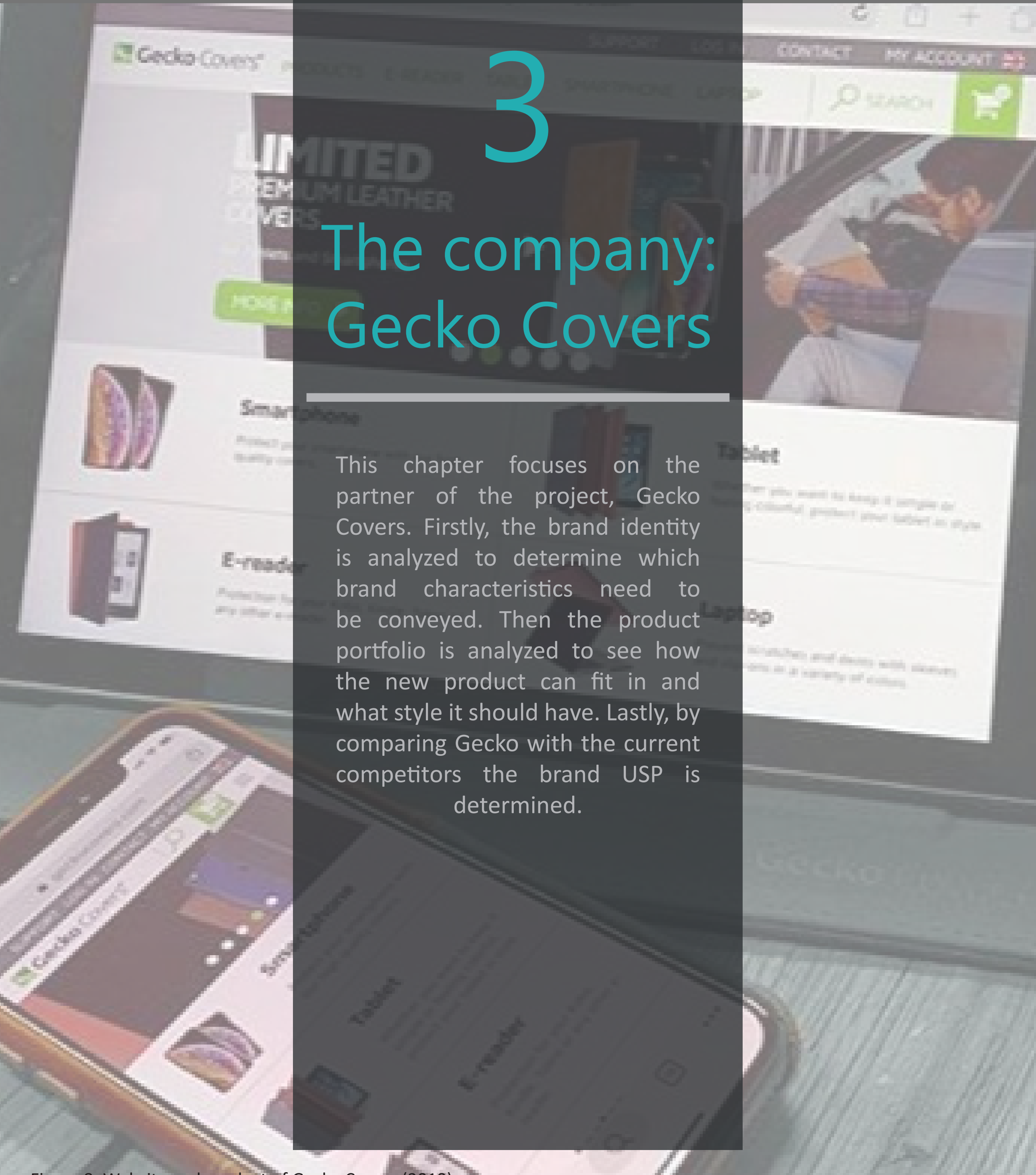



Figure 8: Website and product of Gecko Covers (2019).

Gecko Covers is part of the main company Telco Accessories, which is located in Houten. Gecko provides protection for devices in the form of covers and sleeves and they are strongest in the tablet cover market.

Before going into the analysis of Gecko, it is important to distinguish between brand identity and brand image. Brand identity is how the brand presents itself to the consumer, and how it would like to be perceived (Kimbarovsky, 2020). On the other hand, brand image is how the consumer actually perceives the brand (Murphy, 2019). This can differ from the brand identity, when the company and the consumer do not see things in the same perspective or because of other factors influencing the brand image.

The brand image was discussed with the company and they mentioned that the brand stands for a good price-quality ratio and is cheerful. This is reflected in their slogan which can be found on their website: ”Quality. Price. Perfect fit.” (see figure 9). The gecko in their name and logo stands for the cheerfulness, as the small animals come in different sizes and color combinations, just like the Gecko protective covers. Beside the slogan, a motto is mentioned: “Appearance does matter”. This gives the impression that the products of the brand are stylish. Based on the website, the brand seems young, bold and simplistic to me.

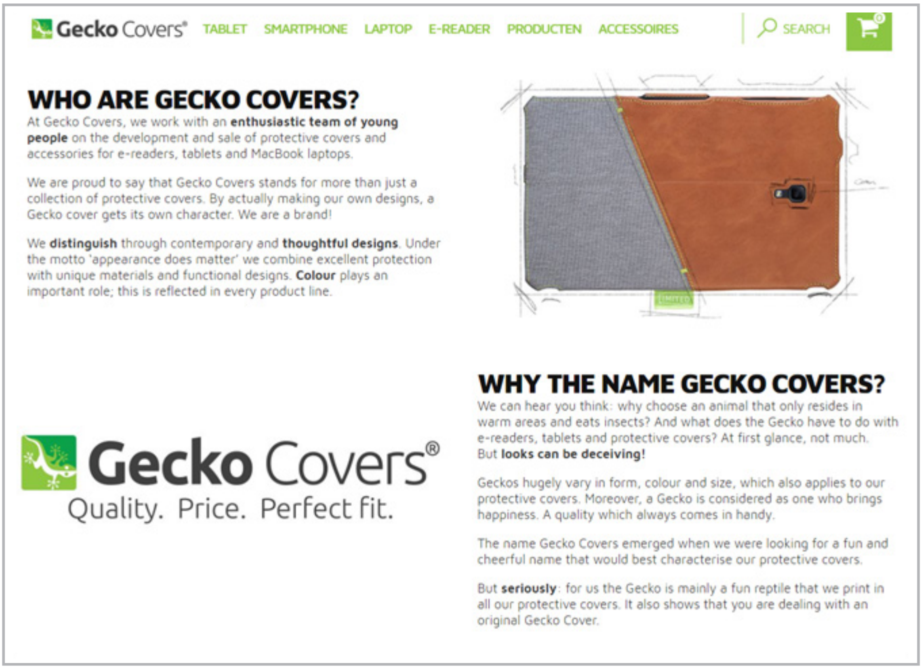



Figure 9: The about us page on the Gecko website (Gecko Covers, 2019).

# 3.2 Product portfolio

**Product lines**
Only the tablet covers have been taken into account for the analysis of the product portfolio, excluding the eReaders, smartphones and laptops as these are not in the scope of this project. Gecko has the following tablet cover lines:

- Gecko Easy-Click (Gecko ColorTwist is a part of this line)
- Gecko Limited
- Origami Covers
- Keyboard Covers

Figure 10 gives an impression of the product lines. Gecko Easy-Click ColorTwist is branded as the more fun, bold and trendy tablet cover. Gecko Limited is the more luxurious product line targeted at business people. The Origami Cover is branded as portable and usable in countless situations, which is similar to the Keyboard Cover. They seem to target people who travel.

Gecko mentions on their website that color is an important aspect of their brand and visible in every product line. However this is not the case, which is a bit confusing. The company explained that this is because even though people mention that they would like to see some color in a tablet cover, the black and dark colored covers sell the most. Gecko wants to add color or a different kind of twist to these products to make a more coherent product portfolio, but they have not yet figured out a way to do this within their current style. Adding a highlight color to black makes it often sporty or gamey, which is not their aim.

A strategy of the brand is not to focus on the premium tablet brands only. However, they do start new product lines with Apple and Samsung products because of the demand. Therefore, the focus of this project will be on designing a cover for an Apple iPad. The product availability for the second tier tablet brands are also based on demands. This means that the different tablet brands do not have the same amount of Gecko products available. For example, Gecko sees the sales of Huawei going up, which means that they are planning on making the Origami or the Easy-Click ColorTwist available for that tablet brand.

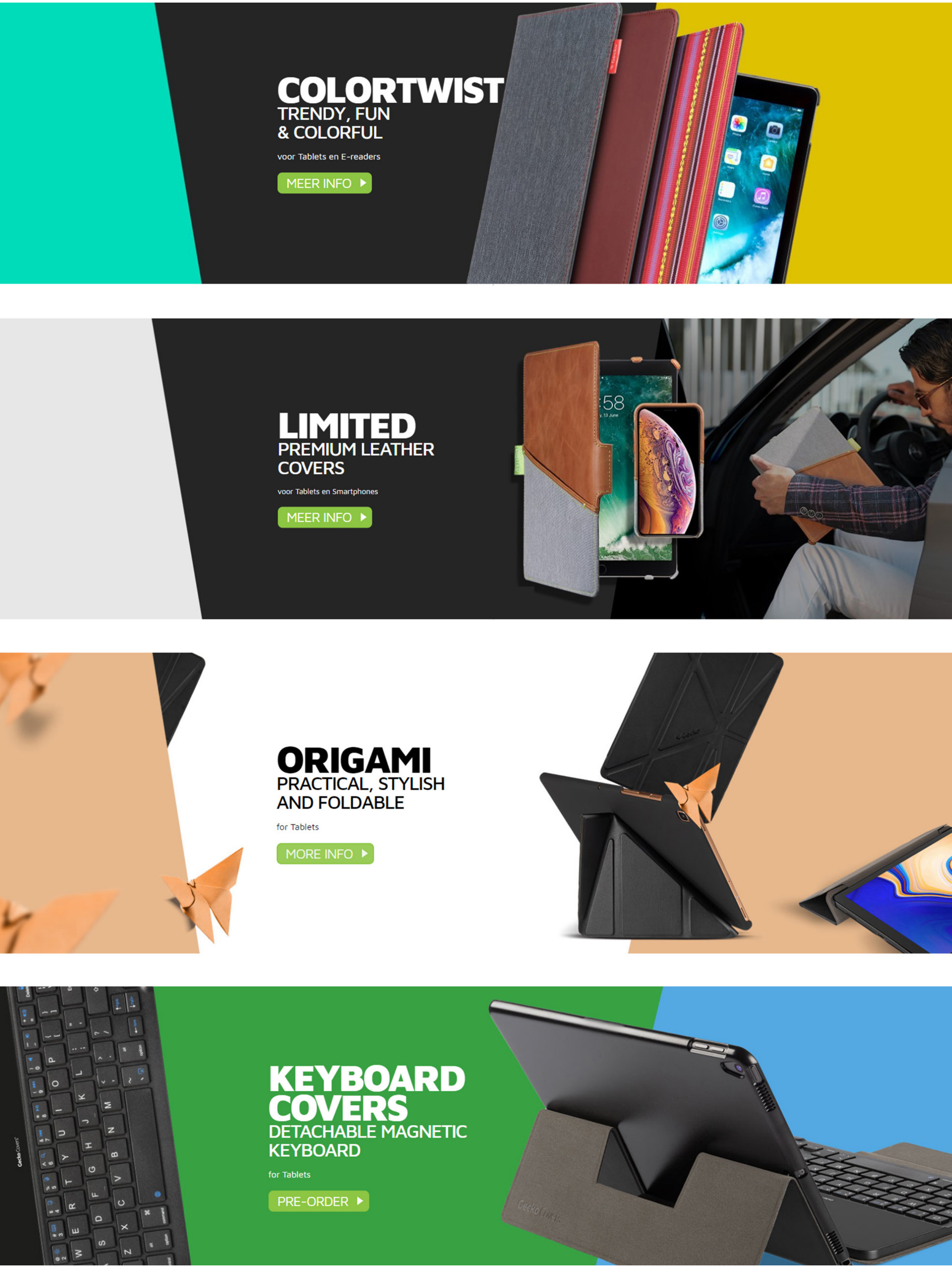


Figure 10: Gecko product lines.

**Product style**

As there is not a coherent product style yet, the focus will therefore be on the styles of the Gecko Easy Click ColorTwist and Gecko Premium. These two product lines are the only ones with color, show a bit of character and fit the brand identity the most.

Figure 12 gives an overview of the styling. In general, Gecko uses two different textures: smooth and rough. These two textures are then emphasized by using two different colors, a bright and darker one. Most of the time the two different materials are textile and (synthetic) leather. Details such as stitches are made and colored in such a way that they pop out. Most of the products have straight lines in the design and are in general simple and stylish. However, the two sublines have additional characteristics:

- The ColorTwist seems young, bold and trendy. This is mainly because of the highlight colors and the use of prints. To make the product line more unique, the company launches a limited edition every year with a certain theme and print (see figure 11).
- Gecko Premium on the other hand is a more expensive product line with premium leather. It gives off a more luxurious, serious and business-like vibe. Nonetheless, Gecko still applied the twist by adding another texture and using a highlight color for the stitches. This makes the product a bit more playful and less serious compared to other business tablet covers.

Figure 11: Limited edition EasyClick ColorTwist.


Figure 12: Overview product styling.

## 3.3 Unique selling point

According to Gecko, their main target group for their current tablet covers are the mainstream buyers: they buy a cover for the first time or they are not fans of the expensive brands, such as Apple and Samsung. Based on a current market analysis (see appendix B), the current main competitors of Gecko are Tucano and Just In Case. These brands are selected because they are in the same market segment as Gecko. Figure 13 shows example products of these competitors.

Gecko's USP compared to the other two brands is their focus on detail. This makes Gecko a stronger brand, as it seems to the consumer that the products are made with more care. Tucano does not use real stitches on their tablet covers, but punches the details on the cover. These details won't last as long as real stitches. Additionally, real stitches look more authentic. The other main competitor, Just In Case, uses one mold for all same size tablets. This causes the buttons not to be aligned correctly with the available holes. Gecko on the other hand uses different molds for each tablet model and tablet brand. Since the focus on detail is what makes Gecko currently stand out, it is important to pay attention to details while designing the new cover.

Gecko Covers stands for a good price-quality ratio and cheerfulness. Different material textures and a combination of bright and calm colors are used to create a high contrast, which is characteristic for Gecko's products. This makes the brand seem young, bold and trendy. At the same time the products are stylish and have simple lines and shapes. Gecko's USP is their focus on details, which makes the product a coherent whole. Lastly, the new cover will be designed for an Apple iPad, as Gecko starts with the premium brands when introducing new product lines.


Figure 13: Example tablet covers Tucano and Just In Case.

# 4

# Potential competitors

Gecko wants to enter a new market segment. Therefore, it is important to find out which competitors are within the market and how Gecko should position itself strategically. Lastly, there will be looked into how Gecko can distinguish themselves from the other brands.

Figure 14: Chess pieces (Chess.com, 2019).

**Main players**

Based on which brands Gecko considers to be their future competitors, along with a market research on the websites of the retailers which offer Gecko Cover products such as Mediamarkt and Bol.com, six main competitors were found. Figure 15 gives an overview of these brands along with one of their main products known for high impact resistance.

As can be seen, most impact resistant covers look alike. They have mainly protection on all sides and are black. The two brands that do stand out are UAG and Tech21. UAG is known for their association with the military, as they use a more industrial look and promote their products with the military standard drop test. Tech21 stands out by doing the exact opposite of all the competitors. They have a thin tablet cover and the product is completely transparent. This makes it possible to still see and feel the design of the tablet, which is why Apple sells and promotes Tech21 in their Apple stores. Tech21 also uses their own material called BulletShield™, which is an impact absorbing material designed originally for bulletproof glass (Businesswire, 2016). The most used materials by the other brands are Thermoplastic Polyurethane (TPU) and Polycarbonate (PC). Some tablet covers also have a built-in screen protector.

To set Gecko apart from the competitors, the focus will be on a new material which will become the USP of the new product. Another USP will be the current style of Gecko, as this is very different compared to the existing impact tablet covers. Most impact covers are bulky and black, which means that a more colorful and slimmer cover will stand out.

**Potential market position**

Now that the future main competitors are defined, it is important to see how the current impact resistant tablet cover market is structured. Because the design of the covers is mainly the same, the target group and price class are analyzed of the six main competitors. Figure 16 shows an overview of the market, along with the advised position Gecko should try to aim for.

Mainly three different user groups are targeted by the impact cover brands:

- The people who like extreme sports or activities like snowboarding, surfing and hiking.
- The people who are on the go such as going to work, traveling or doing outdoor activities, like camping and biking.
- The people who just live their normal daily lives and do average things, including short trips such as city trips.


Figure 15: Product overview of impact competitors.

Because Gecko Covers wants the new product to be in the same price category as their Gecko Premium Line which is around €60,- to €70,-, the brands Lifeproof and Catalyst are not considered competitors. They have more expensive products that are dust-, water-, snow-, and dirtproof. Also, Gecko Covers is not considered a sporty or extreme brand. The other segment Normal day consists of Tech21. This brand was known for its tablet protection, but has now shifted more towards the smartphone covers. Due to the fact that there is only one brand in this segment which has shifted away from tablet covers, it is assumed that there is little demand for an impact cover in the Normal day segment.

The most promising segment for Gecko seems to be Life on the go. In general the tablet covers in this market segment are less extreme looking and thinner than the impact cases of the Extreme sports/outdoor activities market segment. This segment therefore fits the type of tablet cover which Gecko wants to develop: a tablet cover which has a balance between impact resistance and aesthetics. The two main competitors are Otterbox and Griffin. Otterbox has a more heavy duty look compared to Griffin. However, the brand targets people who do non extreme outdoor activities, such as camping and travelling in their daily lives (see figure 17). Griffin is branded similar to Otterbox, but their impact cases are in general more stylish. Griffin is therefore a bigger threat to Gecko than Otterbox. To differentiate Gecko from Griffin, the needs and the behavior of tablet users on the go have to be further analyzed.

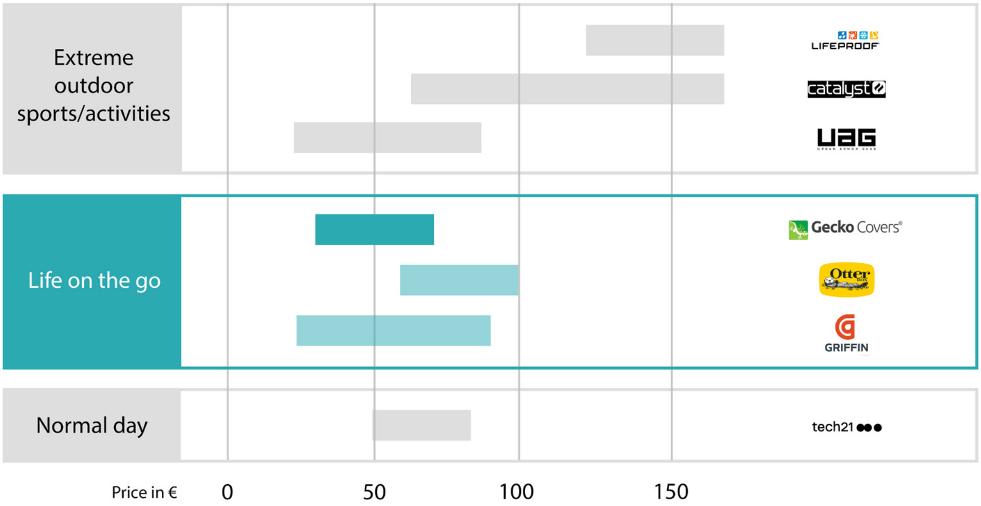
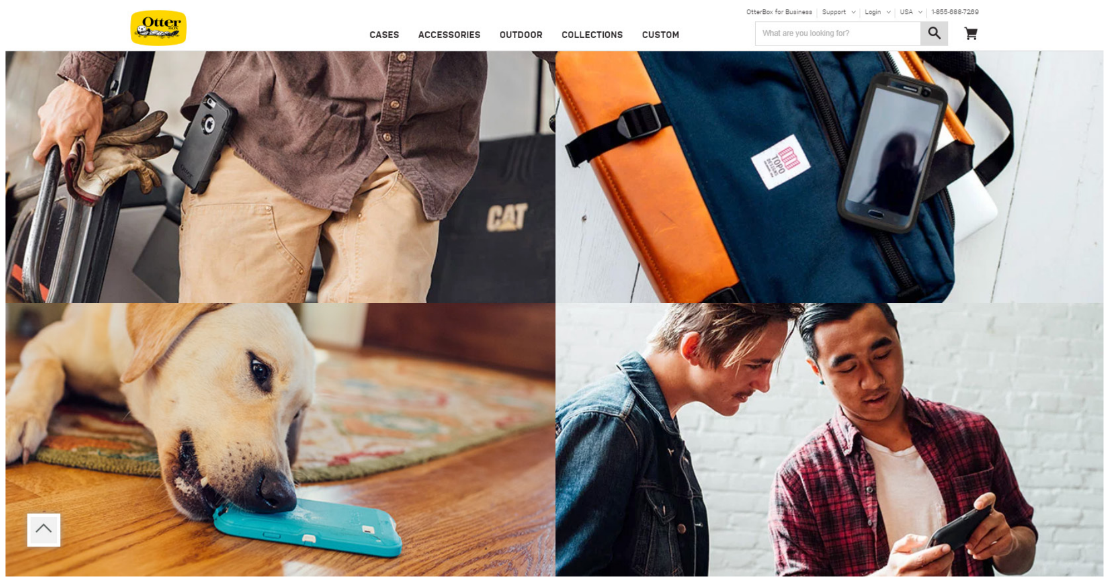



Figure 16: Current impact cover market.



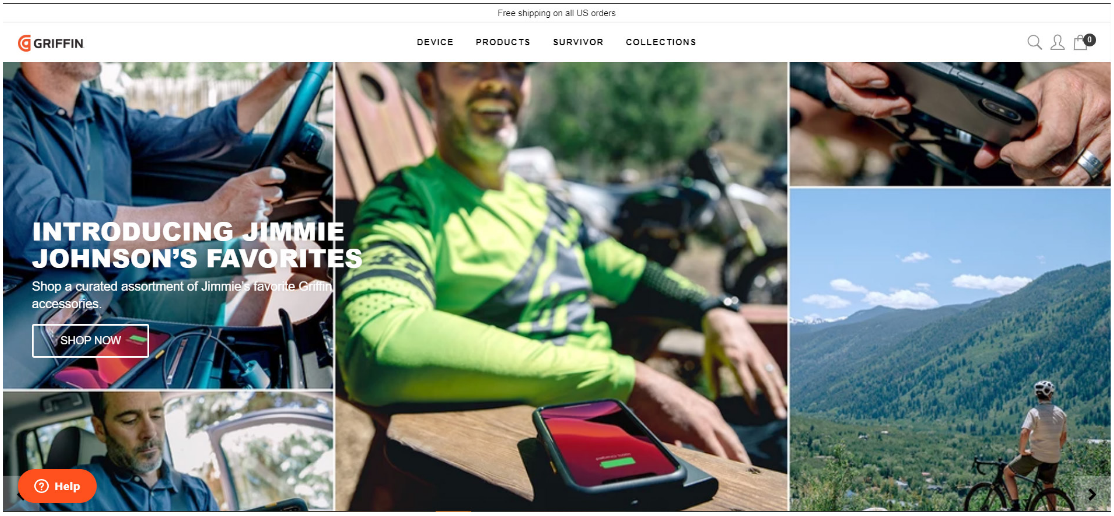




Figure 17: Branding of Otterbox (top) and Griffin (bottom).

# 4.2 Differentiation strategy

**Trend**

Adapting to emerging trends can also help to stand out amongst the competitors of tablet impact covers. An upcoming trend is sustainability. Consumers and companies are becoming more aware of their impact on the environment and want to minimize this. In this subchapter there will be looked into what tablet cover brands do concerning sustainability and where the opportunities lie for Gecko.

**Impact cover brands**

In general, the impact cover brands try to improve one or multiple stages of the life cycle of tablet covers. Otterbox mentions that they are at the beginning stage of managing their environmental footprint and are mainly looking into how to improve the life cycle of their products (Otterbox, 2019). Their products are one of the few that have separate parts with different materials, which makes it easier to recycle compared to covers using mixed materials. UAG also mentions that their cases are recyclable, but do not elaborate on how to separate the PC and TPU parts of their covers (UAG, 2019).

Tech21 on the other hand is working on plant based materials. They have already replaced 30% of their materials with the plant based alternatives (Tech21, 2020). However, it is not mentioned what type of material this is.

**Other cover brands**

Aside from the main players of the impact tablet cover market, other tablet and smartphone cover brands are looking into sustainability as well. The Finnish brand Lastu uses wood from Finland that supports sustainable development and are not endangered (Lastu, n.d.). They looked into other natural materials they could use, and came up with salmon skin from Iceland for cardcases on the smartphone covers (see figure 18).


Figure 18: Salmon skin cardcase on wooden smartphone cover (Lastu, n.d.).

The brand Pela Case is working with flax shave and a plant based biopolymer (see figure 19). They make it possible to use your old Pela cover as compost in your own garden. If you don't want to use it as compost, they have a recycle program where new products will be made out of the old material.

Lastly, the brand Native Union has a product which is made out of Jesmonite which is known for its durability and impact resistance (see figure 20). It consists of a gypsum-based material in an acrylic resin. It is not a bio-resin which is made out of biobased materials but an eco-resin, because it is water based and non-toxic (Casting About, n.d.). This shows that there are more sustainable alternatives to materials that are currently being used, which don't have to be fully sustainable but are a step in the right direction.


Figure 19: Flax shave and plant based polymer cases (Pela Case, 2020).

Figure 20: Jesmonite case (Native Union, 2020).

**Opportunity**
Not all the impact tablet cover brands are currently improving the sustainability of their products. By improving one of the stages of the life cycle of the new product, it can lead to a head start for Gecko in the impact cover market. As mentioned in 4.1, to gain competitive advantage the focus will be on selecting and/or developing a new material. There are many ways to measure the impact of the material throughout its life, for example through energy consumption or $CO_2$-emission. However, many aspects have to be taken into account to get an complete overview and not all data is available or of good quality (Kozderka et al, 2015). Gecko has not focused on sustainability before and therefore recyclability of the new material is considered a good starting point. If it is not possible to make the cover out of a single material, the different parts should be separable.

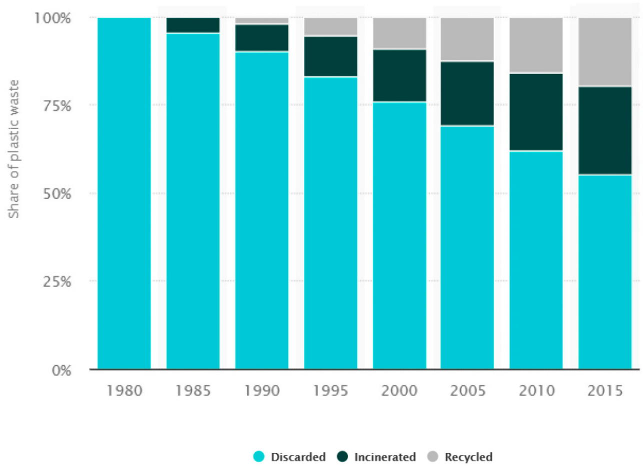



Figure 21: Distribution of plastic waste globally (Statista, 2018).

Especially when the new material is a plastic, the waste at the end of life is currently a big problem. Figure 21 shows how much of the total plastic waste is being recycled, discarded or incinerated globally. Even though the percentage of recycled plastic is increasing, it does not mean that more of the plastic waste is being recycled as the total amount of plastic waste is also increasing every year. A second option to improve the sustainability of the new material is to consider biomaterials. Biomaterials are biodegradable and recyclable. By using a biomaterial not only the waste at the end of life is reduced, but it is also made from renewable resources.

Because Gecko is entering a new market segment, it is important for the brand to distinguish themselves from the competitors. The most effective way is by focusing on a new material for the impact cover. Furthermore, another strength will be the unique product style of Gecko compared to the competitors. A third way for Gecko to stand out is to include sustainability in the design and the material choice of the new impact cover. This means that recyclability and biomaterials need to be considered. Lastly, the target group of the new cover will be the tablet users on the go. Additional research is needed to establish the requirements of these users, so that Gecko can distinguish themselves even further.

# 5

# Target group

In this chapter, the last relevant stakeholder is analyzed. First, the perception of the general tablet user on impact resistance is researched through a user test. This determines what characteristics the new impact cover should have to be perceived as impact resistant. Then the target group users on the go is further studied and compared to other tablet user groups through a questionnaire.

Figure 22: User with tablet in the bus (SolStock, 2016).

**Research questions**

The perception of the impact resistance of the user is important to take into consideration as this does not have to correspond with the real reasons why a specific tablet cover has a certain impact resistance. For example, the consumer might think that a thicker cover is better, because there is more material protecting the tablet. However, there might be a thin cover of a more impact resistant material. If there are certain characteristics that influence the perception of the impact resistance, they have to be taken into account while designing the new impact cover.

Even though people buy an increasing number of products online, they still like to go to physical shops to see, touch and feel the product (Danziger, 2019). The user perception might change after seeing and interacting with the product. Previous research on perception change after product trial shows that it is possible that the perception changes after trial (Saeed et al., 2013). An example of this was told by a fellow graduate student. She did not like her current Otterbox smartphone cover when she first saw it in the shop, because she thought that it would not protect her smartphone enough. However, after she put her phone into the cover, she noticed that the phone snugly fit into it. This caused her to change her perspective, as she now believes that the phone would not fall out of the cover and is well protected.

Lastly, there will be looked into the relation between style and impact resistance. The hypothesis is that the tablet covers are characterized as either stylish or functional. To verify this, the selected tablet covers will be scored on both style and impact resistance by the participants. In chapter 3 brand image was discussed. To find out what tablet users think of the Gecko brand and products, an iconic Gecko cover will be added to the selected impact resistant covers. It is expected that this cover will score lower on impact resistance and higher on aesthetics compared to the real impact resistant tablet covers.

Based on these hypotheses the following research were formulated:

1. Which characteristics make people think that a tablet cover has high impact resistance?
2. Which characteristics make people change their perception on impact resistance after product trial?
3. What is the relation between style and impact resistance?

**Method**
There was chosen to conduct this user test via a product trial where the participant was asked to think out loud. Questions were asked during and after the test. The user test was conducted in Dutch, as the participants were Dutch. The reason behind this is that the focus of this project is mainly on the European market, and the company Gecko Covers is located in the Netherlands. By using the mother language of the participants, it is easier for them to think out loud. This led to honest opinions and interesting discussions, as the participant talked about the first things that came up. The user test was done with 5 females and 2 males, including the pilot. They all own a tablet and belong to different user groups such as home tablet users, on the go tablet users and users who work outside with their tablet. This was done to get a general view on the perception on impact resistance. The age of the participants ranged from 18 to 60+.

The setup of the user test was as following:

- Introduction project
- Warming up exercise talking out loud
- First impression product
- Product trial
- Tablet stand try out (if there was one)
- Ranking style, ranking impact resistance and background information of the participant

A user test guide was used to talk about the same subjects with all the participants (see appendix C). The user test was recorded with consent and used to make transcripts of the user tests (see appendix D).

Four different tablet covers were used in this interview (see figure 25). The covers are from leading competitors in the impact cover market within the price range of the new tablet cover. They were selected based on the layers of protection, materials and aesthetics to create a diverse product range with different impact resistant characteristics. The order in which the tablet covers were presented was randomized each time. The participant got only one tablet at a time (see figure 23). After the tablet was tested, it was swapped with another one. At the end, to be able to rank the cases properly, all the covers were presented to the participant (see figure 24).

Figure 23: Participant performing a product trial.



Figure 24: Participant ranking the four tablet covers.

Figure 25: Selected covers for the user test.

*From top to bottom: Gecko Covers Easy Click, UAG Metropolis, Otterbox Defender, Tech21 Impact Clear*

**Results**

*Impact resistance characteristics*

Figure 26 shows the most mentioned characteristics of a tablet cover that give the participants a feeling of impact resistance, along with how many out of the seven participants mentioned something about this specific characteristic.

There are three characteristics that all participants mentioned during the user test and interview: the screen edge, direct screen protection and edges. First of all, all participants mentioned that the screen is the most vulnerable part of the tablet. Therefore, they believe a direct protection such as a book cover protects the screen best. However, it should be possible to close it properly, otherwise it will open during the fall, which means that the screen will still be damaged. Another characteristic concerning the screen is the screen edge. This is the edge that goes over the screen itself. It is an important part that gives the participants a feeling of impact resistance, as it provides a better fitting which makes it harder for the tablet to fall out of the cover. Thus the further this edge goes over the screen, the more reinsurance it gives the participants. Also, the height of this screen edge determines whether the screen will hit the surface it falls on, such as a table or the ground. A higher edge gives a feeling of better protection. Lastly, the edges surrounding the tablet were mentioned. These protect the tablet additionally, like car bumpers, and it gives a more reinsured feeling if all the edges are protected. Thicker edges create good fitting and provide more protection according to the participants. However, the buttons should still be easily reachable.

One characteristic is mentioned by six out of seven participants: the number of layers within the cover. This was mainly concerning the Otterbox cover, as this was the only cover with three layers. The participants thought that more layers mean that more material is available to protect the tablet from impact. However, with this many layers it was unclear to them what the added value was of each layer. It seemed like an overkill for the tablet itself, which is slim and easy to use. On the other hand, UAG also has two layers but overmolded. This means that two different materials are visible, but it is all contained in one layer. The participants did mention that this gave a more impact resistant feeling compared to the other covers.

The corners and material characteristics were mentioned by five out of seven participants. According to them the thicker the corners, the better the protection. This also causes the overall cover to seem stiffer. This gives the participants a feeling of robustness. In the case the edges are not fully protected, the further the protection goes around the corner, the better. Finally, multiple material characteristics were mentioned. The participants prefer a softer material as it is more flexible and has more damping compared to a harder material. However, some stiffness is still preferable as this relates back to robustness. A thicker material breaks less easily, adds more protection and seems robust. Yet it should not be too heavy.

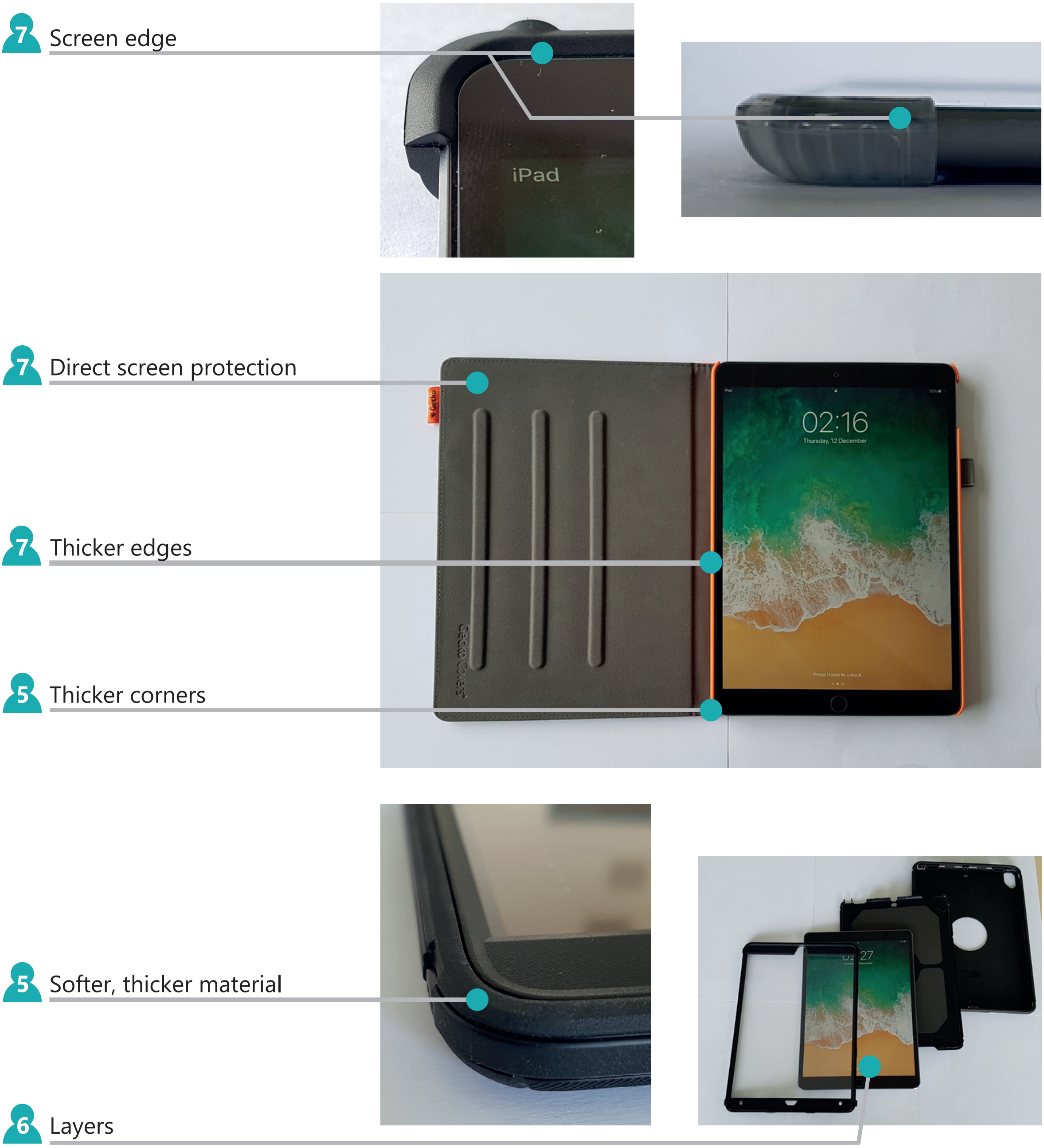



Figure 26: Characteristics impact resistance.

*Effect of product trial*

The participants were asked to put the tablet into the different tablet covers. After this product trial, they were asked whether their trust in the product had changed and why so. To be able to find the product characteristics that change the perception of impact resistance after trial, there was only looked at the answers of participants that led to a change in trust. Based on the these answers four categories were made:

- Fitting of the tablet in the cover
- Properties of the material
- Protection of the screen
- Cover design

Out of the 28 product trials done in total with the seven participants and four different tablet covers, 16 times the trust of the participant changed. Figure 27 shows the characteristics that were mentioned by the participants per category that made them change their trust in the tablet cover.

| Category | Characteristics |
| --- | --- |
| 6 Fitting | • Corners, edges<br>• Effort to put in tablet<br>• Effort to put in tablet<br>• Effort to put in tablet, screen edge<br>• Edges, effort to put in tablet<br>• Tight fitting |
| 4 Material | • Weight<br>• Softness<br>• Softness<br>• Softness & thickness |
| 4 Screen protection | • Direct screen protection<br>• Height screen edge<br>• Height screen edge<br>• Unprotected side |
| 1 Cover design | • Layers |

Figure 27: Characteristics which changed trust uring product trial.

*Style vs impact resistance*
At the end of the user test, the participants were asked to rank the four tablet covers on both style and impact resistance. The scores ranked from 1 to 4, with 1 being the best and 4 the worst. Figure 28 shows the average scores on style and impact resistance.

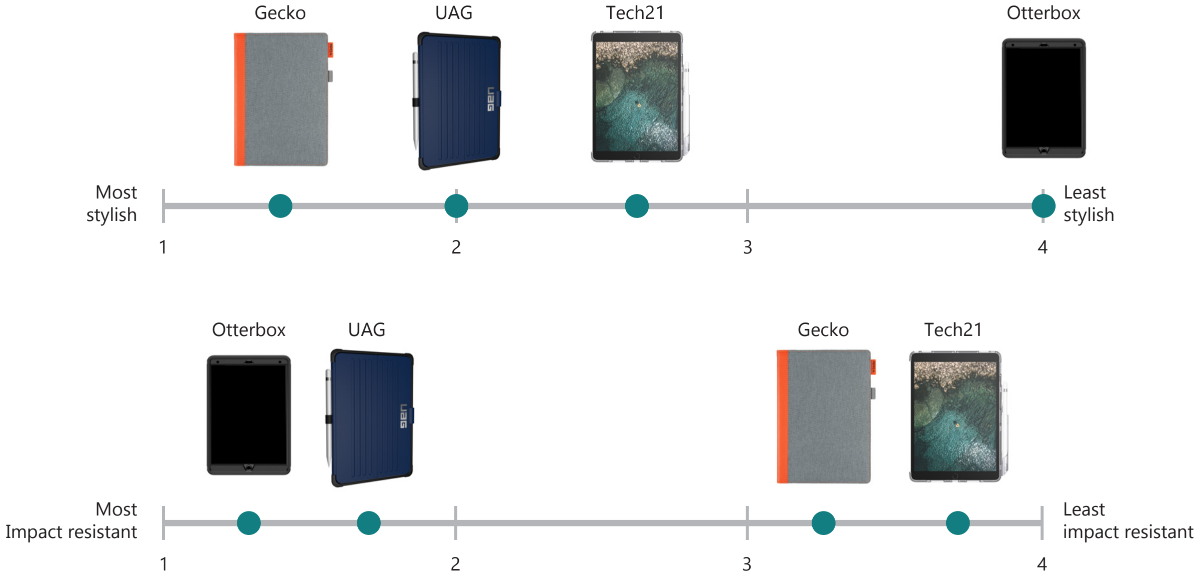



Figure 28: The average scores on style and impact resistance.

Aside from the scores, the participants were asked why they chose to rank the tablet covers the way they did. The style ranking is connected to the following product attributes:

- *Gecko*
  slim, simple, colorful, neat, beautiful, businesslike, fun, refined
- *UAG*
  a bit fake, slim, practical, beautiful, industrial look, neutral, design is too much
- *Tech21*
  thin, simple, transparent, makes the tablet pop out, impractical, cheap
- *Otterbox*
  chunky, non-elegant, covers the whole tablet, too big, heavy, ugly, over the top, thick, robust

The product characteristics that influenced the impact resistance ranking are:

- *Otterbox*
  fragile screen protector, lot of material, rubber, a lot of damping, hard material, thick, completely protected
- *UAG*
  robust, soft material, all sides protected, flexible, screen cover, screen edge goes far enough over screen, screen edge is high enough
- *Gecko*
  tablet falls out of the cover, thin, screen edge does not go far enough over the screen, screen cover, unprotected sides
- *Tech21*
  breaks, hard material, not a lot of material, no screen protection, thin, minimal protection

## Conclusion

The research questions will be discussed one by one, along with the implications the results will have on the new impact resistant tablet cover.

*1. Which characteristics make people think that a tablet cover has high impact resistance?*
The three characteristics that all seven participants connected to high impact resistance are the screen edge, direct screen protection and the edges of the tablet cover. The first two are related to the screen protection, which all participants think is important. The reason is that the participants unanimously find the screen the most vulnerable part of the tablet cover. The edge around the tablet gives additional protection and was compared to car bumpers. Other characteristics that were mentioned are: the number of layers or different materials used in the cover, the protection of the corners and material characteristics such as hardness/softness, damping and flexibility. Even though these characteristics were not mentioned by all the participants, they should be taken into account during the selection of the material and while designing the new tablet cover.

Based on these results, an ideal impact resistant tablet cover can be made. The cover would have a screen edge that goes far enough over the screen and is high enough to ensure that the screen won't touch the surface it falls on. The edges would all be protected and are relatively thick, as it ensures better fitting and provides more protection. However, the buttons should still be reachable. When working with multiple layers, the added value should be clear. The participants prefer to have multiple materials in one layer instead of having multiple layers, as this makes the cover thinner. The corner protection is important as well. The thicker the material at these locations, the stiffer the overall feeling of the tablet cover which gives a more robust feeling. Lastly, the material should be relatively soft as it is still flexible and has more damping compared to a harder material.

*2. Which characteristics make people change their perception on impact resistance after product trial?*
16 out of the 28 product trials resulted in a change of trust in the tablet covers concerning impact resistance. This means that roughly during half of the product trials, the participants were able to make a correct estimation of impact resistance based on visual elements of the different covers. When there was a change in trust, it was mainly because of the fitting of the tablet cover. Out of the six times this was mentioned, four times the reason was that the effort needed to put the tablet in was different than expected. There are two other factors that were mentioned four times, which are the material and the screen protection. For the material, three out of four mentioned that the softness/hardness of the material was different than expected. The most mentioned reason concerning the screen protection was the height of the screen edge.

It can be concluded that the fitting of the tablet cover is the biggest factor that could change the perception on impact resistance of the user. Two other things that the user might find difficult to estimate correctly by visual elements only is the softness/hardness of the material and the height of the screen edge. A solution could be to have clear pictures of the tablet cover with a tablet on the packaging, so that the user can make a better estimation on fitting and the height of the screen edge. For the material, the user should be able to feel it, which is not always possible such as in the case of online shopping.

*3. What is the relation between style and impact resistance?*
When looking at figure 27, there is no relation visible between style and impact resistance. Otterbox is ranked in average as the most impact resistant cover and the least stylish one. Gecko on the other hand is ranked the most stylish but not ranked as the least impact resistant one. UAG scores relatively high and Tech21 scores relatively low on both style and impact resistance. However, there is a certain pattern visible. The covers that are scored extremely high on one aspect also score relatively low on the other. The covers that are score more in the middle on one aspect, stay relatively in the middle with the other aspect.

For the new tablet cover the current position of UAG is the most ideal. This cover was considered relatively stylish and relatively impact resistant. The product characteristics which the participants mentioned during the ranking correspond to the found characteristics of research question 1. Regarding style, all participants agreed that Otterbox took away the elegance and the sleek design of the iPad. However, Tech21 did not add something to the design of the tablet. Also, color stands out a lot. Gecko was the only one with more vibrant colors, which was recognized by the participants as more stylish even if the overall design and colors were not in line with their personal preference. All in all, the most important thing is to make a good balance between providing enough protection and not making the cover too heavy or thick.

**Discussion**

This user test was done with just seven participants, therefore the data is qualitative. To validate all the findings, the user test needs to be done with more participants. The sample size taken from all the tablet users could be of one specific part of the total group which results in a bias. If a bigger sample size is taken, the chances of having only one type of user becomes much smaller.

The user test was done in real life, with products the participants could really see, touch and feel. Because a lot of purchases are done online nowadays, it would be interesting to see if there is a difference in expectations of people who can inspect the tablet cover in real life and people who can only judge the cover by photos.

An important aspect to take into account is that during the ranking of the tablet covers on both style and impact resistance, the participants unconsciously took other criteria into account. For example, Otterbox was scored lower by some participants than UAG on impact resistance. When asking for the reason behind this, the participants mentioned that they found it ugly and therefore trusted Otterbox less compared to UAG.

Lastly, there was no relation found between style and impact resistance. However, some kind of pattern was visible. To validate this, a quantitative test needs to be conducted with more tablet covers.

**Research questions**

Based on the market research in chapter 4, it was decided to focus on the market segment Life on the go. To get a better understanding on the behavior of the user group which belongs to this segment, additional research needs to be done on the user group. The following research questions are defined:

- Which different user groups are there and what are their characteristics?
- Which impact resistant characteristics are mentioned per user group and is there a difference?
- What is the relation between impact resistance and style and is it similar to what was found in the user study?

First of all, it is important to find all the different tablet user groups. Based on the market segments found in chapter 4, the hypothesis is that there are mainly three groups: the home users, the on the go users and the extreme outdoor users. To validate this and to have a control group to compare the user groups with, people who do not own a tablet were also taken into account. Furthermore, it is expected that the tablet usage differs per user group. Therefore, additional questions will be asked about tablet usage and their tablet cover.

Main tablet cover characteristics were found during the user test which influence the perception of impact resistance. However, these were not linked to specific user groups. Therefore, the tablet users have to judge tablet covers again on impact resistance and mention why they scored the cover in a certain way.

Lastly, In the user study there was no relation between style and impact resistance. On the other hand, there was a pattern visible. To validate this, another comparison has to be done between style and impact resistance scores, but with a larger sample size and with more tablet covers.

**Method**

To be able to reach as many people as possible, a questionnaire was used. A total of 17 respondents filled in the questionnaire, of which eight are female and nine are male. The age of the respondents range from categories 18-25 to 60+. The questionnaire was in Dutch, for the same reasons as mentioned in subchapter 5.1.

The questionnaire is divided into four parts:

- *Tablet usage*
  Here information was asked about the tablet usage of the respondents, such as where do they mainly use their tablet, what do they use the tablet for and whether they have dropped their tablet before. If the respondent does not own a tablet, they will be redirected to the third part.
- *Information about current tablet cover*
  If the respondent has a tablet cover, some basic information about the brand, price and experience are asked. Because the new tablet cover is recyclable, there are also some questions about what they currently do at the end of life of their tablet cover. If the respondent has no tablet cover, they are redirected to the third part.
- *Impact and style perception*
  In this part the respondent has to give a score for both impact resistance and style. Additionally, there was asked on what grounds they scored the impact resistance. At the end the respondent has to choose the best impact resistant cover, and the cover that they would choose themselves.
- *Background information*
  Lastly, some background information was asked such as gender, age, family situation and whether they participated in the user interview.

The same four tablet covers of the user test were used with an addition of two other covers (see figure 29). This is to test whether the style vs impact resistance scores show the same kind of pattern with more tablet covers included. To make it easy for the respondents to score the tablet covers in the questionnaire, the scoring is done per tablet cover. This is because the respondents have to judge style and impact resistance based on the presented images alone.

To ensure that the order of the tablet covers in which they are presented will not influence the respondents, six different versions were made. Each tablet cover is put onto one of the six positions once. The scoring is done differently compared to the user test. Because the respondents only can see one tablet cover at a time, there was decided to use a seven point Likert scale instead of a ranking (see example below).

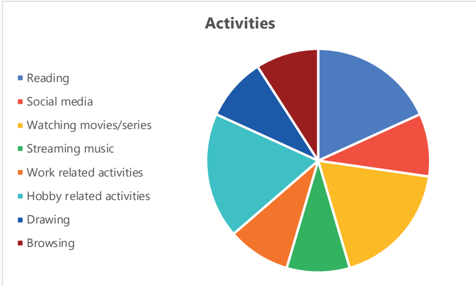
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Not impact resistant | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Impact resistant |

Figure 29: The added tablet covers UAG Plasma (top) and Griffin (bottom).

**Results**

The results of the questionnaire are presented per user group (see figure 30). See appendix E for all the results of the questionnaire. A total of four groups were found: the user on the go, the outside user, the home user and the reference group which do not own a tablet. All tablet owners who own a tablet cover mention that they throw their old cover away. Some recycle the cover if it is possible, but most covers are made out of multiple materials which cannot be separated. Aside from the information presented in the figures, there was also asked which tablet cover the user would prefer. This was open for interpretation, thus it could be based upon style, impact resistance etcetera. Only the user group on the go and the home users had a clear preference: the metropolis for the on the go users (3 out of 6) and Gecko for the home users (4 out of 6). Lastly, an overview is shown on the scoring of the six tablet covers on impact resistance and style (see figure 31).

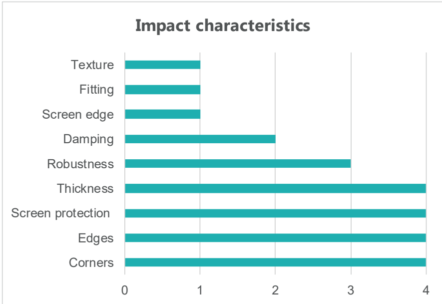
## On the go user




**Respondents:**
6 (3m:3f)

**Location of use:**
At home, in the train, car, airplane and/or someplace else such as at school and work.

**Owning a tablet cover:**
- 6 out of 6
- Average price: €52,-
- Main reasons choice cover: impact resistance, good price-quality ratio, nice design.

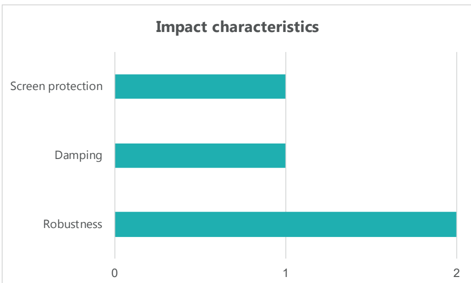


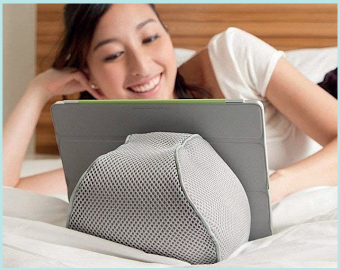

## Outside user


**Respondents:**
2 (1m:1f)

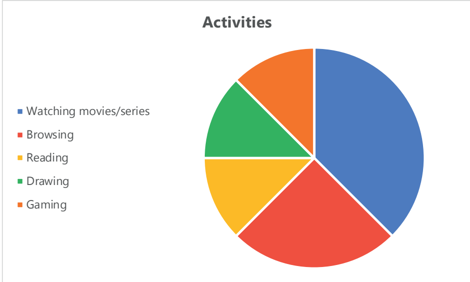
**Location of use:**
Outside and inside for work.

**Owning a tablet cover:**
- 2 out of 2
- Average price: €60,-
- Main reasons choice cover: impact resistance.

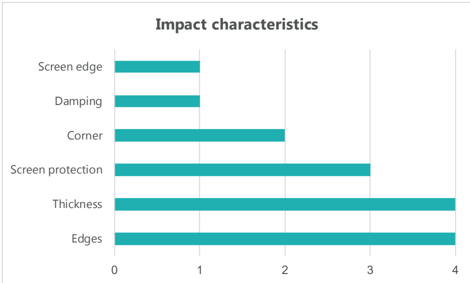




## Home user



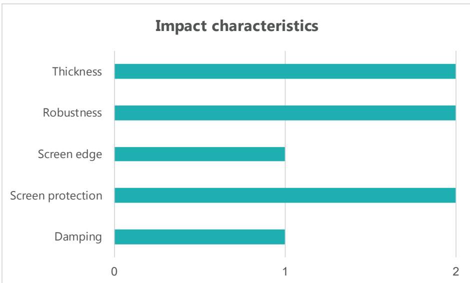

**Respondents:**
5 (2m:3f)




**Location of use:**
Only at home.

**Owning a tablet cover:**
- 4 out of 5
- Average price: €23,-
- Main reasons choice cover: Simple, nice design, could be ordered with the tablet.

## No tablet user




**Respondents:**
4 (3m:1f)

Figure 30: Overview of results per user group.

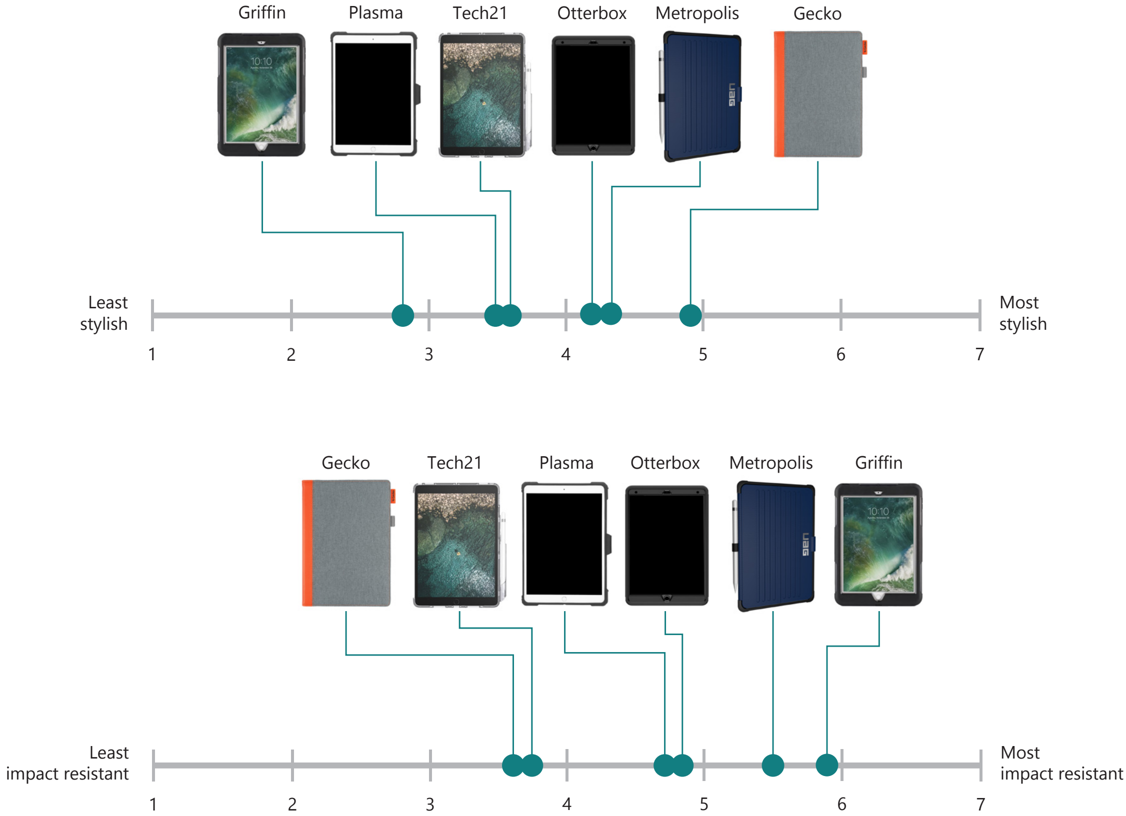



Figure 31: Overview of style and impact resistance scoring per tablet cover.

**Conclusion**

*1. Which different user groups are there and what are their characteristics?*

Three different user groups were found, which confirmed the hypothesis. The outdoor user mainly uses their tablet for work purposes and wants a more impact resistant cover. The on the go user travels mainly from A to B and uses their tablet during these trips, as well as at their destinations. This is reflected in the activities they undertake with their tablet. Furthermore, they want to have a good price-quality ratio, impact resistance and good design. Lastly, the home users. These users just want a simple tablet cover and don't mention impact resistance at all as a reason for buying a tablet cover. Based on these findings, the people who travel from A to B and want to use their tablet during these trips fit the best into the Life on the go segment. They are from now on considered the target group for the new impact cover.

*2. Which impact resistant characteristics are mentioned per user group and is there a difference?*
When looking into the mentioned impact resistant characteristics of the different user groups, overall the same characteristics are found. But when looking at the most mentioned ones, some differences can be seen between the user groups. The on the go group finds corners, edges, screen protection and the thickness of the material the most important. For the home users it is only the edges and the thickness. The outside user group mentioned robustness the most and lastly, the reference group think the thickness, robustness and the screen protection matter most. Most of the elements also correspond to what was found in subchapter 5.1.

*3. What is the relation between impact resistance and style and is it similar to what was found in the user study?*
Based on figure 31, no direct relation could be found. However, the pattern which was visible in the user study is also visible when looking at these results. The cover which ranked highest on impact resistant, Griffin, is ranked lowest on style. This time, the same is applicable for the most stylish cover Gecko. The other covers stay in the middle and are not ranked much different for style compared to impact resistance. Therefore, it can be concluded that if a tablet cover is found to be the most or the least impact resistant, it will have the opposite score in style and if a cover is more in the middle with one score, it will also be in the middle with the other.

An interesting observation is that UAG Metropolis scored second best for both style and impact resistance yet again. Otterbox on the other hand has dropped in score compared to the user test. Tech21 stays at the lower end for both scores.

**Discussion**
First of all, the sample size of 17 respondents was not enough, as for example the outdoor tablet users were only represented by two people. The results might have been influenced by this. Secondly, the respondents had to rank the style and impact resistance based on photos only of the covers. The results might be different if they would have done the test with the real tablet covers, such as in the case of the user test of subchapter 5.1. Furthermore, this makes it not completely comparable to the mentioned user test. Lastly, some respondents only filled in a score for impact resistance and did not actually mention any impact resistant characteristics they based their score on.

Based on the user test, impact resistant characteristics of the tablet cover which give the user a more impact resistant feeling are found, such as the screen edge and the normal edges. Furthermore, users are more than half the times able to make correct estimations about the performance of the tablet cover. In the cases that the product trial was different than expected, it was mainly about the fitting of the tablet. In an additional user study three user groups were found, of which the tablet users who go from A to B while using their tablet along the way and at their destination are taken as target group. Lastly, there is a pattern visible in the ranking of impact resistance and style. The more extreme scores for one product attribute stay extreme for the other product attribute, while the covers which scored more in the middle for one, will also score more in the middle for the other.

# 6

# Design criteria

Based on the findings of part 1, the design brief is reformulated. Then, some requirements are set regarding the new product. These will be taken into account while designing the actual impact resistant tablet cover.

Figure 32: Breaking iPad (JerryRigEverything, 2018).

The design brief which was formulated at the beginning of this project can be further narrowed down. The tablet cover will be used to enter the Life on the go market segment of the impact resistant tablet cover market. The target group that belongs to this segment are the users on the go, which travel with their tablet from A to B. This group uses both their tablet indoor and outdoors and travel via car, train and airplane. To further differentiate the tablet cover from its competitors, the tablet cover should reduce its environmental impact by making the cover for example recyclable.

Below the requirements and wishes are listed, which are based on the findings of part 1. Some additional requirements are added by the company.

**General**

- The new product should enable Gecko to enter the Life on the go market segment of the impact resistant tablet cover market.
  *This market segment fits the wish of Gecko to enter the market with a balanced product. Also, a gap in this market could be found for Gecko to enter (see 4.1).*
- The new product has to have a life expectancy minimally 2 years.
  *Gecko gives 2 years warranty on their products.*
- The new product limits its environmental impact.
  *This is based on the fact that Gecko does not currently do something with sustainability, as well as most impact tablet cover competitors. Sustainability could therefore be used to differentiate the new product (see 4.2).*

**Design**

- The size of the product should correspond with the Apple iPad 10.5” of 2017.
  *This is because Gecko introduces new product lines with the bigger brands first (see 3.2) and because the company had this tablet available.*
- The design has to highlight the SRPP and its USPs.
  *The new material is what differentiates the new product from its competitors (see 4.1). Therefore it is important to highlight this through the design. The USPs of the SRPP are impact resistance, lightweight and recyclability (see 7.2).*
- The new product should fit in the current product portfolio of the brand.
  *This can be done by taking the current style (e.g. two different textures, a highlight color and simple design) and brand image (trendy, young, bold, cheerful and focus on detail) in account (see chapter 3).*

**User**

- The target group are the tablet users on the go, which belong to the Life on the go segment of the impact resistant tablet cover market. The new product should be tailored to their usage.
  *These users take their tablet with them during travel from A to B. They mostly use their tablet inside, such as at work, school or in the train. However, it is possible that they use it outside as well, e.g. waiting on the train (see 5.2).*
- The tablet cover should have a balance between aesthetics and impact resistance.
  *The user group wants to have a good looking cover, and the design should be suitable for multiple environments, such as a more formal working environment. The design should however not reduce the impact resistance of the cover, as traveling and being on the move contain risks (see 5.2).*
- The maximum weight of the product is 450 grams.
  *This is to enable the user to use the cover easily while traveling.*
- The tablet cover should withstand a fall of at least 1 meter on concrete.
  *This is considered the minimum extreme usage, as the user on the go sometimes use their tablet while walking on the street (see 11.2).*

**Production**

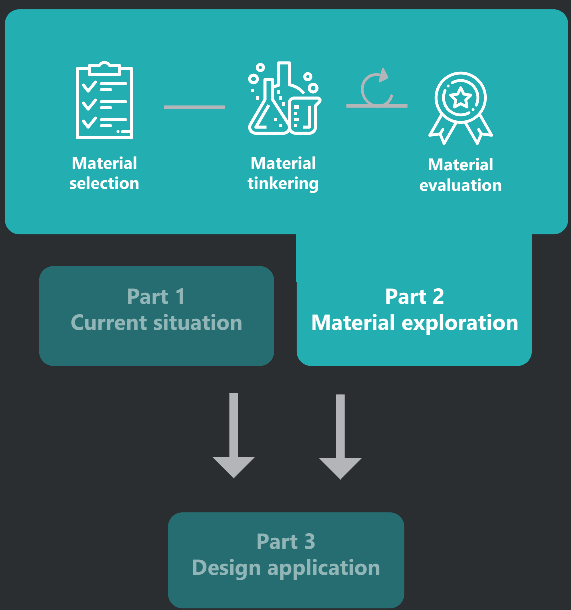
- The selling price should be in the range of the Gecko Premium line, which is around €60,- to €70,- (the price margin of Gecko is also taken into account, but cannot be mentioned).
  *This is a requirement of the company which also corresponds with the market opportunity found in chapter 4.*
- The chosen production process should be suitable for larger volumes.

**Wishes**

- As many of the impact resistant characteristics found in chapter 5 should be incorporated in the design of the tablet cover.
  *These characteristics will let the user perceive the cover as more impact resistant, and gives them more trust.*

# Part 2
# Material exploration

The material exploration is about finding the right impact resistant material for the new tablet cover. This part starts with the material requirements and the most suited material group, along with more in-depth research on reinforced polymers in general and SRPP (Chapter 7). Then the SRPP is made and evaluated in an iterative process (Chapter 8). Lastly, the final material composition is evaluated by a bending fatigue test and alternative Izod impact test (Chapter 9).



# 7

# Material selection

In this chapter the most important material properties that are required of the new material are determined. Then suitable materials that fit these requirements are analyzed. Lastly, a material is chosen and further elaborated.

Figure 33: Woven fibers (PragasitLalao, 2016).

**Toughness**

The new tablet cover aims to be impact resistant. Impact resistance is a measure of the resistance of materials to mechanical impact without undergoing any physical changes (Papavinasam, 2014). There are mainly two material properties that are related to this: toughness and fracture toughness. Toughness is defined as the amount of energy dissipated before the fracture of the material (Vaidya et al., 2019). As can be seen in figure 34, it is a combination of strength and ductility. Toughness can be calculated by integrating the area underneath the stress-strain curve. Fracture toughness, on the other hand, is an indication of the amount of energy required to propagate a preexisting flaw (NDT Resource Center, n.d.). It has been decided to mainly focus on toughness, as fracture toughness is hard to measure and because it is generally known that there is a positive correlation between toughness and fracture toughness. This means a high toughness equals a relatively high fracture toughness.

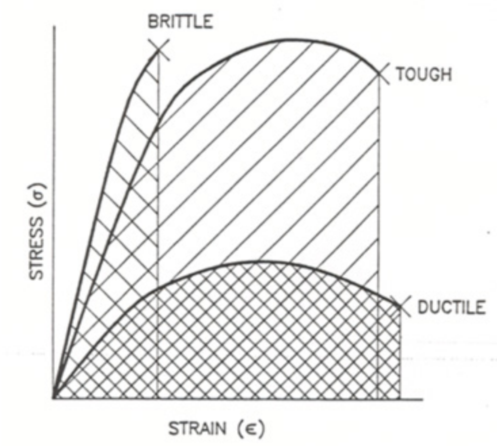



Figure 34: Stress-strain curve. (NDT Resource Center, n.d.)

**Ductile-to-brittle transition temperature**

Another important requirement is the ductile-to-brittle transition temperature, which will be called DBTT from now on. This is the temperature at which the material transitions from ductile to brittle behavior (see figure 35). Below the DBTT the material will fracture before yielding. Gecko mentioned that their current material, PVC, sometimes shows cracks after transportation via airplane from China. The DBTT of PVC is between -40 °C and -5 °C and depends on the amount of plasticizers. The temperature in the airplane cargo hold is around 7 °C, which explains the behavior of the material (Morris, 2017). Figure 36 shows the impact energy versus temperature curve of PVC and two other low impact materials.

The temperature in the air cargo is not the lowest temperature a Gecko product potentially has to endure. Gecko sells their products also in Nordic countries. Therefore, the average winter temperature of these countries is taken into account, which is -20 °C according to Tveito et al. (2000). This will be the minimum required DBTT for the material, as -20 °C is also the lowest advised operating temperature of an iPad (Thompson, n.d.).

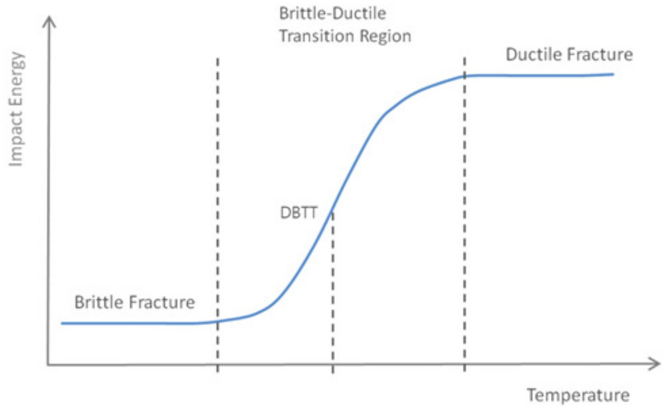



Figure 35: Impact energy versus temperature (Polymerdatabase, 2015).

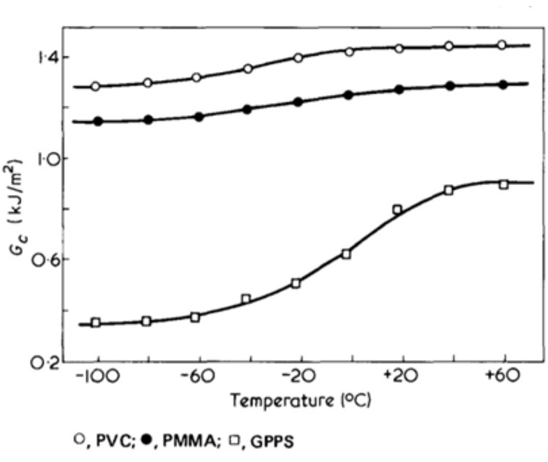



Figure 36: The effect of temperature on low impact strength materials (Plati et al., 1975).

**Density**

To make the new impact cover suitable for on the go usage and less heavy compared to competitors, the new material needs to have a relatively low density. The company wants the cover to have a maximum weight of 450 gram. The chosen Apple iPad model to focus on is the Apple iPad 2017 10,5 inch, which has a height of 251 mm, width of 174 mm and thickness of 6,1 mm (see appendix F for the technical drawings).

**Material group**

The first step in selecting a suitable material for the impact resistant tablet cover is to see which material group fits the material requirements. The focus is on a comparison of the impact resistance and density of the different groups, as there is no minimum quantitative value for these requirements in contrast to the DBTT, which will be used as a limiting factor. Figure 37 shows the comparison in CES with fracture toughness, as toughness was unavailable in the program.

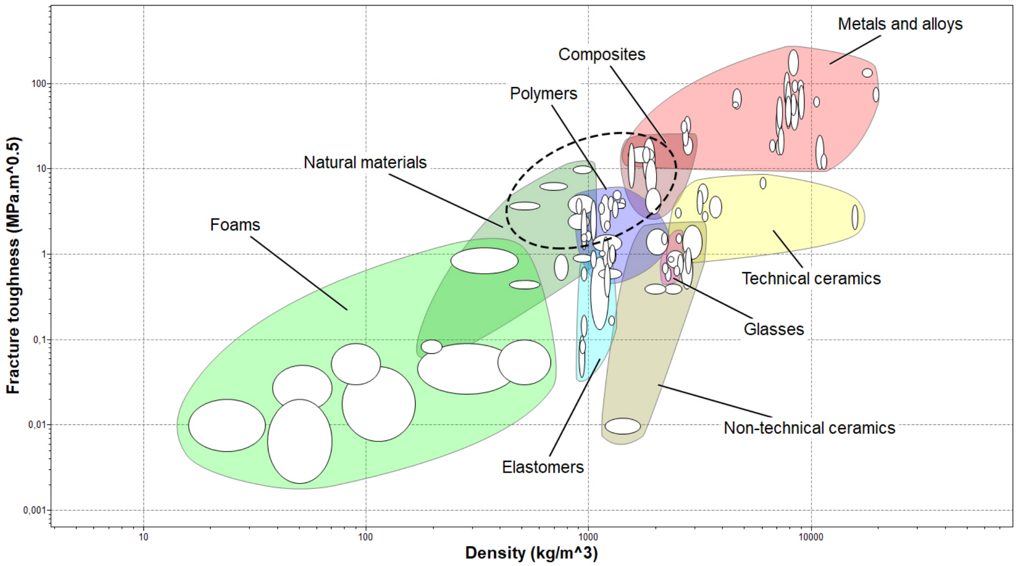



Figure 37: Comparison fracture toughness and density (CES, 2019).

Since a high fracture toughness and a low density is preferred, the ideal material would be located at the top left corner of the graph. However, as can be seen, there is no material that has these ideal properties. Therefore, there needs to be looked at material groups that are positioned relatively at the top (high fracture toughness) and relatively to the left (low density). Three material groups fit into this: polymers, natural materials and composites (dotted circle). Composites have a higher impact resistance compared to polymers and natural materials. To keep the preferred lower density, the focus will be on reinforced polymers which are composites with a polymer matrix.

**Reinforced polymers**

There are many different polymer composites available. To be able to find a suitable polymer composite an overview was made (see figure 38). This overview shows different categories that a polymer composite can belong to when looking at the different compositions of the composite. The blue categories were further analyzed, the grey ones were ruled out. This will be further elaborated.

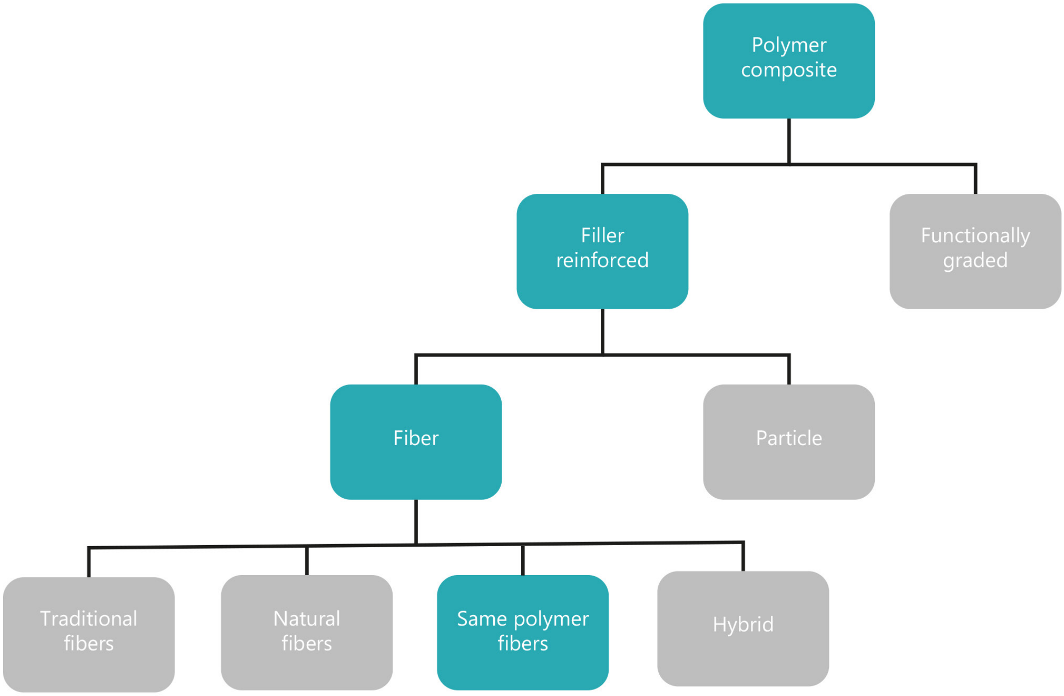



Figure 38: Overview impact resistant polymers.

Based on a literature review on different polymer composites, two main groups were found: polymers that are reinforced with fillers and functionally graded polymers (FGPs). FGP is a fairly new way of reinforcing a polymer by gradually varying the material and structure. It is based on functionally graded materials that can be found in nature, such as teeth, bones and bamboo (see figure 39). FGPs are therefore mainly used in the biomedical field to replace dental or bone structures, an example is polymeric functionally graded scaffolds (Scaffaro et al., 2017). However, no literature is available about the effect of applying functionally gradation on the impact resistance of a polymer composite. Furthermore, there are very few methods available to create FGPs and most manufacturing processes are either not suitable to create large gradation areas, cannot compete with mass production of other polymer composites or are very costly (Ahankari et al., 2017). Thus, it has been decided to focus on reinforcing a polymer with fillers instead.

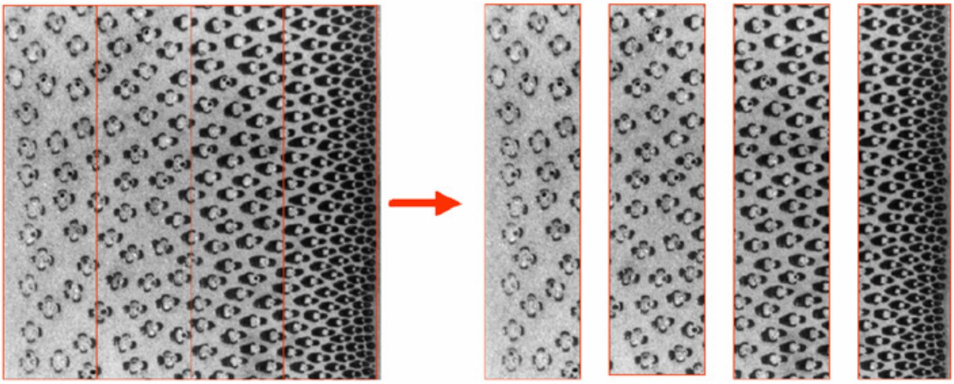


Figure 39: The gradually changing structure of cellulose fibers and lignin matrix in bamboo (Ghavami et al., 2003).

Filler reinforced polymer composites have a matrix of a polymer with added fillers. There are mainly two different filler types: fibers and particles. The shape and size of the different fillers have an influence on the impact resistance of the material. According to Wypych (2016), the aspect ratio or length to diameter ratio is the most important parameter that determines the impact resistance. A higher aspect ratio provides better impact resistance, which means fibers are preferred (Friedrich, 1993). The fiber category can be divided into four groups:

- *Traditional fiber reinforced composites (TFRCs)*
  TFRCs usually have a thermoset polymer such as an epoxy resin as the matrix with organic fibers such as carbon and aramid or inorganic fibers such as glass. Carbon is known for its high strength and high stiffness; glass is more affordable and offers relatively high strength; aramid is known for its impact resistance (Composite World, 2016).
- *Self-reinforced polymers (SRPs)*
  SRPs have the same polymer for both the matrix and the fiber. It is known for its impact resistance, low density, recyclability and low material costs (Biron, 2014).
- *Natural fiber reinforced polymers (NFRPs)*
  Natural fibers are made from renewable sources. The most known fibers are: flax, jute, hemp, kenaf, ramie, banana, sisal, cotton, oil palm and coir (Varghese et al., 2018). They are in general known for their low density, relative high strength, low costs and low environmental impact (Pickering et al., 2016). However, they have lower strength and specifically impact strength compared to synthetic polymers (Pickering et al., 2016). Currently research is done on how to improve this.
- *Hybrid fiber reinforced polymers (HFRPs)*
  HFRPs combine two different type of fibers within one composite.

Throughout chapter 4 it became clear that reducing the impact a product has on the environment is a very actual subject, even in the tablet and smartphone cover markets. It would be both responsible of Gecko and leading to a competitive advantage within the new impact tablet cover market if the new product would limit its environmental impact. It has been decided to start with the end of life of the product as this is something Gecko has not done before, which means the focus is mainly on the recyclability of the material.

TFRCs are difficult to recycle: these composites are strong, durable and non-homogeneous (Job et al., 2016). The current processes to recollect the fibers cause it to have lower material properties and shorter length (Olivieux et al., 2015). This makes the fibers not suitable anymore for their original high end use, which results in downcycling. HFRPs use a hybrid of two different fibers of either the same category or a mix of two different categories. This mixture of fibers makes it even harder to recover the materials through recycling.

The remaining two polymer composite groups NFRPs (with a biopolymer matrix) and SRPs are easier to recycle. NRFPs with a biopolymer are also called biofiber biopolymer composites. They are made of renewable materials and are fully biodegradable. A major downside to biofiber biopolymer composites is poor fiber dispersion and poor interfacial adhesion, which causes the impact resistance to be lowered significantly (Shahzad, 2016). Additionally, biodegradable polymers are currently more expensive compared to fossil based ones (Oever et al., 2017). SRPs on the other hand are made out of one thermoplastic polymer. This makes them stand out compared to TFRCs as they can be completely re-melted without the need of a fiber recovery process (REF, 2014). As mentioned before, SRPs are known for their impact resistance (Biron, 2014). In a study of Kuan et al. (2011) a comparison was made between SRPP, basalt-, flax- and hemp fiber reinforced PP where SRPP showed superior impact resistance compared to the natural fibers. The only downside is that they are made of fossil based polymers. Nonetheless, impact resistance is the main requirement for the new material which means SRPs are more suitable for the new impact tablet cover.

**SRP overview**

As mentioned before, SRPs are mainly made with thermoplastics. There has been a lot of research done on the different thermoplastics that can be used, such as PMMA, PET, PLA, PP and PE. However, the impact tests done in research only focused on one SRP and did not follow the same standard or a standard at all, which makes them incomparable. For example, sample size influence the total absorbed energy during the impact test and a different setup means that the data has to be interpreted differently. There was no research or database found in which multiple SRPs are compared. This means that the impact resistance of the SRPs cannot be used as an indication of which material would be best suitable for the new impact cover.

To still make it possible to select a SRP to focus on, the scope is limited by looking into SRPs that have been subject to more research and are already developed. Three SRPs meet this requirement: self-reinforced polypropylene (SRPP), self-reinforced polyethylene (SRPE) and self-reinforced polyethylene terephthalate (SRPET). This is because even though other SRPs are currently researched and in development, to be able to apply the material to the new tablet cover the material should be commercially available. Otherwise Gecko has to start the development of the material themselves, which seems not realistic as they miss certain required resources, such as knowledge and suitable equipment.

Of these three SRPs, SRPP was chosen. The base polymer PP has the lowest environmental impact out of all the fossil fuel based polymers (REF, 2014). Furthermore, SRPP has the lowest density compared to SRPE and SRPET and is cheaper (Jerpdal, 2017). Lastly, SRPP has globally generated the greatest commercial interest, which means various techniques have been commercialized to produce this composite on an industrial scale (Alcock et al., 2011).

**Self-reinforced Polypropylene**

Commercially there are three SRPPs available: Armordon®, PURE® and Curv®. PURE® is chosen as the main material to focus on, since the company DIT is located in the Netherlands which makes it easier to communicate with them and to receive the material.

PURE® is different compared to Curv®. It consists of two types of PP instead of one and are coextruded (see figure 40). Polymer B is the homopolymer, which has a higher crystallinity than polymer A. This means that the melting temperature of Polymer A is lower, as it has a lower crystallinity and is therefore called a copolymer. After the coextrusion, the material is drawn in thinner threads and joined using hot compaction into tapes. These tapes are then woven into fabric. The woven fabrics will be stacked, then pressed and heated at the same time. This results in laminated PURE ® sheets, which are called laminates. When laminated sheets are made, polymer A will act as the matrix and polymer B remains as the fiber.

There are certain variables in the lamination process which can influence the final material properties of the SRPP, including the impact resistance (Gao et al., 2012). To find out which values these variables need to have to get the highest impact resistance possible, the SRPP laminates will be produced while changing the variables that might influence the impact resistance of the material. These variables will be elaborated in the next chapter.

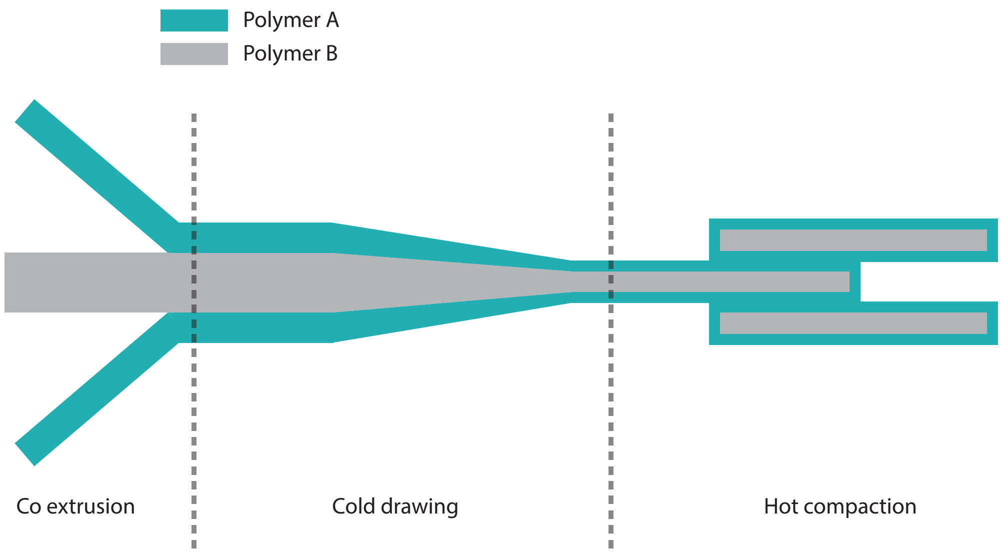



Figure 40: Manufacturing process of PURE® (based on DIT, 2020).

The chosen material to focus on is SRPP PURE®. SRPs in general are known for their high impact resistance, low density and recyclability, of which the last matches the differentiation strategy chosen in chapter 4. It also meets the limitation of a minimum DBTT of -20 °C. Out of all the SRPs, SRPP has a lower environmental impact compared to other fossil fuel based polymers, lower density and is the most suitable for production on industrial scale. PURE® is a commercial brand of SRPP (of which the manufacturing company DIT is located in the Netherlands) and it consists of two types of PP with different crystallinity which makes it different from its competitor Curv®. Lastly, the production of the PURE® laminates influence the material properties including impact resistance of the final material.

# 8

# Material tinkering

To be able to use SRPP for the new impact cover, laminates need to be made. In this chapter a manufacturing process is chosen and the most important variables are discussed. Then the first setup to make the SRPP laminates with the results are presented. Based on a material evaluation and feedback from DIT, an iteration was done in which the setup was adjusted and new laminates were made and evaluated as well.


Figure 41: Made SRPP laminates.

**Manufacturing process**

Because PURE® consists of two different types of PP, there are three different possible ways of manufacturing: Hot compaction with just the material itself, film stacking with additional PP films and a combination of hot compaction and film stacking.

- *Hot compaction*
  The layers of fibers will be put under a hot press with a high enough temperature and pressure. PURE® consists of a homopolymer with high crystallinity (core) and copolymer with lower crystallinity (outer layers). The temperature is high enough for the copolymer to melt, which results in a consolidated composite. This is the method which DIT uses to create laminated sheets.
- *Film stacking*
  Even though PURE® already has a matrix included in the material, it is still possible to add another matrix by using additional PP films. This method is called film stacking (see figure 42). Between each layer of woven fiber, a separate sheet of PP film will be inserted. Then the material will be also put in a hot press, but with a lower temperature as the copolymer should not melt.
- *Film stacking + hot compaction*
  Another possibility is a combination of both film stacking and hot compaction. The difference compared to just film stacking is that both the PP film and the copolymer will become the matrix, which means that lamination is even better between the fiber layers.

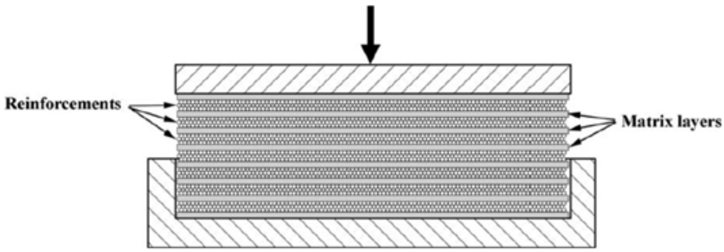



Figure 42: Scheme of composite processing via film stacking (Kmetty et al., 2010).

Based on a research of Hine et al. (2007) on the material properties of laminates made out of woven SRPP and SRPE which are manufactured in the three ways described above, it can be concluded that the combination of both hot compaction and film stacking improves the impact resistance of the composite. This is because the main challenge of SRPs is to find a suitable processing window that is short enough to keep the fibers intact, but still large enough to impregnate the fibers with enough of the matrix (Izer, 2010). By using a combination of hot compaction and film stacking the interlayer peel load is increased and lower temperatures are needed which makes the window frame to form the material much wider (Hine et al., 2007). This manufacturing combination is therefore chosen for the production of the material samples.

**Manufacturing parameters**

Within the manufactuing process, there are parameters that can be changed. The three main parameters that have to be taken into account are: temperature, pressure and time. These will influence the properties of the material. To have a starting point to work with for the three parameters, the company DIT was contacted for more information. Table 1 shows their data. According to DIT there are three basic rules:

- PURE seals at temperatures higher than 130 °C.
  For compaction heating and cooling is necessary.
- PURE relaxes (shrinks) at temperatures higher than 130 °C.
  Pressure or clamping is needed. If pressure is used, shrinkage is avoided.
- A minimum of 19 bar (kg/cm2) is necessary, higher is preferred.

Table 1: Effects of parameters on PURE® (DIT, 2019).

| Parameter | Minimum | average | Maximum |
|---|---|---|---|
| Pressure (bar = kg/cm$^2$) | 5-10, check level of consolidation! Not suitable for thin-wall products | 10-40 | 50-100, due to high pressures risk of color changes |
| Temp(°C) | 130-135°C, check level of Consolidation! Sufficient time and pressure! | 145-155°C | 170-175°C Avoid shrinkage! Sufficient pressure! |
| Time | Thickness-dependent. | Thickness-dependent. | Thickness-dependent. |

However, DIT uses only hot compaction as manufacturing process while during this project a combination of hot compaction and film stacking will be used. This means that the temperature and duration of the pressing will be different compared to table 1. Hine et al. (2008) mention in their study that the optimum temperature was 191 °C with a pressure of 4,9 MPa for 5 minutes for the combination of hot compaction and film stacking.

**Fiber related parameters**
There are three main fiber related parameters that are taken into account: weaving pattern, number of layers and layer orientation.

*Number of layers*
The number of layers will influence the impact resistance of the material. The thicker the composite, the stiffer it will become. The thickness of the other impact tablet covers were used as reference. As most participants mentioned that UAG and Otterbox were either too thick and heavy or looked over the top, it was decided to stay in between Tech21 Clear Impact with a thickness of 1 mm and Gecko Easy Click covers with a thickness 2 mm. Whether this thickness is impact resistant enough, must be validated (see subchapter 11.2).

In the first stage of the material research 3 and 6 layers of material were used. This was to mainly focus on the manufacturing parameters. After these parameters were narrowed down, the samples were all made with 7 layers of fiber and 8 layers of film which is in average 1,2 mm thick. This number of layers made the laminates stiff enough while keeping their ductility (this will be elaborated in subchapter 8.3).

*Weaving pattern fibers*
PURE® is being produced in two weaving patterns: plain weave and twill weave (see figure 43). A research of Yang et al. (2015) show that there is no significant difference between different weaving patterns and the impact resistance of a woven fiber composite. Therefore, to limit the number of parameters that have to be tested, the plain weave was chosen.

*Ply orientation*
Because the SRPP fiber is already woven, one layer or ply is uni-directional. This means that both the 0° and 90° orientation of the fiber is in the layer (see figure 44). There are many ply orientations possible, the most used ones are 0/90 and 45/-45.

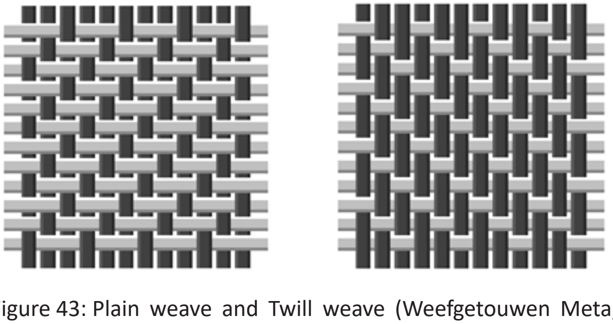


Figure 43: Plain weave and Twill weave (Weefgetouwen Meta, n.d.)

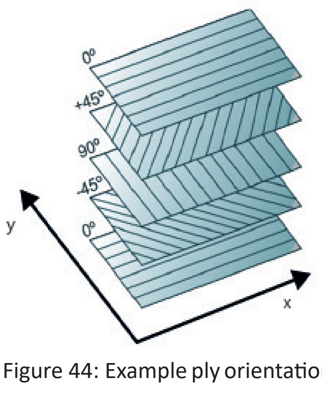



Figure 44: Example ply orientation.

The effects of these ply orientations on the impact resistance of a woven fiber composite have already been analyzed by Malik et al. (2017). The tests were conducted on Kevlar K-770 with an araldite epoxy resin, with layers of 3, 6 and 9 plies. Three different orientations were used: [0/0/0], [0/45/0] and [45/0/45]. The impact resistance was tested via a Charpy test, which is an impact test where a notched specimen is hit by a hammer (see figure 45). Via the pointer the absorbed impact energy can be read from the scale. Depending on how much energy is absorbed and whether the sample fractured, a material is either tough or brittle.

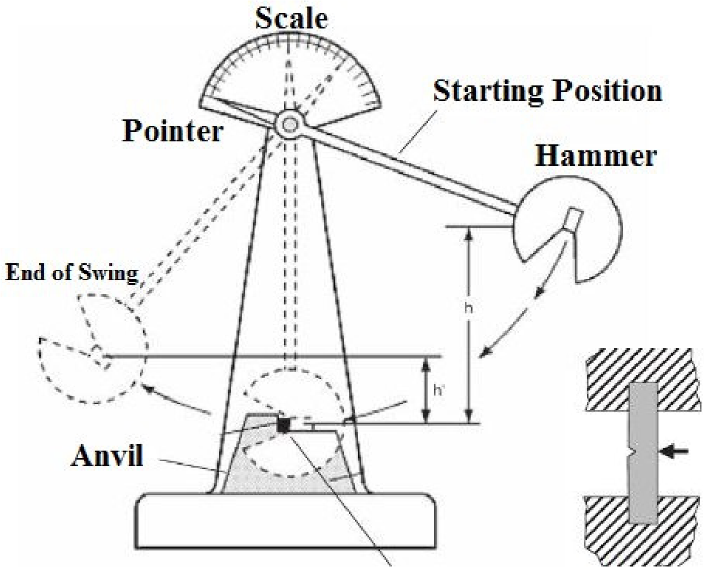



Figure 45: Charpy test setup (Okumoto et al., 2009).

The results of Malik et al. (2017) show that the angled orientation with 0° as top layer has the best impact energy absorption, followed by the 0° uni-directional and then angled 45°. The more layers used, the bigger the difference between the energy absorption of the different orientations. To validate that the same principle is also applicable for SRPP, the same setup has been used (see figure 46).

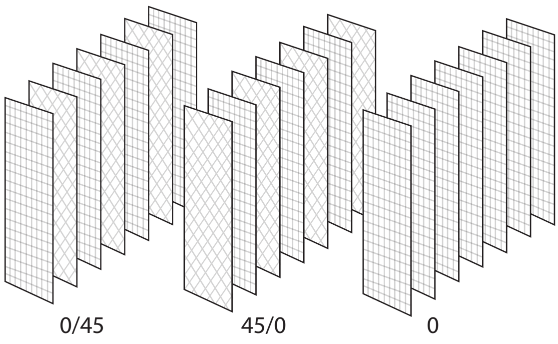



Figure 46: Chosen layer orientations.

**Goal**
Laminates will be made by using both hot pressing and film stacking. The goal is to find the right parameters for temperature, time, pressure and the number of PP films needed to give the composite good adhesion between the fiber layers. To limit the number of parameters at this stage of the research, it was decided to keep the other parameters the same for now: the orientation was kept at uni-directional 0 orientation and the number of fibers was kept at three layers. These will be further explored during the second part of the laminate making.


Figure 47: The used hot press.

**Instrument**
To make the laminate samples, the available Carter 3690 hot press in the materials lab of the faculty Industrial Design Engineering was used (see figure 47). The press is heated via convection and the temperature can be regulated. However, there is no built-in cooling system which means that the sample cannot be cooled actively or in a controlled manner such as with water or oil cooling. The pressure can also be regulated manually and is available in either psi or Metric Ton (MT). Based on the press surface area of 39 cm by 43,5 cm, 1 MT was recalculated to 0,578 bar. The maximum pressure of the hot press is 22 MT, which is a total of 12,7 bar.

To validate the internal thermostat of the hot press, a thermocouple was used to measure the temperature directly between the hot press plates. After two trials, it became clear that the temperature values were similar and the thermocouple was not used any further.

**Method**

The SRPP and PP film, which is regular packaging PP film with a thickness of 25 micron, were cut into a size of 15 cm by 5 cm with scissors. Then they were stacked in the following order: [film/fiber/film/fiber/film/fiber/film] (see figure 48). The number of films in between the fiber layers is variable. This stack is then put between two sheets of baking paper and two aluminum plates. The baking paper improves ease of removal from the plates and the plates are used to protect the surface area of the press itself. After the hot press heated up to the assigned temperature, the aluminum plates were put in the hot press. Then the right pressure was built up and a timer was set. Afterwards, the pressure was removed and the sample was taken from the hot press.

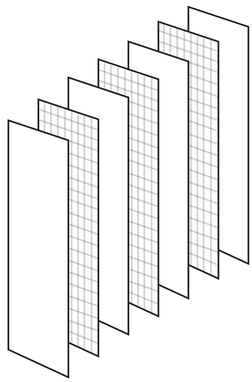


Figure 48: The stacking order of film and fiber layers.

By trial and error multiple samples were made with the different variables shown in figure 49 of the parameters time, pressure, temperature and film layers. Before the testing, the starting point for the values were decided upon. Based on the results during tests, more values were used. Additionally, extreme values were used as minimum and maximum to be able to tell something about the effect of the parameter on the laminate. The chosen starting values will be discussed per parameter below.

- *Time*
  Because DIT did not give any time related guidelines, the 5 minutes that was found as optimal time in the study of Hine et al. (2008) was chosen as starting value.
- *Pressure*
  The pressure was the limiting factor, as the maximum pressure that the hot press can reach is 12,7 bar (22 MT). This means that the found values in research could not be used. Therefore 1 MT (0,578 bar) was used as starting point and increased during testing.
- *Temperature*
  As starting point 125 °C was used, as 130 °C is roughly the melting temperature of PP. Steps of 25 °C were then used while increasing the temperature.
- *Film layers*
  The PP films are used to create better adhesion between the fiber layers, which make the overall laminate more impact resistant. The number of layers between the fiber layers started on 1 film, which was increased during testing.

| Time | Pressure | Temperature | Film layers |
|---|---|---|---|
| 5 min | 0,578 bar | 100 °C | 1 film layer a time = 4 layers total |
| 10 min | 1,16 bar | 125 °C | |
| 15 min | 1,73 bar | 150 °C | 2 film layers a time = 8 layers total |
| 30 min | 3,47 bar | 160 °C | |
| | 6,94 bar | 175 °C | 3 film layers a time = 16 layers total |
| | 10,4 bar | | |
| | 12,7 bar | | |

Figure 49: Used variables of the four parameters for making laminates.

The evaluation of the samples was done based upon visual inspection (e.g. color, delamination) and by performing a manual bending test to determine whether the samples were properly laminated. For the bending test, the samples were all cut in the same size: 11 cm by 2,5 cm (see figure 50). This is because not all the layers within one sample were correctly aligned or completely similar in size, which resulted in bad lamination at the edges.


Figure 50: Delamination after cutting the sample in the right size.

## Results

The most important aspect of the manual bending test was the delamination. When a sample was already delaminated or became delaminated during the bending test, it is considered as failed. The samples which did not delaminate after the manual bending test are presented in table 2.

Table 2: Overview variables of the best samples.

| Sample | Temperature (°C) | Pressure (Bar) | Time (Min) | Film layers | Comments |
|---|---|---|---|---|---|
| 19 | 150 | 1,73 | 10 | 1 | • Sample has burn marks and a smooth surface.<br>• No mark after 90 degrees angle bend, stiff and ductile. |
| 10 | 150 | 3,47 | 5 | 1 | • Less burn marks than sample 19 and a smooth surface.<br>• Less stiff than sample 19, and a small line visible after 90 degrees angle bend. |
| 14 | 150 | 1,73 | 5 | 1 | • Similar burn marks as sample 10. Surface is not smooth, it seems as if the plastic film is drawn vacuum but air bubbles still visible.<br>• After 90 degrees angle bending cracking is heard and a bending mark can be seen. Less stiff than sample 10. |
| 11 | 125 | 6,94 | 10 | 1 | • Less burn marks than sample 10 and 14 and surface is smooth.<br>• Less stiff than sample 14. Bending in 90 degrees angle gives a bending mark and more cracking sounds than sample 14. |
| 7 | 125 | 6,94 | 5 | 1 | • No burn marks and smooth surface. Stiffer than sample 11, but less stiff than sample 14.<br>• Same bending behavior as sample 11. |
| 17 | 150 | 1,73 | 5 | 1 | • Seems a bit burned and has shrinkage, but has good damping and is still ductile.<br>• Stiffest of these six samples. When bending in 90 degrees angle, cracking can be heard, but no mark is seen. |

## Discussion & Conclusion

Table 2 shows that all the samples which did not delaminate were made with 1 layer of film between the fiber layers. Therefore this parameter is set on 1 film layer. Also, a shorter active heating time results in better lamination, as 15 and 30 minutes delaminated after the manual bending test. Furthermore, a relation between temperature and pressure is visible. A higher temperature combined with lower pressure (sample 19) gives a better result compared to a high pressure with high temperature (sample 10). Yet, sample 17 is not among the top 3 even though it has a higher temperature and lower pressure. This particular sample also looks quite different compared to the other samples as it shrunk to the size of 12 cm by 3,5 cm, which is a shrinkage of 44% (see figure 51). The reason for the shrinkage  could be that the pressure is not high enough. However, if the lack of pressure did cause the shrinkage, the samples made with the highest pressure possible of 12,7 bar should have relatively better results compared to the ones made with lower pressure. This was not the case, as the samples with 12,7 bar are not among the best rated samples in table 2. Therefore the company DIT was contacted to see what the possible problem might be. They suggested to keep the sample in the hot press under pressure until it cooled down below 80 °C.

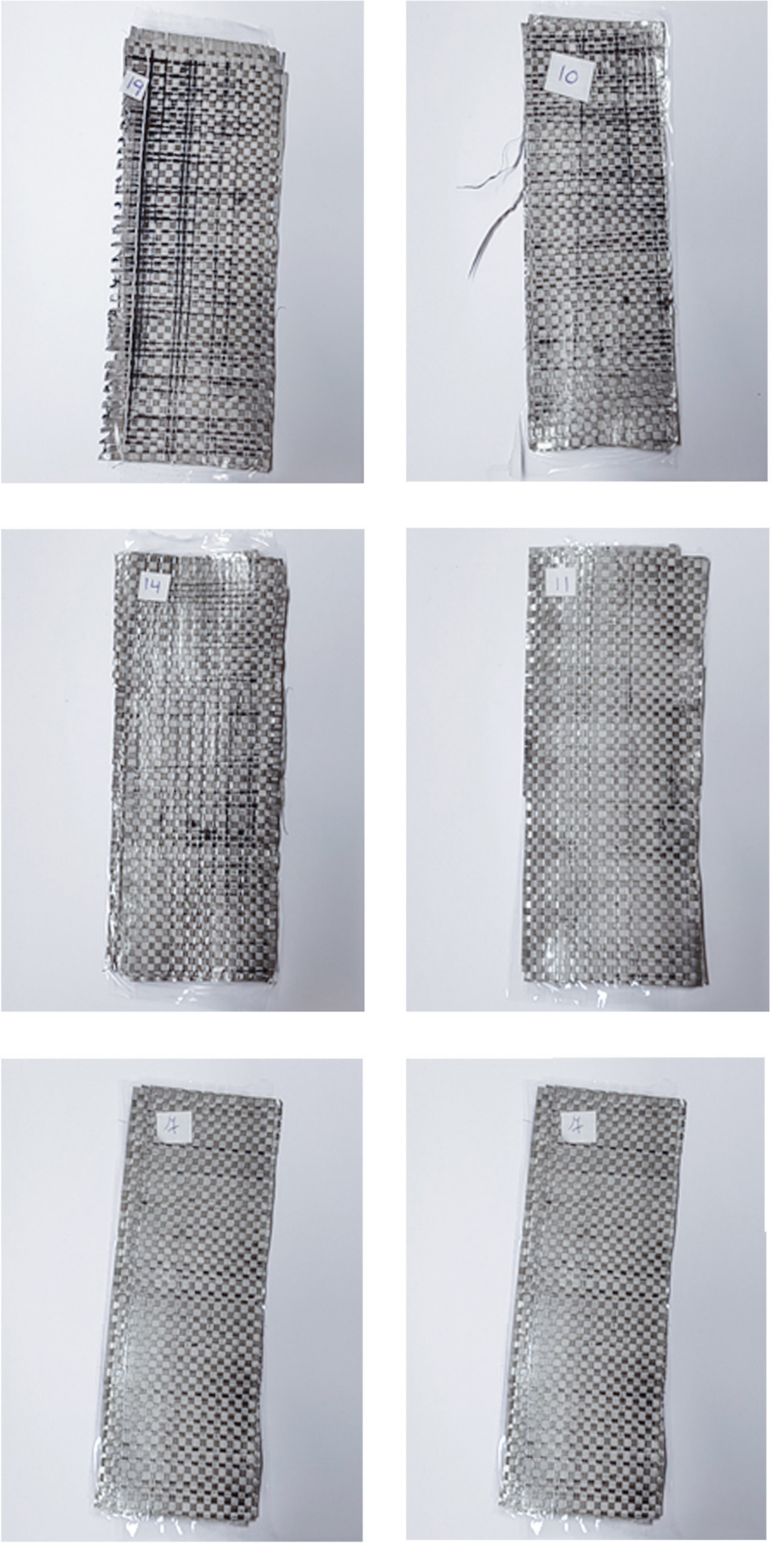



Figure 51: Best samples of the manual bending test mentioned in table 2.

# 8.3 Making laminates 2

**Goal**

Based on the feedback of DIT, the first objective is to validate whether keeping the pressure on the mold has an effect on the laminate. Then the final pressure, temperature, time span and number of PP film layers will be chosen. Lastly the fiber layers and ply orientation will be taken into account.

**Method**

The setup was modified by turning off the heating of the hot press after the set time, but keeping the internal thermometer on. This way the temperature of the sample could be checked. Cooling down happened naturally and took between 3 to 5 hours, depending on the set temperature. After the sample reached a temperature of 79 °C, the pressure was removed and the sample was taken from the hot press.

To validate this new setup, the starting point for the parameters was the same setting of sample 17 as it makes it possible to compare the two samples and conclude whether the new setup has any effect. Figure 52 shows the difference between the results of the adjusted setup (sample 31) compared to the old setup (sample 17) with originally the same sample size of 15 cm by 5 cm. As can be seen, the new setup improved the lamination of the material and caused no shrinkage at all. Therefore, it was decided to keep the modified setup as it is.


Figure 52: Result of adjusting the setup (sample 17 at the left, sample 31 at the right).

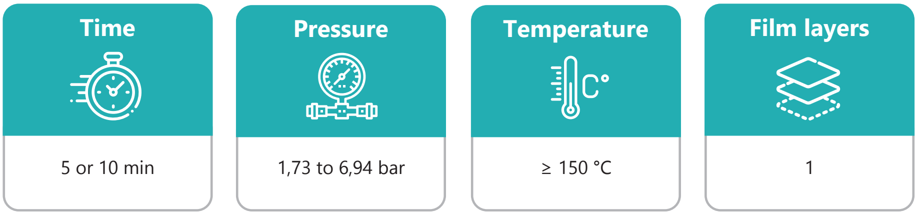



Figure 53: Used values for the four parameters.

The values for the parameters that were used in this part of the production process are presented in figure 53. As mentioned in 8.2, the number of PP film was fixed on 1 based on the results. For temperature, the focus was on 150 °C and higher, as the laminates made with these temperatures generally performed better. For time, it was decided to use the two variables that were in the best six samples: 5 minutes and 10 minutes. The same was done for the pressure. After the values for these parameters were set, the orientation and total number of layers were taken into account.

**Results**

After trial and error, the samples which are made with 160 °C; 1,73 bar and 5 minutes of active heating (see figure 54) and the samples made with 170 °C and similar pressure and time (see figure 55) came out as the best samples based on visual inspection (delamination) and manual bending (stiffness, ductility). These two different parameter settings were used to test both the total number of layers and ply orientations. There was chosen to keep the number of layers on 7 fibers and 8 films, as less layers gave off a feeling of not having enough stiffness and more layers made the laminate feel too stiff. For the orientation, no difference in material properties could be visually found or felt during manual bending.

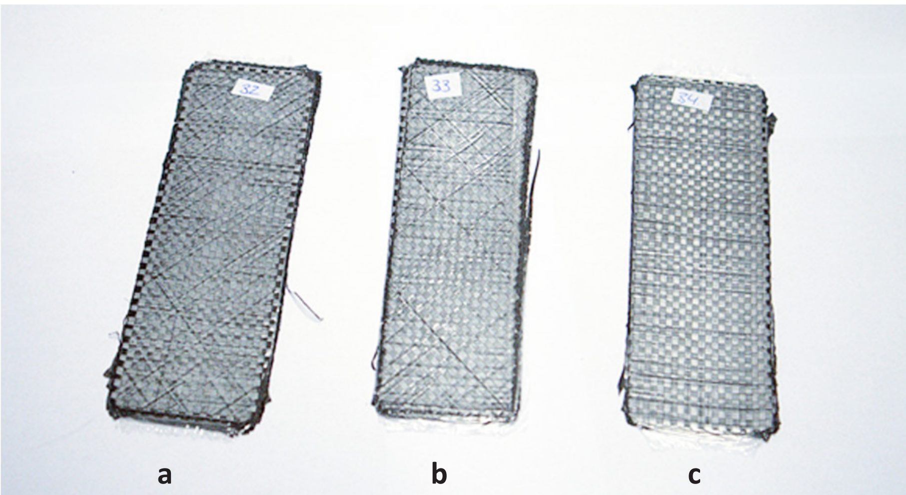



Figure 54: Samples made with 160 °C; 1,73 bar and 5 min with the following orientations: a) 0/45, b) 45/0, c) 0.

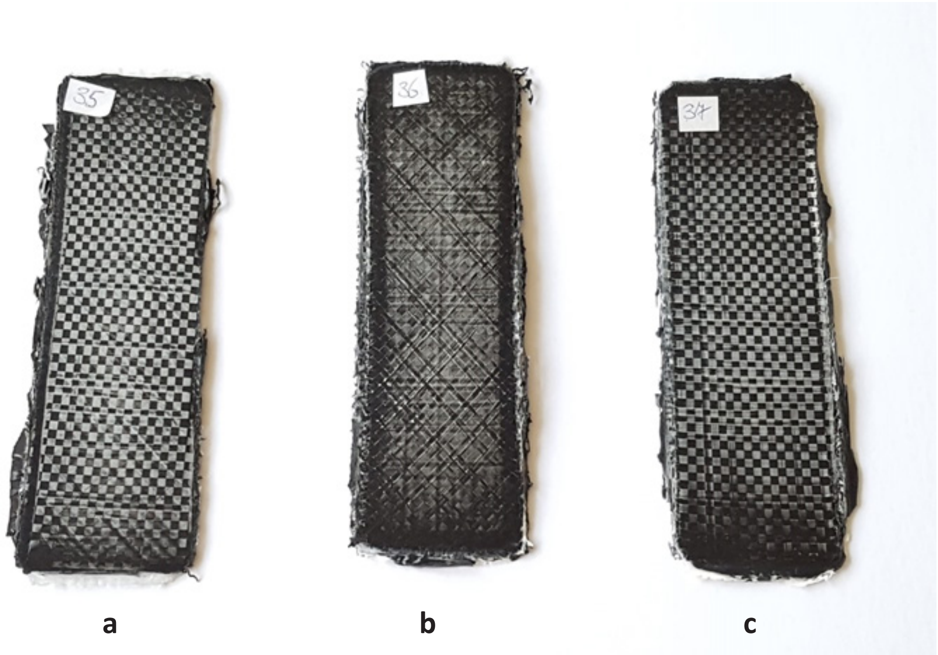



Figure 55: Samples made with 170 °C; 1,73 bar and 5 min with the following orientations:
a) 0/45, b) 45/0, c) 0.

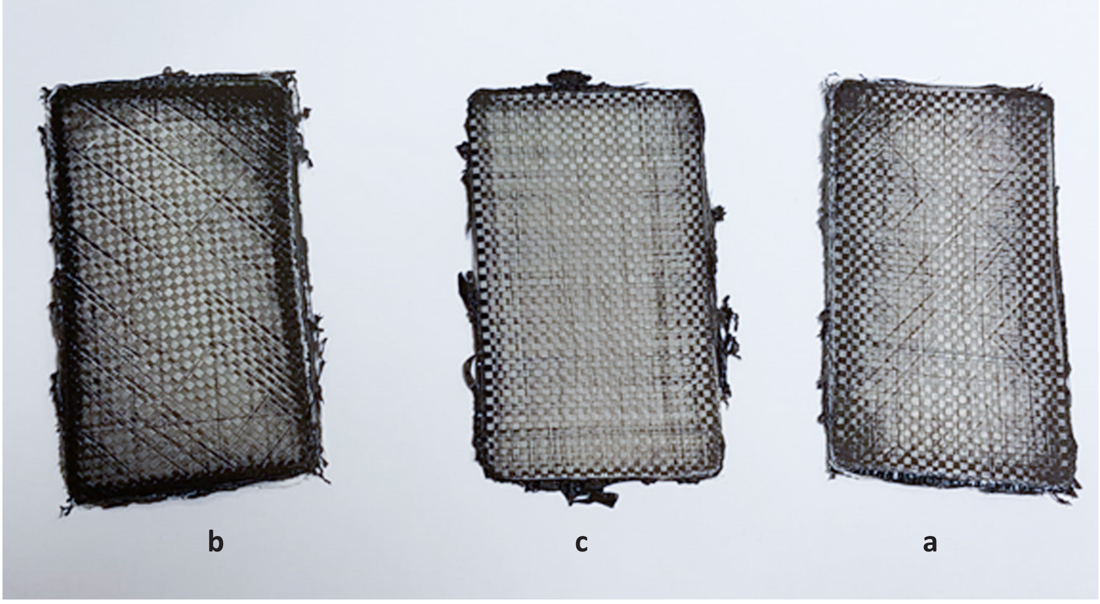



Figure 56: Bending test samples of 170 °C with the following orientations:
a) 0/45, b) 45/0, c) 0.

**Discussion & Conclusion**

Based on the results, a value can be set for three out of five parameters which will result in good lamination, stiffness and ductility. However, orientation and temperature could not be selected based on the results only. Therefore, a bending test was done with the temperatures 160 °C, 165 °C and 170 °C and the three orientations: 0, 0/45 and 45/0 (see chapter 9). Based on the results from the bending test, the final values will be chosen to get the best material properties.

However, when making the bending test samples, it became clear that the slightly bigger samples of the bending test did not react in the same way as the smaller sample size that was used in this chapter. For the bending test, laminates were made in the size 13,3 cm by 8 cm, which is an increase of size by around 30%. As can be seen in figure 56, the bending test samples are less burned than the smaller samples made also with a compaction temperature of 170 °C (see figure 55). The coloring of the bigger samples seem to be in the middle of the smaller samples of 160 °C and 170 °C (see figure 54 for smaller 160 °C samples). Therefore, it is expected that the differences between the bigger size 160 °C, 165 °C and 170 °C will be very small in coloring, but also in lamination. To get a bigger difference, the compaction temperatures are adjusted to 160 °C, 170 °C and 180 °C for the bending test samples.

The reason behind this difference in color and lamination could be the fact that the bigger bending samples are made three at a time, instead of only one for the smaller samples.

There are many parameters which can influence the material properties of SRPP during the manufacturing process. First of all, a combination of hot compaction and film stacking is used to make SRPP laminates, as it gives better lamination and widens the process window. Secondly, keeping the pressure on the sample while it cools down till 79 °C is important to avoid shrinkage. Lastly, the following values of the other parameters that were taken into account give the best results: 1 layer of pp film, a pressure of 1,73 bar, a temperature higher than 160 °C, an active heating time of 5 min. Orientation could not be evaluated manually.

# 9

# Material evaluation

In this chapter the best laminates of chapter 8 are evaluated. First the material is tested with a bending fatigue test on ductility and delamination. Then, the material is tested with an alternative Izod impact test on impact resistance.

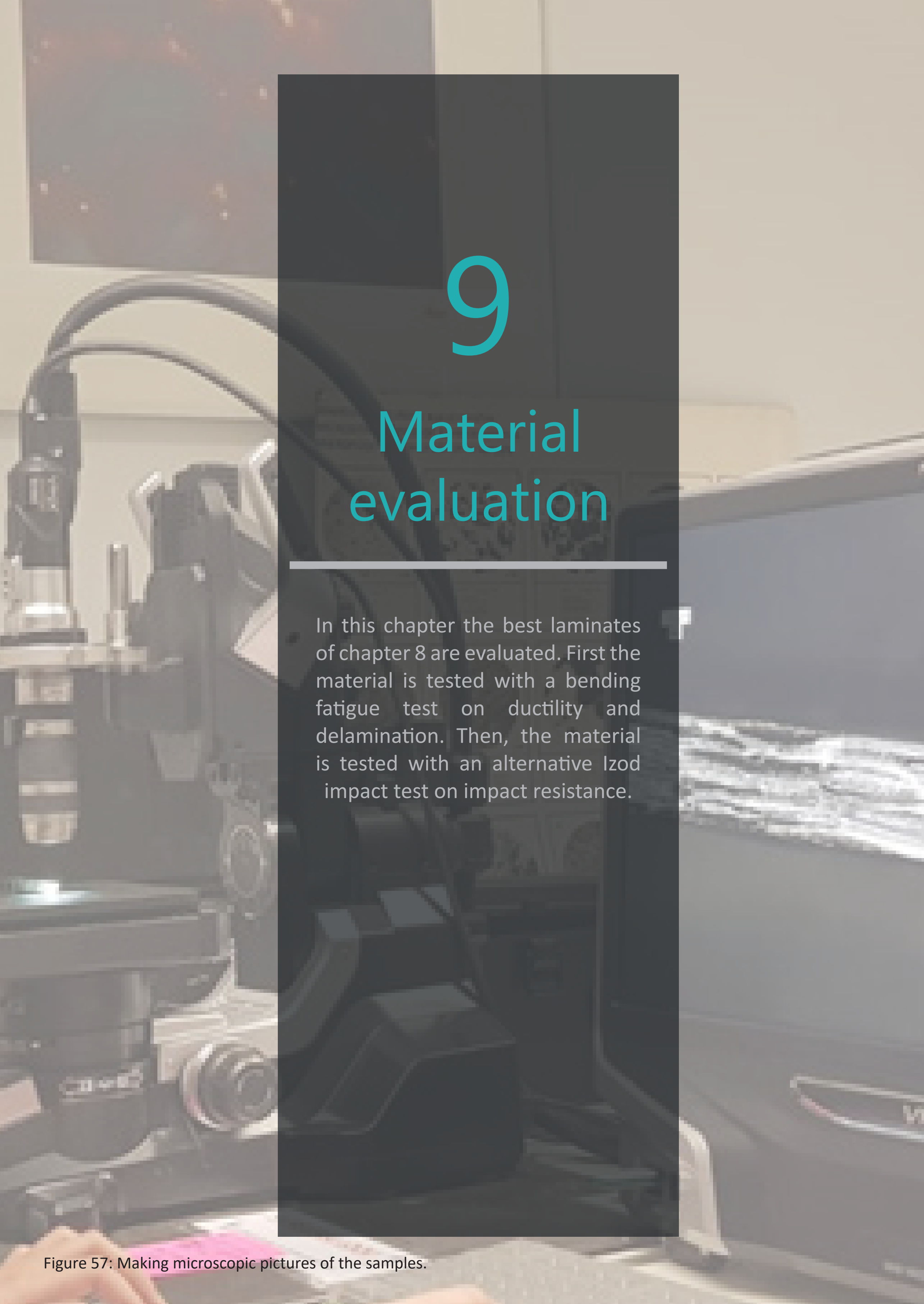


Figure 57: Making microscopic pictures of the samples.

**Goal**
To find out which combination of hot compaction temperature and orientation has the best lamination, a bending fatigue test was done. Additionally, there is looked at the estimation of toughness, which is the area beneath the stress-strain curve.

**Method**
For the setup standard ASTM D 7264 was used, which is a standard test method for flexural properties of polymer matrix materials. There was chosen for procedure A, which is a three point bending test (see figure 58). The machine used is a Zwick/Roell Z010 with a load cell of 0,5 kN. However, some adjustments were made to the standard. The maximum displacement was set to 12 mm with a speed of 15 mm/min. This is because in the real life situation the impact will be at a higher speed than was advised in the standard. There was additionally chosen for a bending fatigue test, which means that the specimen were tested by doing 10 bending cycles instead of one, i.e. loading to 12 mm displacement back to 0 for ten times.

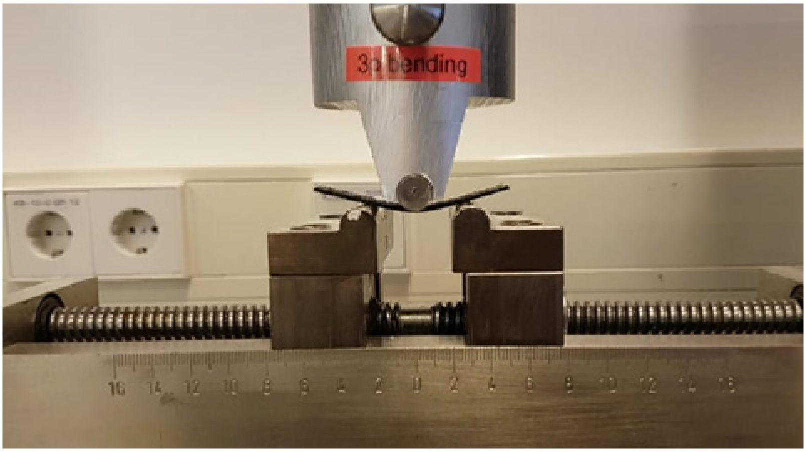



Figure 58: Three point bending test setup.

To be able to look at the effect of different temperatures, samples of 160, 170 and 180 degrees Celsius made with a pressure of 3 MT were chosen, along with the three different orientations:

- 0: [0/0/0/0/0/0/0]
- 0/45: [0/45/0/45/0/45/0]
- 45/0: [45/0/45/0/45/0/45]

Seven layers of plain woven PURE were used, with eight layers of plastic PP films. The samples were laser cut into five specimen to make sure that they all have the same dimensions: a span length of 38,4 mm of which 20% was used for support and a width of 13 mm (see figure 59). The thickness is adjusted, it ranges from 1,1 to 1,3 mm because of the different temperatures. There has been tested with 5 specimens per sample to increase reproducibility and statistical relevance.

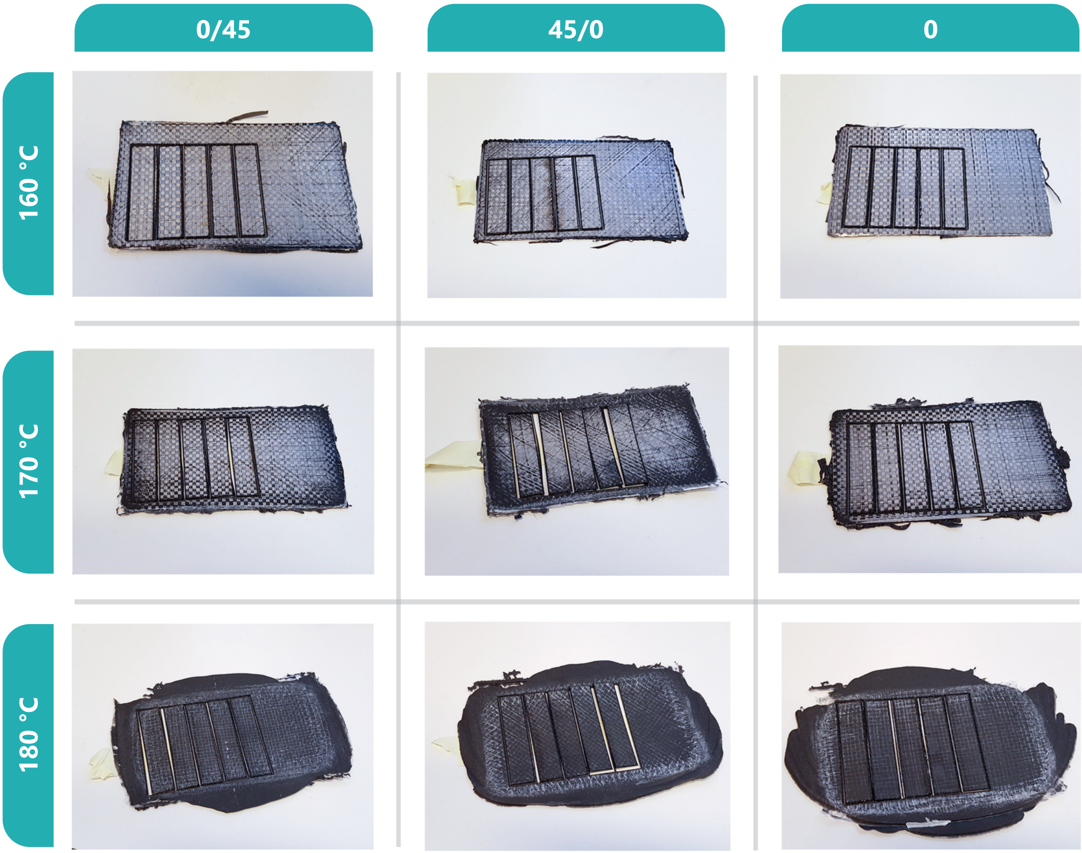



Figure 59: Overview of the laminates with the five specimens.

**Results**

Figures 60, 62 and 64 show the stress-strain curves of the three different orientations. These has been calculated by taking the average load and displacement of the first bending cycle of the five specimens from one sample. This is because of the saturation behavior of the curve by the increasing number of cycle which can be seen in appendix G. Then the average load and displacement has been recalculated to stress and strain by the use of formulas from the standard. Below each stress-strain curve, microscopic pictures are presented of the third specimen of each of the three compaction temperature samples (figures 61, 63 and 65). The red arrows indicate delamination. Lastly, table 3 shows the average toughness, which has been calculated by taking the area beneath the average stress-strain curves.

Table 3: Average toughness in J/m$^3$.

| | 0/45 AVG±STDEV | 45/0 AVG±STDEV | 0 AVG±STDEV |
|---|---|---|---|
| **160 °C** | 96±11 | 81±7 | 85±7 |
| **170 °C** | 129±15 | 111±1 | 133±13 |
| **180 °C** | 81±3 | 92±1 | 105±3 |

**Discussion & Conclusion**

The stress-strain curves can be divided into four parts:

- Part 1: an initial 'elastic' part with a low slope till 5% strain
- Part 2: a sudden increase in slope at 5-6% strain
- Part 3: reaching the maximum stress at 7-9% strain
- Part 4: decrease in slope at 9-10% strain

Part 1 is related to the E-modulus of the material and is elastic deformation. Part 2 is known as strain hardening: the strengthening of a material during large strain deformation where the chain molecules align and orient themselves in the direction of the load (Polymer database, 2015). Part 3 with the ultimate stress says something about the ultimate strength of the material. Lastly, part 4 is where the material reaches its ultimate stress or failure point, depending on whether the material fractured.

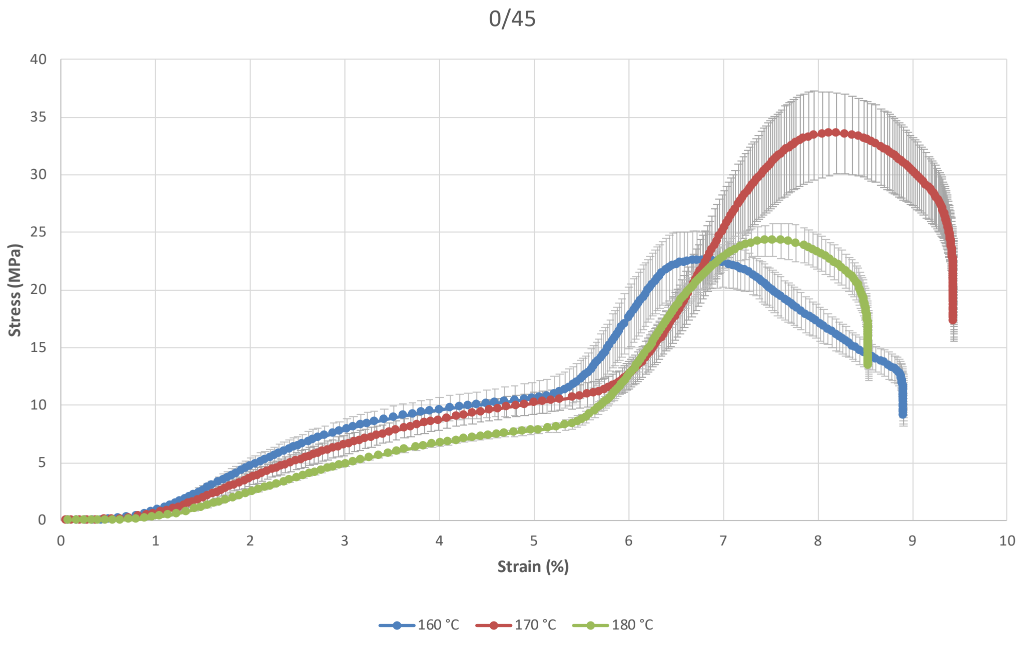



Figure 60: Average stress-strain curves of te first bending cycle of 0/45 orientation.

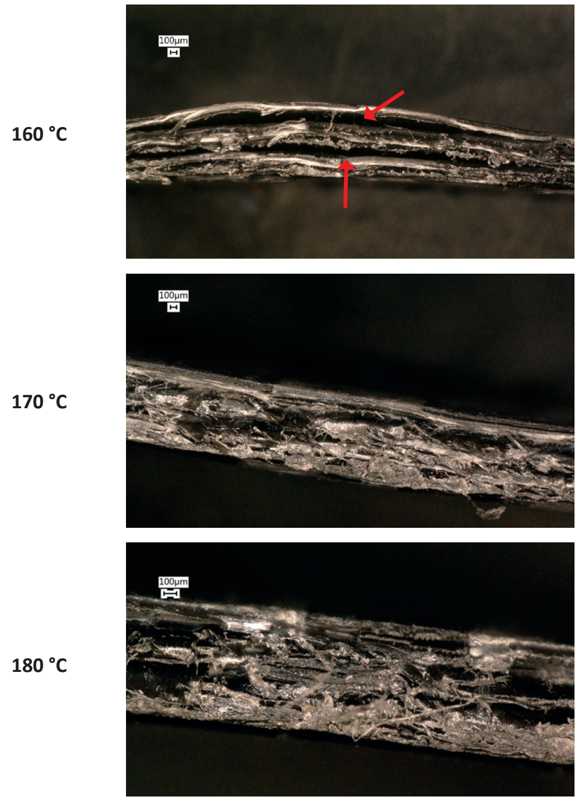



Figure 61: Microscopic pictures of samples 0/45.

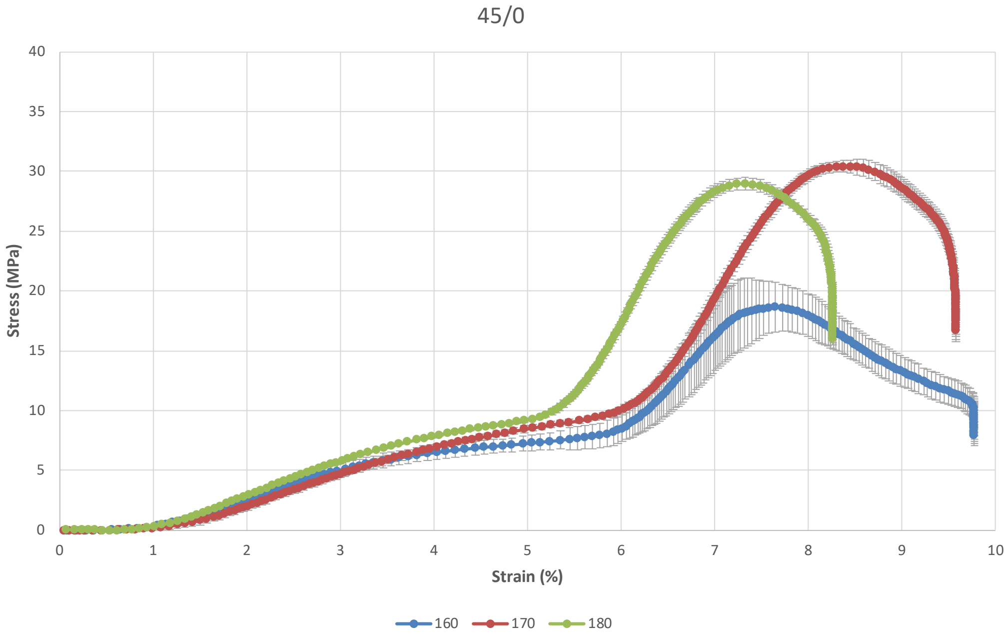
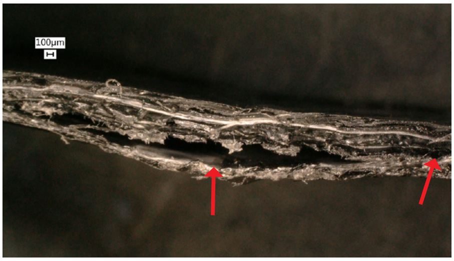
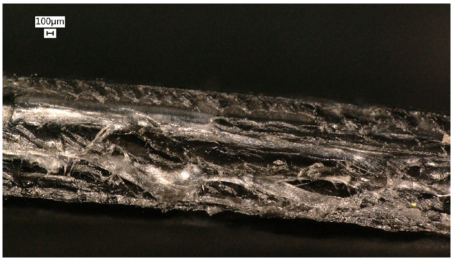



Figure 62: Average stress-strain curves of te first bending cycle of 45/0 orientation.

**160 °C**



**170 °C**



**180 °C**

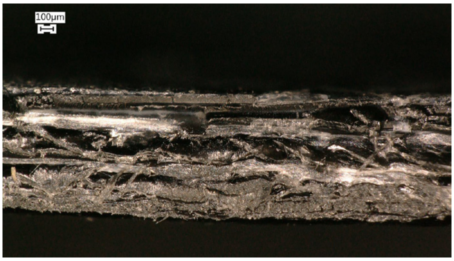


Figure 63: Microscopic pictures of samples 45/0.

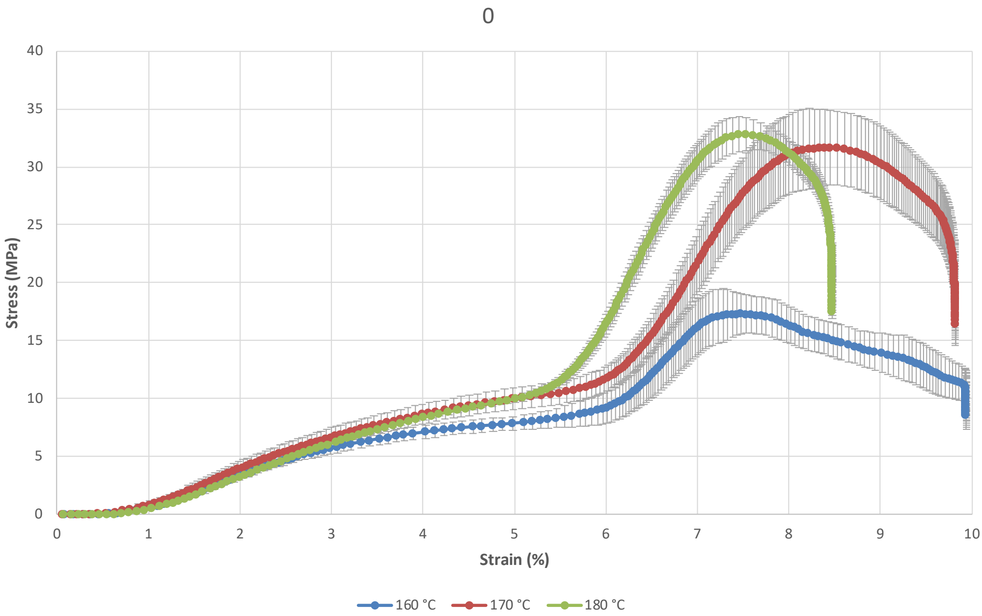



Figure 64: Average stress-strain curves of te first bending cycle of 0 orientation.

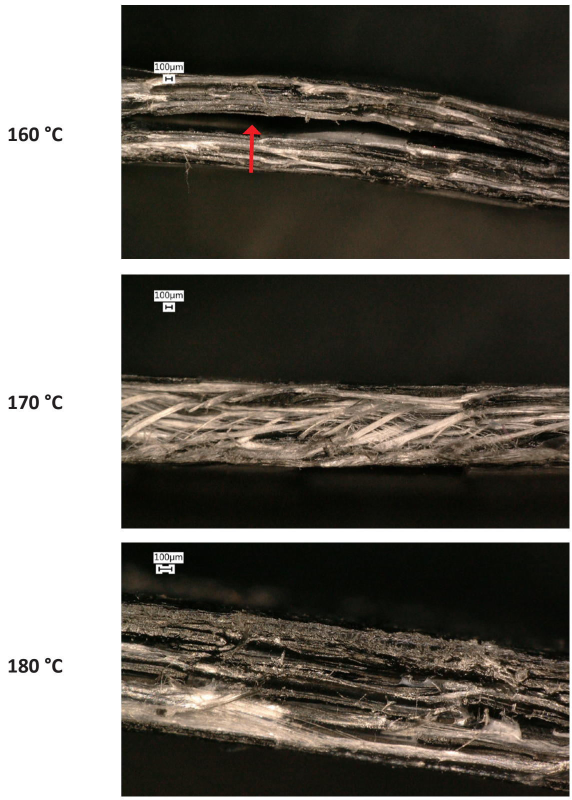



Figure 65: Microscopic pictures of samples 0.

During the bending tests of the specimens compacted at 160 °C cracking sounds were heard. The microscopic pictures of the 160 °C specimens of all three orientations show clear delamination at the areas indicated in figure 66. When looking back at the stress-strain curves, there is a lower maximum stress compared to the other temperatures. Because the chain molecules align themselves in the direction of the load, there will be additional stress on the adhesion parts between the different fiber layers. In this case, the bonds between the layers are not strong enough to hold the layers together. The average toughness of this compaction temperature is also the lowest.

Based on both the stress-strain curves and the average toughness, the compaction temperature of 170 °C has the best results. It has 43% higher toughness compared to the average of 160 °C  and 33% compared to 180 °C. The stress-strain curves of 170 °C show more deflection which is an indication for ductility and a higher maximum stress which is the flexural strength of the material.  The only exception is with orientation 0 where 180 °C has a higher maximum stress than 170 °C, but the difference is minimal and thus not considered significant. Of the three different orientations, 0 and 0/45 show better toughness than 45/0.

The stress-strain curve of a three point bending test with regular PP can be used as a reference condition for the stress-strain curves of SRPP. This curve was found in the research of Bispo et al. (2015) (see figure 67). However, the sample size of this research was according to the standard ISO 178, which is bigger compared to the size used for the SRPP samples, and has a minimum thickness of 3 mm. Also, a different bending speed of 1 mm/min was used. This might explain why the maximum stress is higher for the regular PP in the study of Bispo et al. (2015) compared to the maximum stresses of the different specimen of SRPP. To be able to really compare the stress-strain curve of PP to SRPP, another fatigue bending test has to be done in the same way with PP specimen.

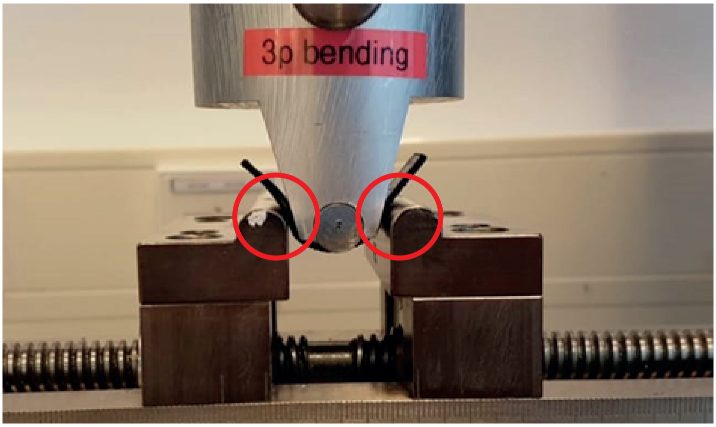



Figure 66: Indication of delamination areas.

Comparing the toughness of the specimen to the results of the study done by Malik et al. (2017) gives the conclusion that the performance of the different ply orientations only partially correspond to the results of Malik et al.. The orientation 45/0 has the lowest toughness with all temperatures, which is the same in the case of Malik et al. (2017). The difference with the bending test is that orientation 0 has higher toughness than orientation 0/45 with two temperatures. However, the estimated toughness and the absorbed impact energy are not completely comparable, as they are tested and measured in different ways. Also, this fatigue bending test was performed at high speed. Therefore, an additional impact test needs to be done to define which orientation performs best on impact resistance with a compaction temperature of 170 °C.

Lastly, the fatigue bending test might be influenced by the laser cutting of the specimen, as the edges of the specimen were melted and sealed. This might have given the samples more stiffness and/or toughness.

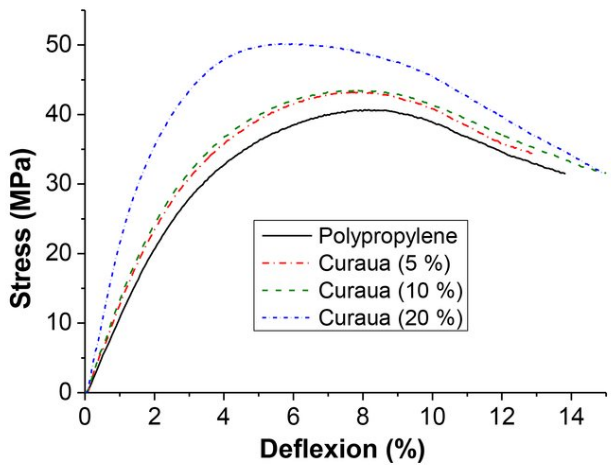



Figure 67: Average stress deflection curves of polypropylene and biocomposites (Bispo et al., 2015).

**Goal**
By performing a fatigue bending test, the best compaction temperature was selected. This means that only one parameter is left to determine. An impact test on the three orientations made with a compaction temperature of 170 °C will be conducted to find the orientation with the highest impact resistance.

**Setup**
The Izod impact test was chosen as the sample thickness does not meet the required thickness of 10 mm for the Charpy standard ISO 179. The required thickness of 3 mm for the Izod impact test according to the standard ISO 180 is closer to the 1,2 mm of the samples. Also, while trying the Charpy test out, it became clear the SRPP sample needs to be clamped down, otherwise it will deform and not stay at its designated position to absorb the impact energy. This is normally not part of a standard Charpy method. The Izod impact test on the other hand has one side of the sample clamped down (see figure 68). However, the thickness of 1,2 mm of the samples do not meet the minimum required 3 mm of the standard ISO 180. Therefore, the standard will not be used, as the test results are qualitative and meant for comparison of the samples only. This can be done as long as it is consistant for all the samples. The consequence is that the results of this impact test cannot be compared to other Izod impact tests which did follow a standard or any other test setup.

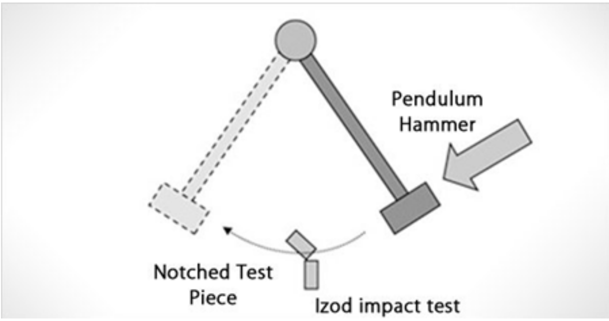



Figure 68: Setup Izod impact test (STL Testlab, n.d.).

Another reason why the standard was not used is because the only available impact test machine is a Charpy tester. Thus an adjusted Izod test setup was needed which was made through trial and error. The final setup can be found in figure 69. The adjustments made to the Charpy test machine can be found in more detail in appendix H. For the impact tests, the 4J pendulum hammer was used.

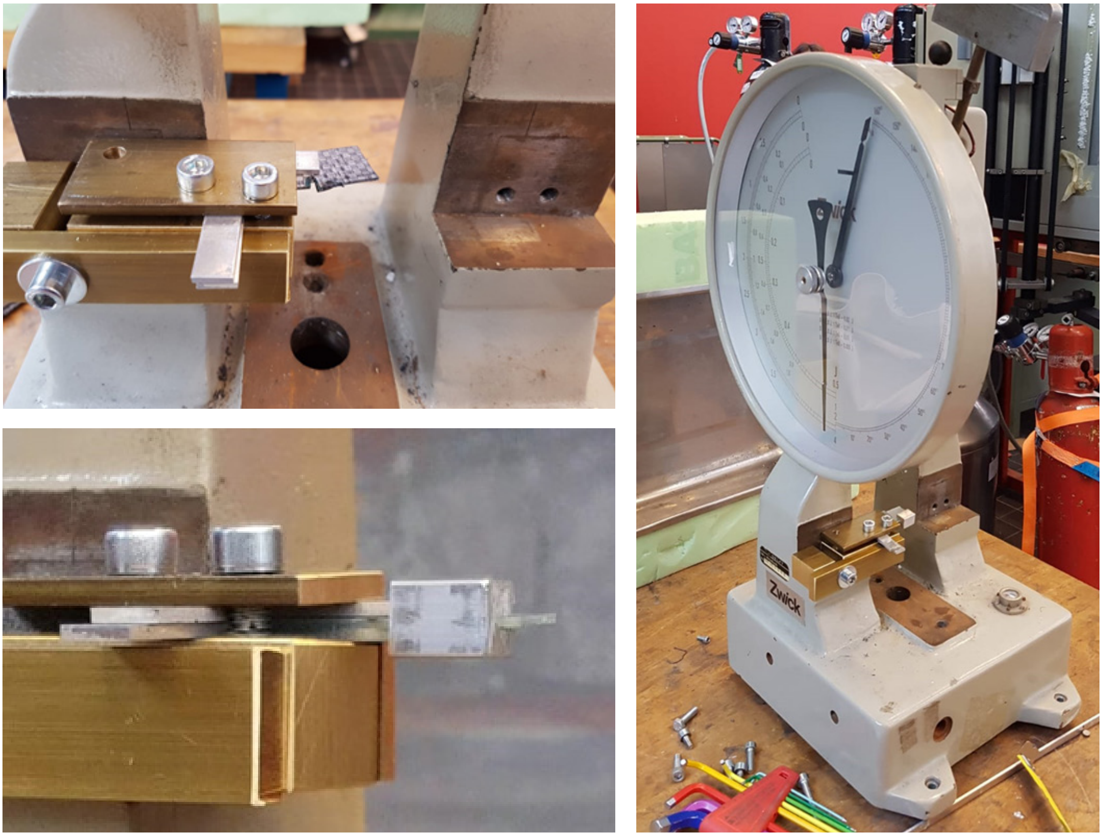



Figure 69: Adjusted setup Izod impact test

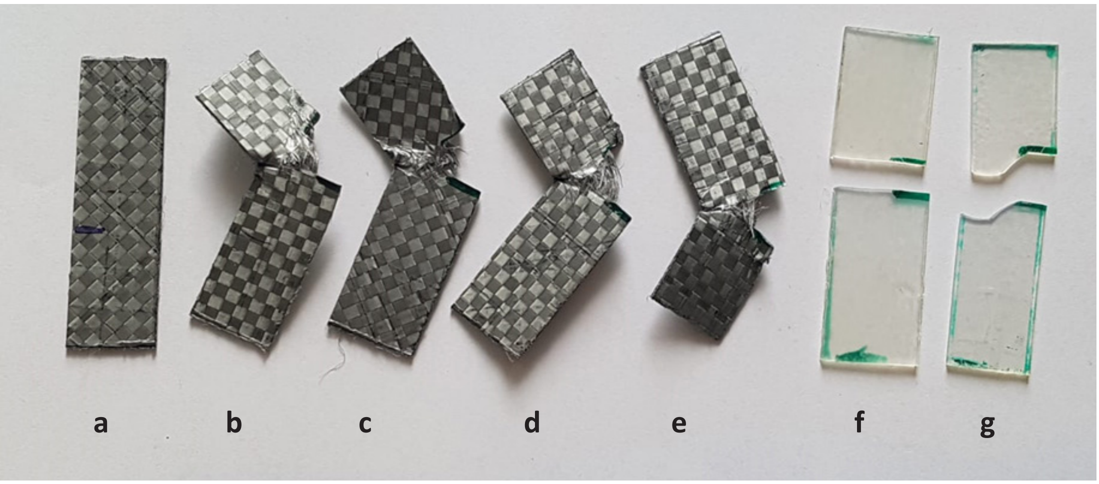



Figure 70: Samples that are used for the Izod impact test.
a) example size & cut size, b) 0 + film, c) 45/0, d) 0/45, e) 0 without film, f) matte pp fil, g) transparant pp film.

The laminates were made of the three orientations with a compaction temperature of 170 °C. To compare their impact behavior, it was decided to also test on regular PP, which was made out of 50 PP films and the original SRPP without PP film, both made under the same circumstances as the other three laminates. The SRPP without film was made with the 0 orientation. The regular PP film had two different areas after production: a mat area at the edges of the laminate and a transparent middle area (see figure 71). The difference in this material is caused by how fast the material cooled down. The transparent area cooled faster than the matte edges. Samples were made of both areas and compared to see the difference in impact resistance.

The laminates were then cut into samples with a size of 5 cm by 1,5 cm and had a thickness of 1,2 mm (see figure 70). No V notch was used as this caused a lot of buckling, which made it harder to get the samples to actually fracture. Instead, there was chosen to make a smaller straight line notch by cutting the sample with a razor blade. The cut was made at 2 cm of the width and was roughly 0,5 cm. Five samples of each laminate was used for testing, unless stated otherwise.


Figure 71: PP laminate with transparent and matte areas.

The sample was clamped at the longer side in between smaller aluminium plates. This is to make sure the sample is hold onto its position, but not fully clamped as clamping will influence the impact results. Because the sample is still thinner than the usual samples used with Izod and because an indent could be seen at the spot where the pendulum hammer makes contact with the sample during trial of the setup, an attachment was used which covered 1,5 cm by 0,5 cm to distribute the force over a larger area (see figure 69).

**Results**

The results of the impact testing can be seen in figure 72. The absorbed energy per different type of PP and different orientation is visible. For the orientation 45/0 and the 0 orientation of SRPP without PP film 10 samples were used instead of 5, as the absorbed energy and the impact behavior of the samples themselves were not consistent. Figure 70 shows a selection of samples that were used for the impact test.

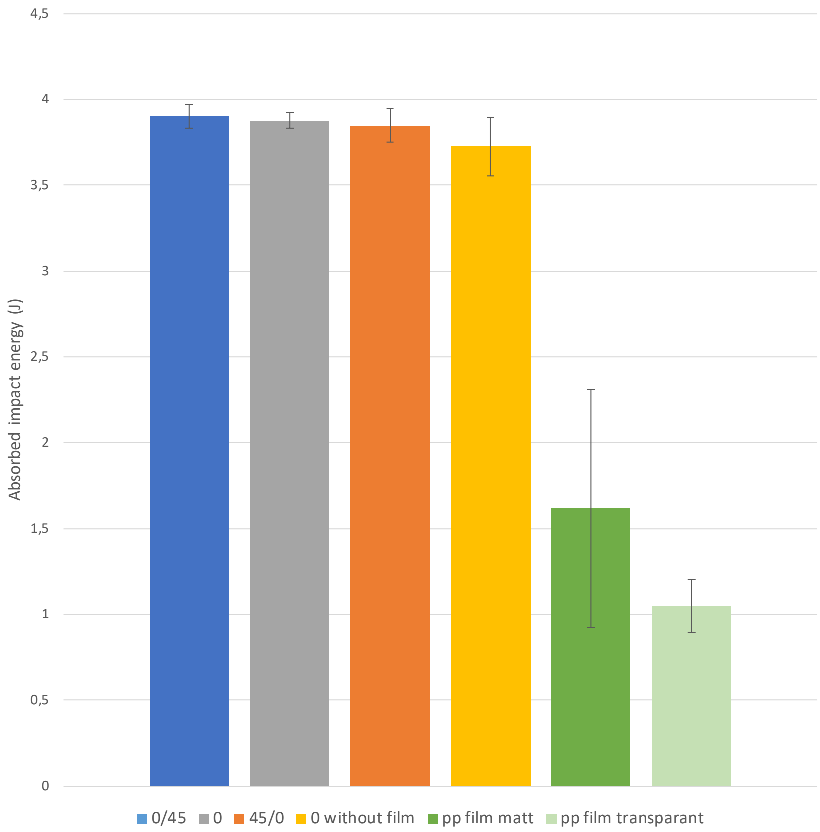



Figure 72: Impact resistance of different kinds of PP.

**Discussion & Conclusion**

Based on figure 72 and the images of the used samples, it is clear that the regular PP are less tough compared to the SRPP samples. The absorbed impact energy of SRPP is around 2,5 times higher than that of PP and the samples show a clear fracture, which means the material is brittle. The SRPP samples all show a similar kind of fracture, but they did not break completely. This means that the SRPP in general is relatively tough.

When comparing the results of the 0 orientation SRPP without film to the other 0 orientation with film, it can be concluded that the addition of the film gives the material slightly more toughness. However, the hammer did slip a couple of times past the sample without really hitting it, which is why more samples were used. To better understand the behavior in the Izod test of the SRPP 0 samples without film, more research needs to be done by for example performing other tests such as the bending test.

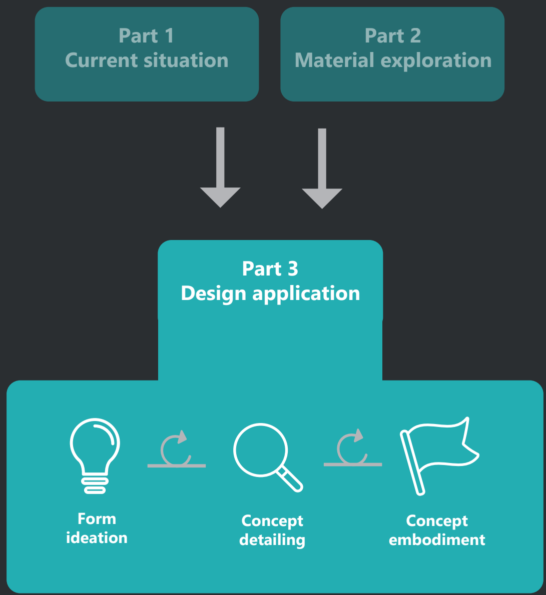
Based on figure 72, the 0/45 orientation absorbs slightly more energy compared to the other orientations. However, the difference is 1%, which is not significant. Therefore, the results from the fatigue bending test were also taken into account for the selection of the orientation. The orientations 0/45 and 0 scored both high and therefore they will be additionally tested with a drop test later on in this project (see subchapter 11.2).

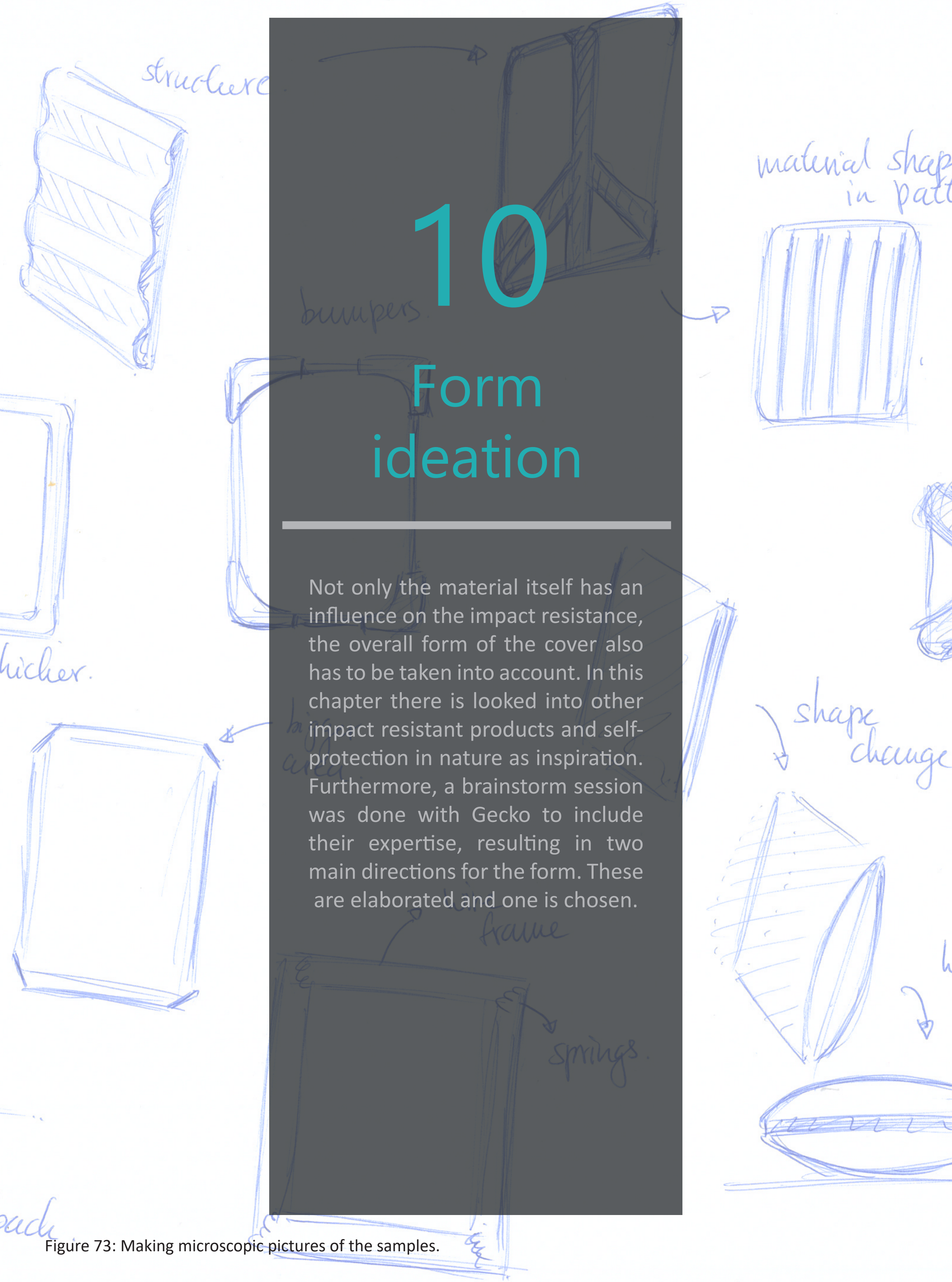
An important aspect to take into account is that the test setup might not be completely optimized, as limited time was available to set up a new testing method. Also, testing the samples after they have been cooled down to at least -20 °C might give more insights in the toughness of the material, as it is closer to the DBTT temperature of the material and fractures are more likely to happen. The material at room temperature did not fracture completely or at all.

To evaluate the SRPP laminates, a bending fatigue test and alternative Izod impact test are conducted. The samples made with a compaction temperature of 170 °C have the most toughness, highest maximum stress and deflection for all orientations. Based on both the bending and the Izod test, the orientations 0 and 0/45 have more impact resistance. To select the best one, they will be evaluated further by the means of a drop test.

# Part 3
# Application

In this part the findings from part 1 and 2 are used as input. Firstly, the overall shape will be determined through ideation (chapter 10). Afterwards, the chosen shape will be validated through a drop test and further detailed in chapter 11. This leads to the final design, along with its embodiment (see chapter 12).






# 10

# Form ideation

Not only the material itself has an influence on the impact resistance, the overall form of the cover also has to be taken into account. In this chapter there is looked into other impact resistant products and self-protection in nature as inspiration. Furthermore, a brainstorm session was done with Gecko to include their expertise, resulting in two main directions for the form. These are elaborated and one is chosen.

Figure 73: Making microscopic pictures of the samples.

# 10.1 Inspiration

At the start of the ideation phase, a brainstorm session was done with Gecko and a fellow graduation student (see figure 73). Appendix I shows the activities that were done during the brainstorm, along with the results. One of the parts of this brainstorm was looking at self-protection in nature which was used as inspiration for the shape of the cover (see figure 75).

Figure 76 shows other impact related products. Many of the impact products use materials to absorb the impact, such as the case with running shoes. The more rubber like material of the shoe sole creates more damping. In the case of car bumpers, the material absorbs the energy upon impact by deforming. Suitcases on the other hand do not want to have any deformation, as it has to protect the items within and it is not aesthetically pleasing. Suitcases are lightweight by using as little material as possible. To make sure the thin walls of the suitcase will not deform, structures are added to the big surfaces that are more prone to deform. One thing that a lot of impact resistant products have in common is that either the shape is rounded or the edges of the product are rounded off.

These two inspirations were used to ideate on how the shape can influence the impact resistance positively. Two directions were found which are elaborated in the next subchapter.

Figure 74: Brainstorm session at Teclo Accessories

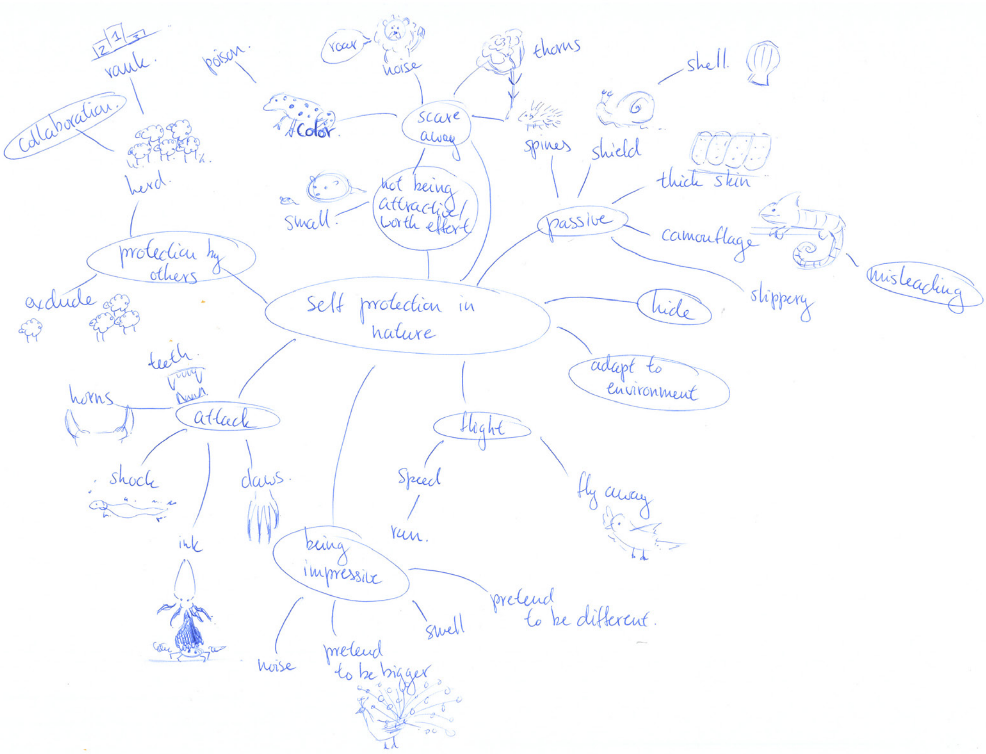



Figure 75: Mindmap self protection in nature.


Figure 76: Impact related product.

**Shuttlecock principle**

The first direction is based on the principle of a badminton shuttlecock. During the brainstorm with Gecko it came up to drop the product on the spot where it is the most impact resistant. When a badminton shuttle is dropped, it will always land on the cork or rubber base. It is assumed that because of the big difference in density, the shuttle shows this behavior. Figure 78 shows ideas based on this principle.

However, when looking more in depth into this phenomenon, it becomes clear that not only the big difference in density causes the shuttle to always fall in the same way. A paper of Kaushik (2017) mentions that it is a combination of both center of mass and center of pressure. In a research of Texier et al. (2012) is is stated that the center of mass is closer to the cork or rubber base and the center of pressure is closer to the center of the volume which is the (plastic) feather skirt (see figure 77). When the shuttlecock is not aligned with its velocity direction, the drag force submits a stabilizing torque to the shuttle (Texier et al., 2012).

Based on these findings it can be concluded that this phenomenon is not easily reproducible. It is most likely due to the specific elements which are only found in the shuttlecock such as big extremes in weight, volume and symmetrical shape. Therefore it was decided not to pursue this direction any further.

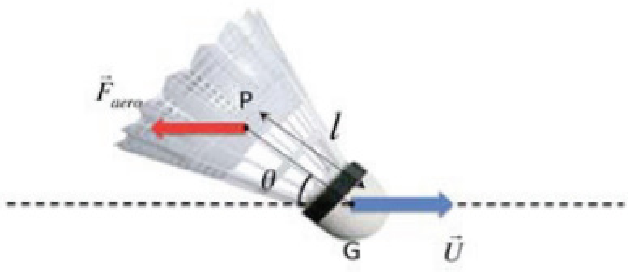



Figure 77: The cause of the flipping behavior of a badminton shuttlecock (Texier, 2012).

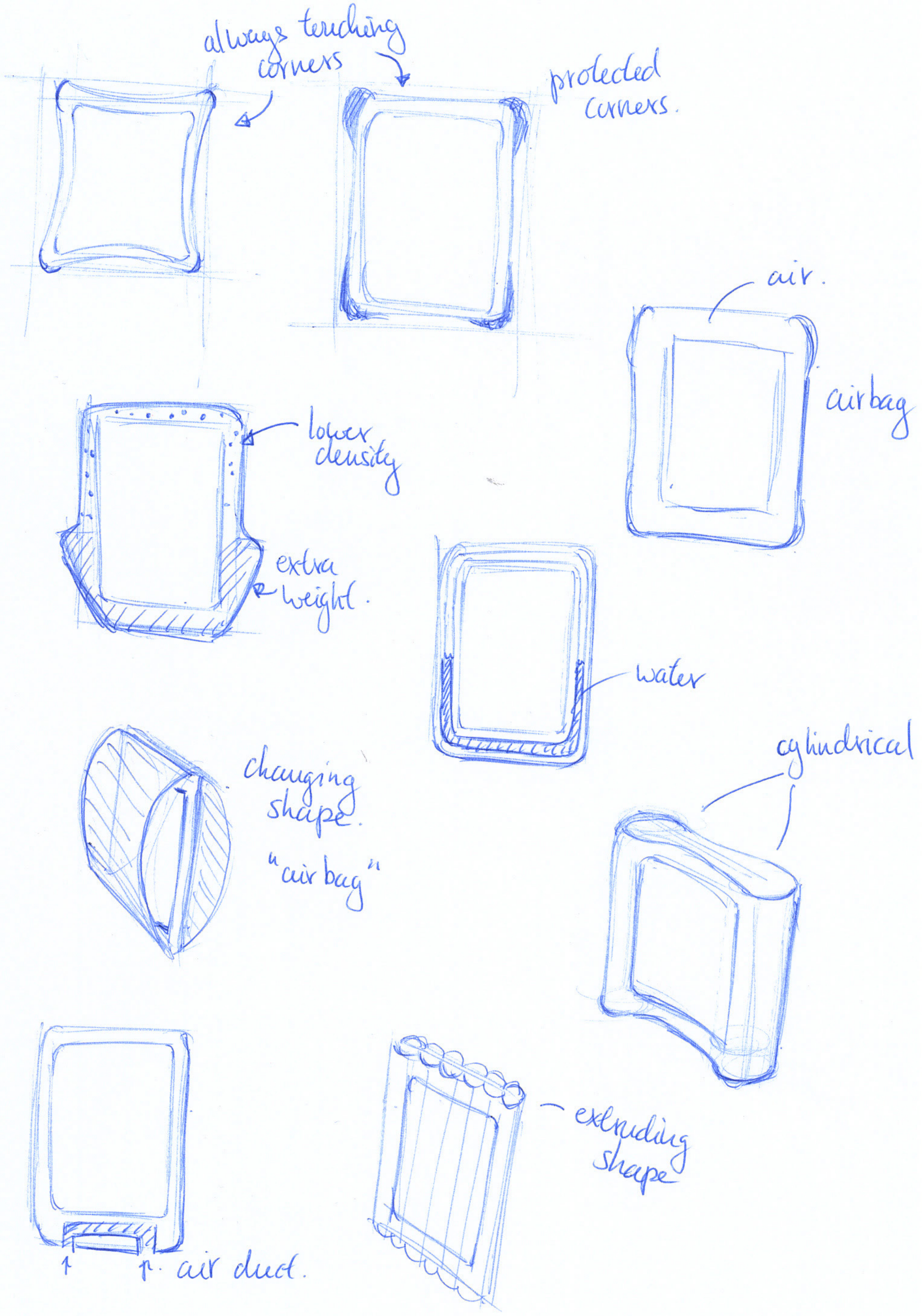



Figure 78: Ideas based on badminton shuttle principle.

**Biomimicry structure**

The second direction is based on the structures that are used on suitcases. Figure 80 gives an overview of different structures that are currently used by big brands such as Samsonite (the blue suitcase) and Tumi (the grey suitcase). The structures are used to stiffen the material to make the product more tough and it is expected that it will have the same effect when applying it to the backside of the new impact cover, as the suitcases are roughly the same shape.

There are many possible structure designs. A reference to nature or biomimicry will stand out compared to other impact tablet covers and connects well with one of the USPs of the material, namely reducing the environmental impact of the cover by making it recyclable. This reference to nature is also used by some of the suitcase brands. Samsonite took a sea shell as inspiration for their suitcase, which is also made out of SRPP (Curv) (Plastic News Europe, 2010). This proves that using a texture is possible with SRPP. Figure 81 shows some ideas for nature related patterns.

The design of shape of the tablet cover is kept relatively simple. There was chosen not to explore any new ways of using shape to make the tablet cover more impact resistant, as the main focus of this graduation project is on applying the adjusted material to make the cover more impact resistant. Therefore, only the main shape elements that influence the perception on impact resistance the most are taken into account (see chapter 5). Those are the following elements:

- a screen edge that goes far enough over the screen and is high enough not to make the tablet screen touch the surface it falls on.
- covering all the edges and corners of the tablet.

These main elements combined with the backside structure will form the minimal viable product (MPV) (see figure 79).

Figure 79: Basic shape elements which are taken into account.


Figure 80: Structures in suitcases.

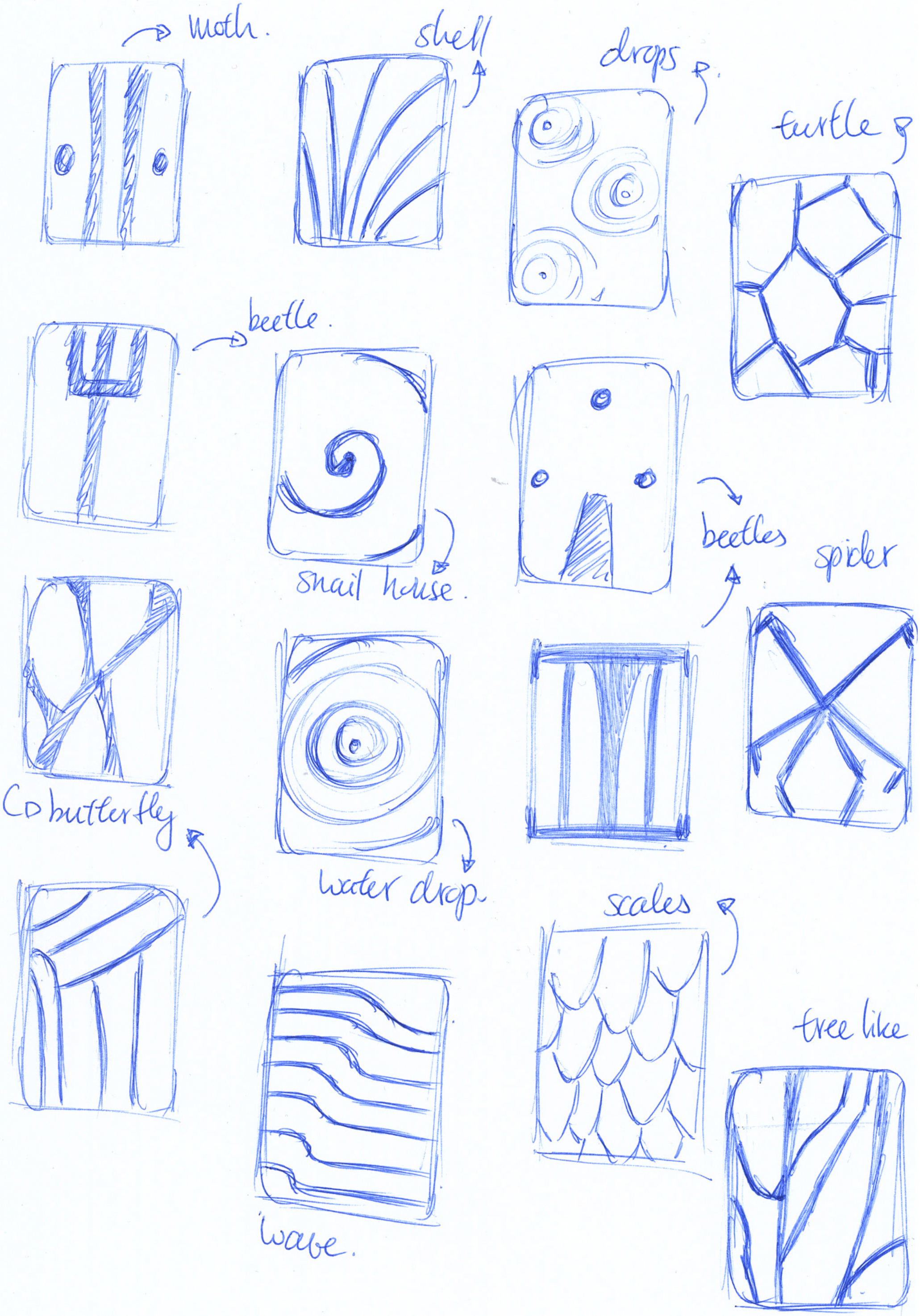



Figure 81: Ideas based on suitcase structure.

To stay in the scope of this graduation project, the decision is made to focus mainly on the shape elements which influence the perception on impact resistance the most. These are the backside structure, the screen edge and the protection on the sides and corners of the tablet and together they form the MVP. For the backside structure a reference to nature or biomimicry will stand out compared to other impact tablet covers and connects well with one of the USPs of the material, namely reducing the environmental impact of the cover by making it recyclable.

# 11

# Concept detailing

In this chapter the MVP is further detailed. First, it is validated whether the shape can be produced out of SRPP by making a proof of concept. Then a drop test is conducted with the proof of concept, so that the ply orientations could be tested on performance and compared to the covers of the competitors. Lastly, the design is adjusted based on the results and the style of the impact cover is determined.


Figure 82: Making a 3D model for the mold.

# 11.1 Proof of concept

The SRPP has so far been shaped into sheets (chapter 8), but to create a tablet cover it needs to be shaped in the form discussed in chapter 10. To prove that it is producible with SRPP, a proof of concept was made. To shape the SRPP, a mold is needed. However, when discussing how to design the mold itself with employees of the PMB at the faculty, it became clear that it would not be possible to make the screen edge out of SRPP. The reason is that the mold would have to be very complicated, and they also advised against it for commercial production of the product as the mold design would be very expensive with more than two moving mold parts. Therefore, the focus will be on the basic shape without the screen edge as a proof of concept. The mold is made out of aluminum which was CNC milled (see figure 83). Appendix J shows the technical drawings of the upper and lower mold parts.

The proof of concept was made in exactly the same way as the laminates: 7 layers of fiber and 8 layers of film with a compaction temperature of 170 °C, 5 minutes of active heating time, a pressure of 1,73 bar and cooled down till the sample itself was 79 °C. Because the heat has to be transferred through the aluminum, a thermocouple was placed in between the two mold parts to check the temperature of the sample more accurately. The setup can be seen in figure 84.

When the sample cooled down to 79 °C, the mold was removed from the hot press. Then the mold was turned upside down, and the female mold part is removed. The sample was left to cool down completely overnight, as it made it easier to remove and shrinkage is avoided. The next day the sample was removed (see figure 85). Lastly, the excess material at the edges are cut.

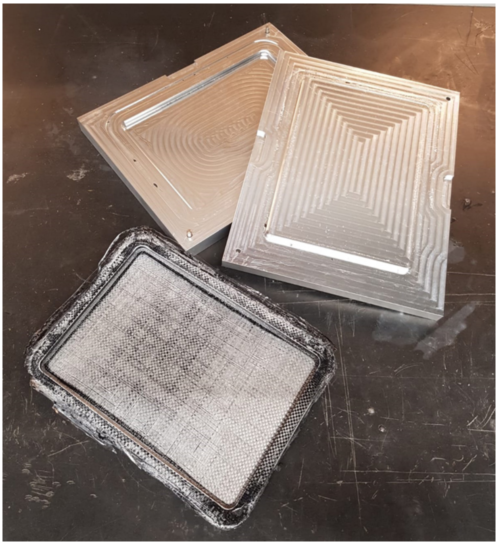


Figure 83: The molds used to make the proof of concept.


Figure 84: The setup with thermocouple.

It was expected that the corners would have a draping problem because the material is made of woven fabric. However, as can be seen in the images, this was not the case. To validate the proof of concept on actual impact performance, a drop test is set up. This was also done to validate which orientation would have better impact properties: 0 or 0/45. Thus a total three proof of concepts were made, as one sample is considered for backup or as visual model (see figure 86, 87 and 88).

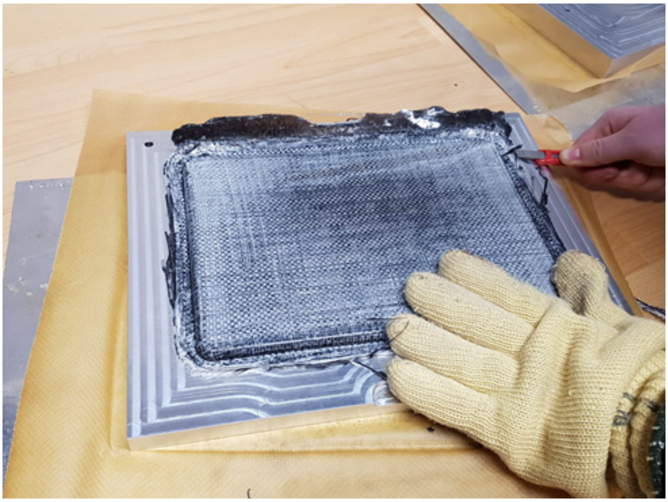


Figure 85: Removing the sample from the male mold.

**a** **b** **c**

Figure 86: The three proof of concepts made: a) 0/45, b) 0/45, c) 0.

Figure 87: Edges of the proof of concepts.

Figure 88: Front side showing the fitting of the dummy iPad.

**Goal**

In chapter 5 the tablet users mentioned the tablet cover characteristics that give them the feeling of impact resistance. To test whether those elements really have an effect on the impact resistance of the tablet, the four tablet covers which were used in the user study of subchapter 5.1 are used in a drop test. Furthermore, there will be looked at the differences in impact resistance of the shaped samples made of the orientations 0 and 0/45.

**Setup**

The most likely way for a tablet user to drop their tablet is either by letting it fall out of their hands while holding it or knocking it off their working space, such as a desk. The most extreme on the go use case was chosen, which is dropping the tablet cover on the sidewalk while working on it. This means that the screen is not covered if there is no built-in screen protector. To mimic this situation, the drop test was done outside on a sidewalk. The drop height is based on the height tablet users usually hold their tablet while standing. As can be seen in figure 90, it is around elbow height. In DINED the average elbow height of females and males with an age of 20 to 60 years is 1084 mm, which also has been used as minimum height for the drop test.

No drop tower or other drop test equipment was available, therefore the drop test is done manually. The setup can be seen in figure 89. The tablet cover is dropped on the corner, as it is expected that this is the most critical area. The corner has the smallest surface area compared to any other part of the tablet cover, which means that the impact per surface area is higher and would more likely result in failure. The drop is recorded in slow-motion with a Samsung Galaxy Fold to be able to observe what happened at the moment of impact.


Figure 89: Setup drop test.

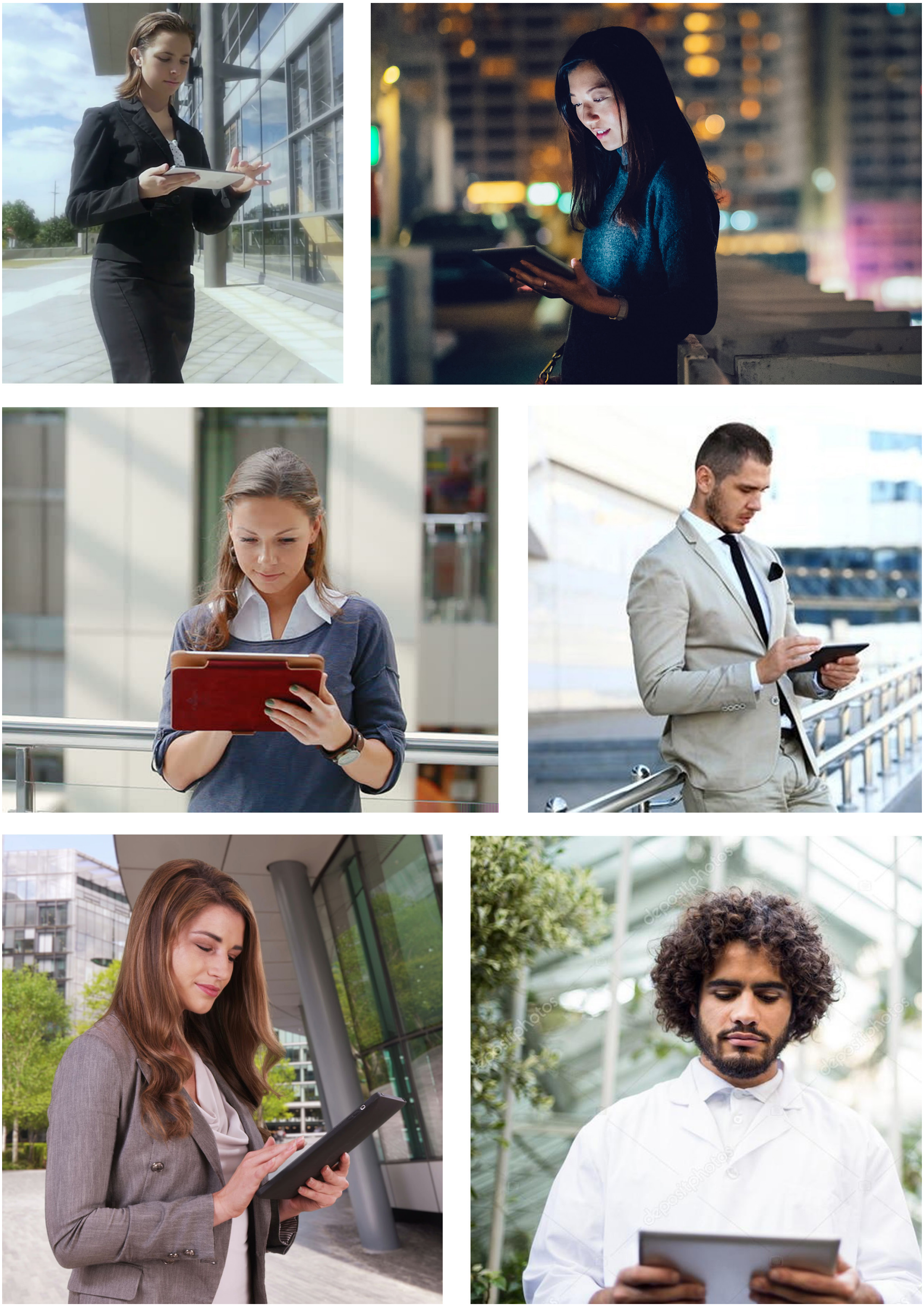


Figure 90: Tablet users mainly use their tablet on elbow height while standing.

As mentioned before, the four tablet cases from the user study in 5.1 were used in this drop test. Additionally, two SRPP sample cases with different orientations were used as well: the 0 and 0/45 orientation. Because it was not possible to use a real iPad for this drop test, dummy iPads of the same size were used which are made out of plastic but have a similar weight. To still mimic the glass screen of a real iPad, H7 glass screen protectors were added. It is expected that these screen protectors break more easily compared to a real iPad screen. However, it will give an indication of where the fracture started and makes it easier to observe during the slow-motion recording. In the case of the SRPP sample covers, the tablet dummies were taped in the cover. This is to prevent the dummy to fall out of the case before the impact happens, since they lack the screen edge.

**Results**

Figure 91: Drop test Otterbox.

- Otterbox
  Protected the tablet dummy and bounced back. No damage was visible on either the iPad dummy, Otterbox tablet cover or the glass screen protector (see figure 91).

Figure 92: Drop test UAG.

- UAG
  Did bounce back with the softer material but the screen did break. There are also some grazes visible on the corner of the tablet cover itself (see figure 92).

Figure 93: Drop test Gecko.

- Gecko
  The edges were not enough to hold the tablet in the tablet cover. The glass screen protector was broken on the corner and in the middle of the screen. On the cover itself an indent was visible on the corner, where the impact happened at first (see figure 93).

Figure 94: Drop test Tech21.

- Tech21
  Bounced back after impact, but the edge of the tablet and screen protector were hit. Especially the corner area of the glass screen protector is shattered (see figure 94).

Figure 95: Drop test 0 orientation.

- 0 orientation
  Had the impact on the corner of the tablet dummy, which causes the tablet to slip out of the cover. There is some damage to the tablet dummy’s corner as it hit the ground (grazes), but there was no damage on the screen protector or the cover itself (see figure 95).

Figure 96: Drop test 0/45 orientation.

- 0/45 orientation
  Fell in an angle forward on the corner, which caused the impact to be more on the tablet dummy and the screen protector than the actual cover itself. The edge was therefore shattered and the tablet dummy was damaged on the corner as well. The tablet cover itself had no damage (see figure 96).

Figure 97: Drop test alternative drops.

As there was no damage found on the SRPP sample covers additional drops were done, such as impact on the edges and the backside. No damage was found on the SRPP sample covers after these drop tests as well (see figure 97). However, the iPad dummies did break (see figure 98).

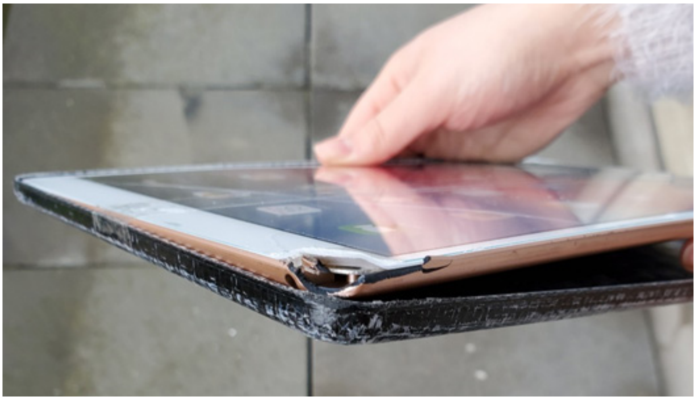


Figure 98: Damage on dummy iPad after alternative drops.

**Conclusion & Discussion**

Softer material does give more damping, which can be seen with the drop test of Otterbox, where the rubber layer made the cover bounce back without any damage. The samples made with SRPP lacked damping and the impact energy was at some point transferred to the iPad dummy, which can be seen in figure 98. This means an additional layer of softer material is needed at the edges and corner of the new impact cover to prevent this impact energy transfer.

Another element which is important to take into account is the screen edge. As the participants in 5.1 predicted, the absence of a screen edge in Gecko's cover made the tablet dummy fall out of the cover during the fall. The same thing happened with the SRPP samples, as it was not possible to make the screen edge out of the SRPP. However, it should be added in the final concept to prevent the tablet from falling out of the cover.

In the case of Tech21 and UAG the screen edge did not prevent the glass screen protector from damaging. When looking at the damage and the way the tablet cover hit the ground, a reason could be that the glass screen protector did not fit under the screen edge. This means that at the moment of impact, the screen edge hit the edge of the screen protector, which made it fold at the corner and crack. No conclusions can be made about whether the width of the screen edge is too short or not, as the glass screen protector might not have this tendency on a real iPad screen.

No difference could be found between the SRPP sample covers of 0 and 0/45 orientation. Both transferred the impact energy to the tablet dummy and did not have any damage themselves.

Lastly, there are a couple of things which have to be taken into consideration. The plastic dummy tablet most likely does not behave similarly to a real iPad, because different materials are used and the weight distribution might be different. For example, some deformation of the plastic screen underneath the glass screen protector could be seen during impact. Also, as mentioned before, the glass screen protector is expected to break more easily than the real glass screen of an iPad because it is thinner. Lastly, because no drop tower or other drop mechanism could be used, it is expected that the tablet covers all got a slightly different drop angle as it was done manually.

**Zen Design method**

The style of the new tablet cover needs to meet the following requirements:

- *It has to highlight the SRPP*
  The SRPP is the USP of the new tablet cover, as it is not used by any of the competitors and makes it possible to recycle the cover completely.
- *It has to fit the target group: the tablet user on the go*
  The user group travels and takes their tablet with them, to work or to kill time. They want a combination of a styleful and impact resistant cover.
- *It has to fit Gecko's style*
  Gecko's style is simple, colorful, an joyful. Their product always has two different textures and two colors: one calm and one highlight color.
- *The overall look of the product should give the impression of robustness*
  Robustness was the most mentioned product character during the user test in chapter 5. People link robustness with impact resistance in the case of tablet covers.

To make sure that the design meets these requirements, a part of the Zen Design method (Bruens, 2011) is used. Following this method the lifestyle of the user, the emotions the product should evoke and the wanted design memes for the product, which are wanted design elements such as shape, color and material, are looked into. The lifestyle of the user has already been analyzed in chapter 5. The emotions and memes will be discussed in the following paragraphs.

**Emotions**

The emotions the product should evoke are confidence, freedom, joy and appreciation (see figure 99). Confidence and freedom enables the user to use their tablet on the go without worrying. Joy and appreciation are linked back to Gecko, as their products are joyful and made with care and focus on details. The emotions can be influenced by the memes, but also by production choices.

Figure 99: Emotion collage.

**Memes**
As mentioned before, memes are the design elements such as color and shape. For the new impact cover, the memes that are left to determine are the backside structure, the shape of the screen edge and the colors. These will be discussed below.

*Structure*
At first, the idea was to make the structure out of SRPP only. However, this did not make the pattern stand out. Because the screen edge, the edges and the corners have to be made out of a softer material, the structure can also be made of this softer material instead of SRPP. This makes it possible to color the pattern, which also fits more in Gecko's style. To still highlight the SRPP, the structure should not be too overwhelming and should not take the attention away. Therefore, the structure cannot be a pattern, as consumers will recognize this and focus on it. Furthermore, it would be nice if the structure could be related back to nature to highlight the recyclability of the SRPP. Appendix K shows all the ideation for the structures, in this subchapter only the chosen structure style will be discussed.

The SRPP itself is robust looking, as it looks rigid, static and hard. It gives off an industrial look. To keep the overall product more in balance, a softer shape needs to "embrace" the SRPP. Straight lines give a more clean and simple look, but should not be used in the same directions as the geometric pattern of the woven SRPP. This will put more emphasis on the rigid and static feeling of the material. For inspiration, Voronoi structures in nature (e.g. bones and fungi) were analyzed (see figure 100).

The Voronoi structures have both curved and straight lines, which become tapered. There are also a lot of open parts, which can help highlight the SRPP. The pattern is illogical to the eye and therefore won't distract the user. Figure 101 shows a selection of the structure ideation with the Voronoi as inspiration. The enlarged sketch is the final chosen pattern, as it gives off a well balanced feeling. Multiple corners and sides are used to connect the lines, which results in a more robust feeling. Moreover, there are not too many lines and a lot of open areas to highlight the SRPP.

Figure 100: Voronoi structures in nature.

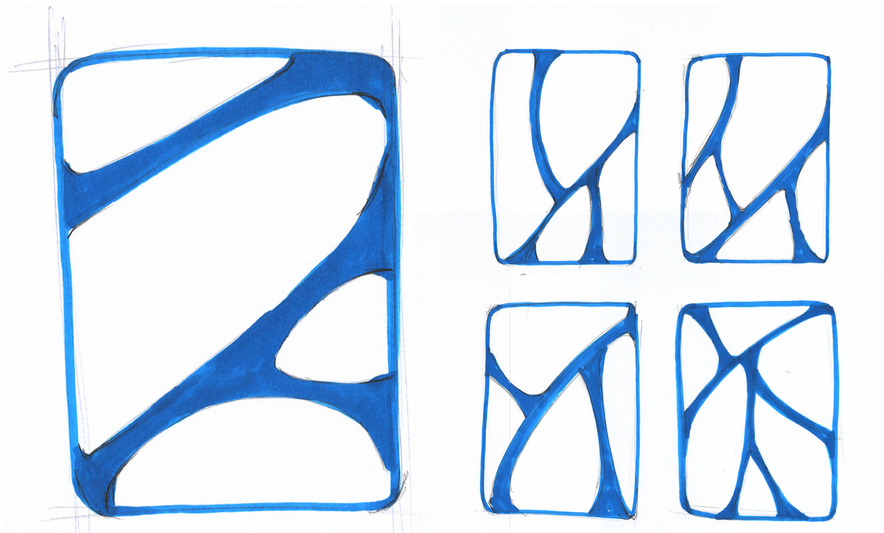


Figure 101: Sketches based on Voronoi structures.

*Screen edge*

The back structure will be connected to the edges and the screen edge. When the user is actually using the tablet, the screen edge will be mainly seen. Thus it is important to add the feeling of robustness and the main style elements to the screen edge as well. However, there is not a lot of design space, as it is mainly a functional element which has to ensure that the screen is protected and that the cover has a good fit. The main focus is therefore on the rounding at the edges and corners. Based on trial and error with 3D printing, the final screen edge is selected (see figure 102). The screen edge is rounded off at the sides but with a different radius than the outer edge, which results in a more playful look. The chamfer on the inside of the edge makes the screen edge look clean and simple. The actual size of the edge will be discussed in chapter 12.

Figure 102: 3D printed screen edge design.

*Color*

As mentioned in chapter 3, Gecko mainly uses a bright highlight color combined with a darker, calmer color. This creates a lot of contrast along with the different textures and is characteristic for Gecko. To keep this in the new product, the back structure will get the highlight color as the SRPP comes originally in black, dark grey, light grey and white. It is possible to color the fibers by using colored PP films, however the cool tones and industrial look of the original colors give the material its robust look.

Figure 103: Possible color schemes for the new cover.

Gecko doesn’t have any white products and the black combined with a highlight color makes a product usually sporty. Thus the light and darker grey are chosen as the two calmer color tones for the new impact cover. For the highlight color, Gecko uses either a cold or warm tone. Because the calm color are the greys of the SRPP, more bright and saturated colors are selected for the structure. Another important requirement is to make the color combination unisex. For inspiration, running shoes were analyzed. In the end, there was chosen to keep the dark grey more in a cool color theme and the lighter grey in a warm color theme (see figure 103).

Figure 105 shows the two final color schemes: dark grey with a clear blue and light grey with a orange yellow. These two color schemes are suitable as unisex, match the colors of the products in the current product portfolio of Gecko, highlight the pattern, and are easy on the eye which would not have been the case with for example red or purple. These combinations give off a trendy look, but are still suitable for business people or office workers.

The proof of concept shows that the main shape of the tablet cover is producible with SRPP. However, the screen edge has to be made in a different way, as it causes the mold to be too complicated and expensive. Furthermore, a drop test is done with the 0 and 0/45 orientation proof of concepts. During the test it became clear that more damping needs to be added to the product by the use of a softer material at the edges and corners, as the proof of concept transferred the impact energy to the tablet dummy. Also, no difference could be found between the 0 and 0/45 orientation. Lastly, a style is chosen. The back structure is inspired by Voronoi structures found in nature, which adds softness and openness to the overall robust, rigid and industrial look of the SRPP. Two color schemes are chosen to make the product more unisex. These colors also fit in the current product portfolio of Gecko and emit a playful and simple look.

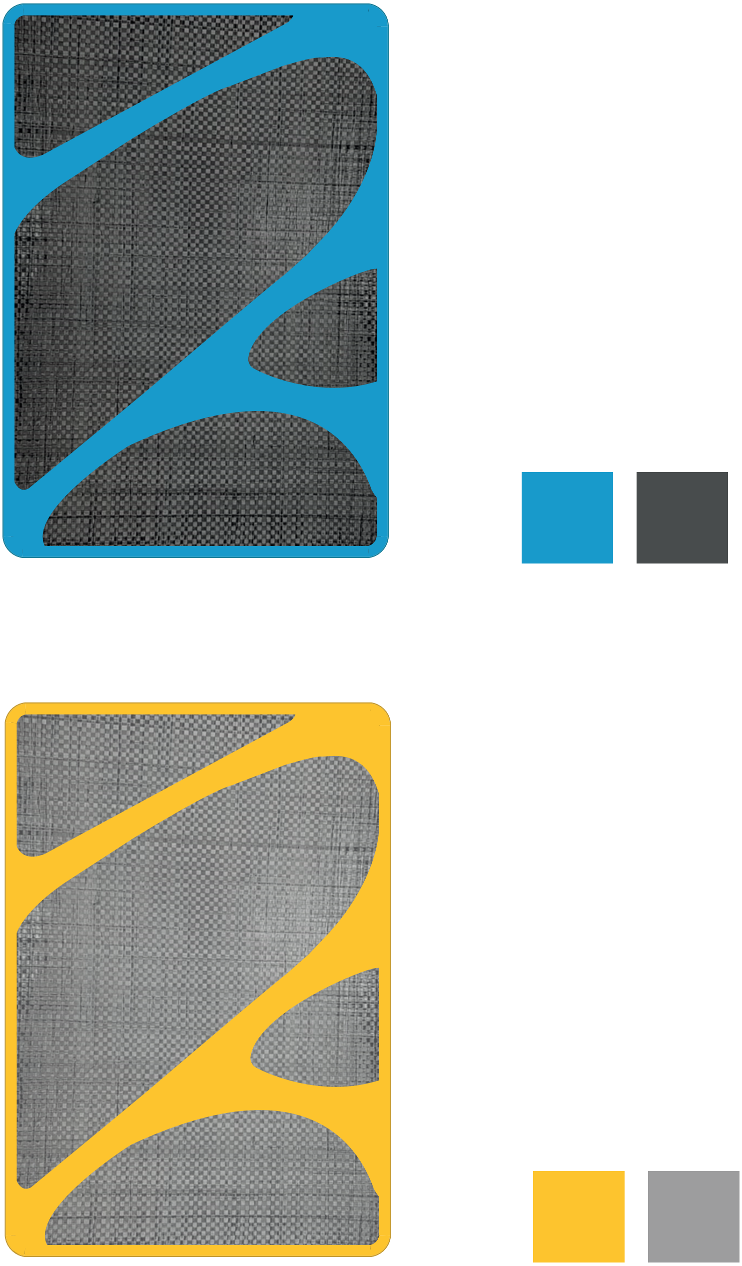


Figure 104: The chosen color schemes along with the final back structure design.

# 12

# Embodiment

In this chapter the final design with embodiment details such as production are presented. Then, the final design is evaluated based on the main requirements from chapter 6.


Figure 105:  Injection molding (Alligator Plastics, n.d.).

# 12.1 Final design

**Gecko Dynamic**

The name for the new cover/cover line is Gecko Dynamic. Gecko gives their product lines simple names that are also broad enough to include the addition of future products. Dynamic stands for the dynamic lives of the user on the go, but it is also a reference to the impact resistance of the cover. Appendix L shows the technical drawing of the back structure. The weight of the SRPP is 50 grams, the injection molded PP is expected to have a similar weight. The final design can be seen in figure 106 and 107. The cover consists of three parts: the injection molded outer part with the back structure, the central SRPP layer made through isothermal molding and the inner part which is also injection molded with PP.

Insert molding was chosen to create the screen edge as it wasn't recommended to do this with SRPP. A complex mold with over three moving parts is needed for the latter, which would be considerably more expensive or even impossible. Insert molding is relatively cheap and provides a lot of design flexibility (Unipipes, 2019). The insert molded material can be of a softer material that provides more damping, which is necessary seeing as the SRPP transferred the impact energy to the iPad dummy during the drop test. Since the main selling point of SRPP is its recyclability due to its single polymer type structure, PP has been chosen for the insert molding as well. The PP material used for 3D printing during the ideation phase is a softer and more flexible type of PP. Therefore, the assumption was made that this kind of PP is also available for injection molding. The inclusion of a softer material also fits the product style of Gecko Covers, which generally utilizes two different materials that create contrast in textures and colors. The back structure is pressed into the SRPP to conjoin the individual parts. This way, the insert molded back structure will act as an inlay and the backside becomes completely flat. Insert molding will additionally provide the product with a better surface finish, which fits the focus on details mentality of Gecko (Flynt, 2019). According to the company DIT, the shaped SRPP is very suitable for insert molding and has good adhesion with the injection molded parts.

**Usage**

As mentioned before, the Gecko Dynamic is designed with the on the go tablet user in mind. The activities that the users undertake are diverse. The main focus lies on scenarios during which the user takes their tablet with them on their travels. The scenario which has been chosen to focus on is the tablet user who uses their tablet during traveling from one spot to another. Figure 108 shows some of the possible steps in the user's journey. A possible user scenario could be the following:

First, the user puts their tablet in their bag before they leave for work. Once they arrive at the train station, the user looks up the time at which the bus will depart from their destination. The train arrives and the user then takes a seat. They may use their tablet in various ways, e.g. to watch videos, read literature or check their email inbox. After having arrived, the user takes the bus to work.

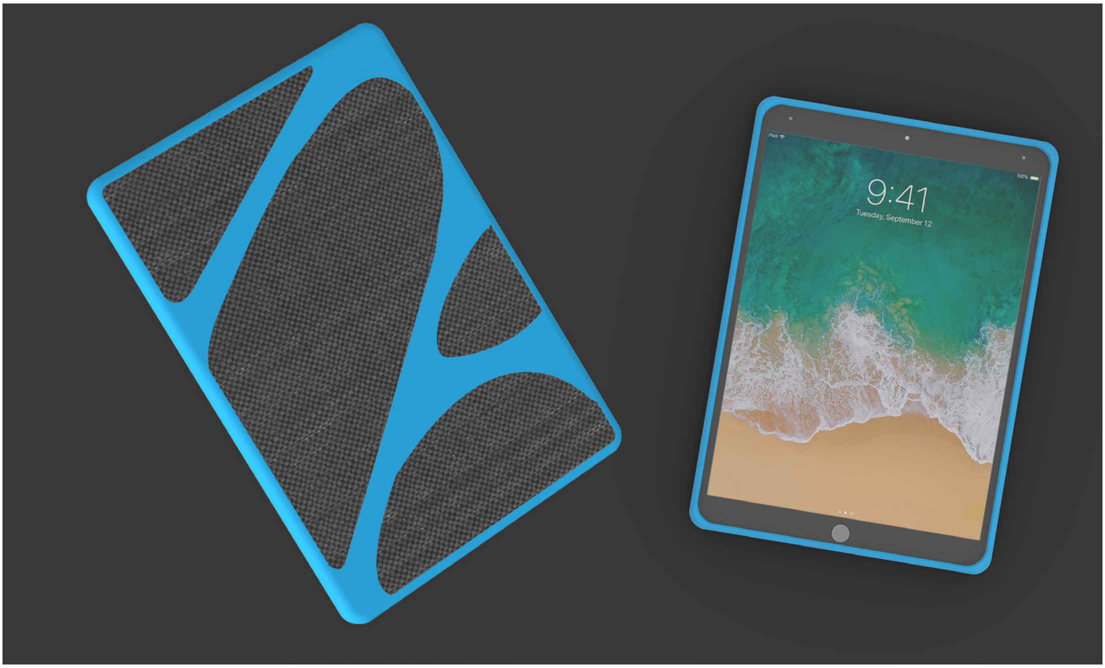



Figure 106: Front and back design of Gecko Dynamic.

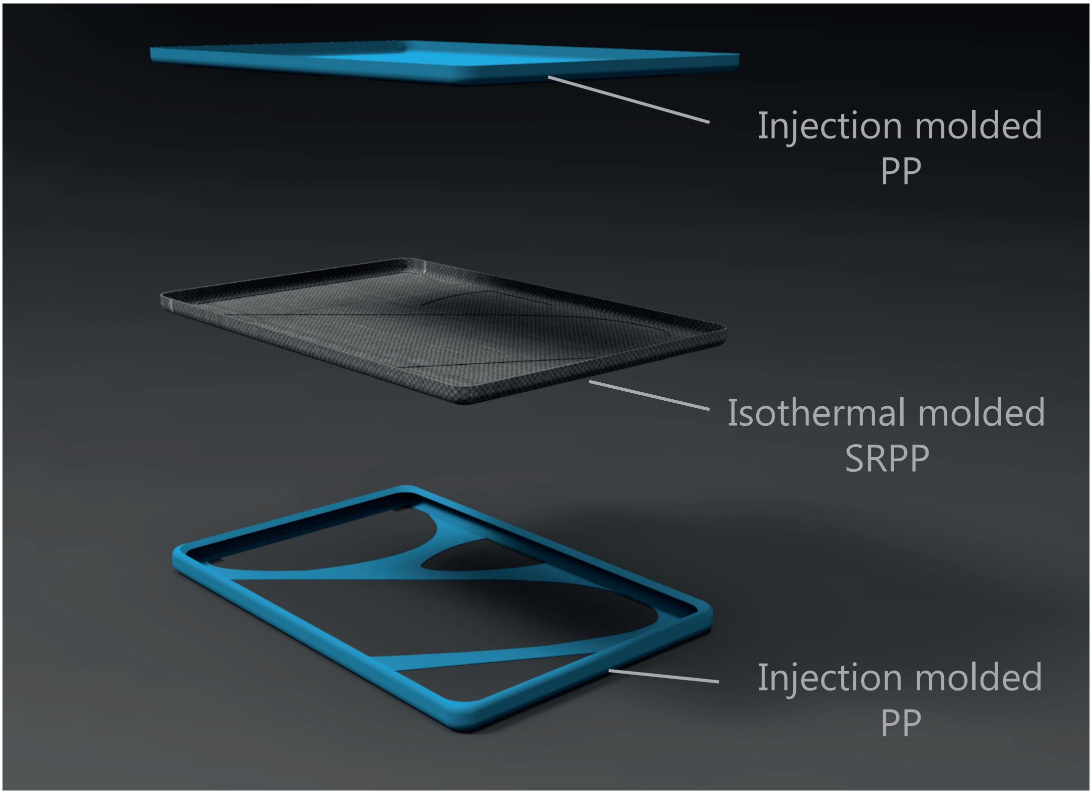



Figure 107: Overview different product parts of Gecko Dynamic.

Figure 108: User scenario.

During this scenario, the tablet could fall on different moments: either on the pavement outside, whilst standing or seated in the train or bus, while at home or in the office. The tablet would have the biggest drop impact on concrete, as it causes a hard blow. Gecko Dynamic has a softer, rubbery layer which should create enough damping for the tablet not to receive any of the impact energy. The SRPP creates stiffness and is tough as well. Furthermore, all the edges are protected. There is enough material to absorb any impact so it doesn't matter from which angle the tablet will drop. The screen edge wraps around the display, preventing the tablet from slipping out of the cover mid-fall. The screen edge is also high enough so that the tablet display won't hit the contact surface upon impact. By protecting the tablet this way, the user may enjoy a sense of freedom as they go about their day without having to worry about their tablet sustaining damage.

**Production process**

The complete production process of the Gecko Dynamic is visible in figure 109. First the material from the material manufacturer DIT has to be transported to the production partner. Since the company DIT is located in the Netherlands, the production will also take place in the Netherlands as to reduce the $CO_2$-emission from transport.

After the material transportation, the SRPP and the PP films have to be cut into the right size. This could be done with a mechanical cutting machine. Then, the material has to be stacked in the correct order and placed into the mold. There are different hot presses available on the market. It is most likely that the hot press of a production partner features active cooling via water or oil. This makes it possible to produce multiple SRPP shells per hour.

There are two options regarding the hot pressing step of the production line. The first option is that an external partner will be in charge of said process. If that's the case, the SRPP part will have to be additionally transported to an injection molding company. The second option is that the injection molding company itself will be in charge of this process. An injection molding company that has the equipment to hot compress SRPP has yet to be found. However, as the insert has to be clean in order to ensure good adhesion between the insert and the injection molded materials, the latter would be the most preferred option.

After that, the SRPP has to be laser cut or water jetted to add holes, for example, for the tablet's power and volume buttons. Most injection molding companies have machines for these purposes already. Lastly, the insert has to be manually put into the mold for the injection molding and after the insert molding, the product has to be removed.

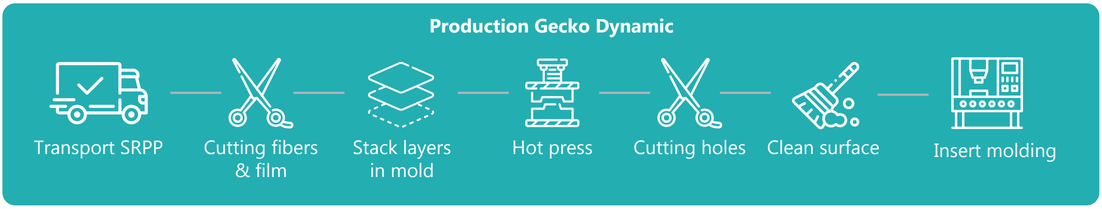



Figure 109: Production process of the Gecko Dynamic.

# 12.2 Evaluation

To find out whether the requirements from chapter 6 are met with the final design, the design will be evaluated.

**General**
Gecko Dynamic enables Gecko Covers to enter the Life on the go segment of the impact resistant tablet market. The product is also balanced between style and impact resistance, however this should be evaluated further with the user group. It is also expected that the tablet cover will at least have an life expectancy of 2 years, but this could not be tested or proven. Lastly, the product reduces its impact by being completely made out of one material which is recyclable and by keeping the production solely within the Netherlands.

**Design**
The product fits the Apple iPad 10,5” of 2017, as could be seen with the proof of concept. However, not all the holes were taken into consideration as this project was mainly about applying the new material in the basic MVP shape. The design of the cover highlights the SRPP by keeping the overall look in balance, applying a big contrast in color and texture, not having a logical pattern to the eye, and the limited amount of lines which creates an openness. The minimal amount of material is used to keep it lightweight and to prevent it from looking bulky or heavy by using thin edges. The recyclability is highlighted by using a natural structure on the backside of the cover. The general design fits the brand image of Gecko by being colorful, having the big contrast in color and textures, keeping the design simple and the overall clean and rounded shape of the cover.

**User**
Gecko Dynamic is designed to give the user a sense of freedom. The impact resistant elements that are used were linked to the perception of impact resistance by the user test. At the same time the cover is not bulky or heavy. Additionally, the chosen style makes it suitable for both formal and casual settings or environments. The tablet cover is estimated to have a weight of 100 grams, which is below the requirement of 450 grams. This final design has not been tested yet on impact resistance, so nothing can be said about whether it meets the requirement of withstanding a fall of 1 meter on concrete. However, the proof of concept that was made of nothing but SRPP did not sustain any damage during testing.

**Production**
The selling price is estimated to be around €60,- which is below the maximum price of €70,- (the price analysis of the impact cover along with the production costs could not be published). There is also enough margin if it turns out that the production costs are a bit higher than estimated. The chosen manufacturing processes are suitable for larger production volumes.

The hot press which was available during this project limited the parameters during the lamination process. It is expected that the hot press of a production partner can reach higher pressure and has active cooling. Therefore, additional research needs to be done when a production partner has been found, to see whether a higher pressure (e.g. 50 bar) and the active cooling change the material properties of the laminates, as suggested by literature research.

No final orientation could be selected based on the findings in this research. The two orientations that had the highest toughness, 0 and 0/45 did not show any significant differences during the Izod impact test or the drop test. Hence, additional testing needs to be done to be able to select the most impact resistant orientation. Also, an additional bending test needs to be done with the SRPP samples without film to get better results and understanding on its toughness, as the hammer in the Izod impact test did not always managed to hit the samples.

This project focused on the MVP. However, there are other impact resistant characteristics which were found during the user research that influence the impact resistance perception of the user such as direction screen protection. All users mentioned that they would like to have a cover over the screen, which is currently left out the of product design. It is recommended to include this is the final product.

The final design could not be tested in the limited amount of time this project had available. It is recommended to test the effect of the back structure and the injection molded PP, as it has not yet been proven that the back structure and the additional material improve the impact resistance and damping of the cover. If the chosen evaluation method is a drop test, it needs to be done repeatedly using the same sample and a drop tower in order to obtain significant data.

Lastly, the design of the new impact cover should be evaluated with the user group. This ensures that the product characteristics match the user perception and that the product has the right balance between design and impact resistance.

# References

Ahankari, S. & Kar, K. (2017). Functionally graded composites: processing and application. In K. Kar (eds), *Composite Materials* (pp 119-168). Springer, Berlin: Heidelberg.

Alcock, B. & Peijs, T. (2011). Technology and Development of Self-Reinforced Polymer Composites. In Abe, A., Kausch, H. H., Möller, M., Pasch, H. (eds) *Polymer Composites – Polyolefin Fractionation – Polymeric Peptidomimetics – Collagens.* Advances in Polymer Science, vol 251 (pp. 1-76). Heidelberg, Berlin: Springer.

Biron, M. (2014). *Thermosets and composites: material selection, applications, manufacturing and cost analysis (second edition).* William Andrew.

Bruens, G. (2011). *Form/color anatomy.* The Hague, Netherlands: Eleven International Publishing.

Business Wire (2016). *Tech21 unveils the science behind the unbeatable phone case protection.* Retrieved on December 4 2019, https://www.businesswire.com/news/home/20161115005534/en/Tech21-Unveils-Science-Unbeatable-Phone-Case-Protection

Casting About (n.d.). *Eco-friendly resins.* Retrieved on February 17 2020, http://www.castingabout.co.uk/Eco-Resins.html.

Composite World (2016). *The fiber*. Retrieved on February 5 2020, https://www.compositesworld.com/articles/the-fiber.

Danziger, P.N. (2019). *Retailers need to engage shoppers' five senses to save physical retail.* Retrieved on December 10 2019, https://www.forbes.com/sites/pamdanziger/2019/08/04/retailers-need-to-engage-shoppers-five-senses-to-save-physical-retail/#658ed6685634.

Gao, C., Yu, L., Liu, H. & Chen, L. (2012). Development of self-reinforced polymer composites. *Progress in Polymer Science, 37(2012)*, 767-780.

Hine, P.J., Olley, R.H. & Ward, I.M. (2008). The use of interleaved films for optimizing the production and properties of hot compacted, self reinforced polymer composites. *Composites Science and Technology, 68(2008)*, 1413-1421.

Izer, A. (2010). *Development and investigation of self-reinforces polypropylene composites based on the polymorphism of PP* (Doctoral dissertation, Budapest University of Technology and Economics, Budapest, Hungary). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.469.7609&rep=rep1&type=pdf.

Jerpdal, L. (2017). *Processing of self-reinforced poly(ethylene terephthalate) composites for automotive applications* (Doctoral dissertation, Kungliga Tekniska högskolan, Stockholm, Sweden). Retrieved from http://kth.diva-portal.org/smash/record.jsf?pid=diva2%3A1166082&dswid=5216.

Job, S., Leeke, G., Mativenga, P.T., Olivieux, G., Pickering, S. & Shuaib, N.A. (2016). *Composite recycling: Where are we now?* Retrieved from https://compositesuk.co.uk/system/files/documents/Recycling%20Report%202016.pdf.

Flynt, J. (2019). *How to choose injection molding surface finishes and what are the grades?* Retrieved on March 8 2020, https://3dinsider.com/injection-molding-finishes/.

Friedrich, K. (1993). *Advances in composite tribology.* Composites & science, volume 8. Elsevier.

Kaushik, V. (2017). Unique flight features of shuttlecock. *International Research Journal of Engineering and Technology, 4(12)*, 521-525.

Kimbarovsky, R. (2020). *What is brand identity and how to create a unique and memorable one in 2020.* Retrieved on February 16 2020, https://www.crowdspring.com/blog/brand-identity/.

Kozderka, M., Rose, B., Koci, V., Caillaud, E. & Bahlouli, N. (2016). High impact polypropylene recycling – mechanical resistance and LCA case study with improved efficiency by preliminary sensitive analysis. In A. Bouras, B. Eynard, S. Foufou, & K. Thoben (Eds.), *Product lifecycle management in the era of internet of things* (pp 541-553). New York City, NY: Springer Publisher.

Kuan, H.T.N., Cantwell, W.J., Akil, H.M. & Santulli, C. (2011). The fracture properties of environmental-friendly fiber metal laminates. *Journal of Reinforced Plastics & Composites, 30(6)*, 499-508.

Lastu (n.d.). *Why Lastu?* Retrieved on February 20 2020, https://lastu.co/pages/why-lastu.

Leiva-Gomez, M. (2017). *Why Are Smartphones So Delicate?* The Quest for Solid Devices. Retrieved on February 16 2020, https://www.maketecheasier.com/why-are-smartphones-so-delicate/.

Malik, O.A. & Khan, H.A. (2017). Impact resistance analysis using multiply fabric orientations. 2015 Forth International Conference on Aerospace Science and Engineering (ICASE), Islamabad, Pakistan, 2-4 Sept. 2015. New York City, NJ: IEEE.

Morris, H. (2017). *Why is it so cold on a plane?* Retrieved on November 29 2019, https://www.telegraph.co.uk/travel/travel-truths/why-are-planes-so-cold/.

Murphy, D. (2019). *Corporate identity, brand identity or brand image.* Retrieved on February 16 2020, https://masterful-marketing.com/corporate-identity-brand-identity-or-brand-image/.

NDT Resource Center (n.d.). *Fracture Toughness.* Retrieved on November 17 2019, https://www.nde-ed.org/EducationResources/CommunityCollege/Materials/Mechanical/FractureToughness.htm.

Oever, M. van den, Molenveld, K., Zee, M. van der & Bos, H. (2017). *Bio-based and biodegradable plastics- facts and figures* (Report No. 1722). Retrieved from, https://www.wur.nl/upload_mm/1/e/7/01452551-06c5-4dc3-b278-173da53356bb_170421%20Report%20Bio-based%20Plastic%20Facts.pdf.

Olivieux, G., Dandy, L.O. & Leeke, G.A. (2015). Current status of recycling of fiber reinforced polymers: review of technologies, reuse and resulting properties. *Progress in Materials Science 72(2015)*, 61-99.

Otterbox (2019). *Otter and the environment.* Retrieved on February 2 2020, https://www.otterbox.com/en-us/sustainability.html.

Papavinasam, S. (2014). *Corrosion control in the oil and gas industry.* Houston, Texas: Gulf Professional Publishing.

Pickering, K.L, Aruan Efendy, M.G. & Le, T.M. (2016). A review of recent developments in natural fibre composites and their mechanical performance. *Composites: Part A, 83(2016)*, 98-112.

Plastic News Europe (2010). *Cosmolite Suitcase (2008)*. Retrieved on November 28 2019, https://www.plasticsnewseurope.com/article/20101117/PNE/311179977/cosmolite-suitcase-2008.

Polymer database (2015). STRAIN HARDENING OF AMORPHOUS AND SEMI-CRYSTALLINE POLYMERS. Re-trieved on March 8 2020, https://polymerdatabase.com/polymer%20physics/Strain%20Hardening.html.

REF (2014). *Lightweight self-reinforced plastics for ultimate recyclability.* Retrieved on February 23 2020, https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=18315.

Saeed, F., Grunert, K.G. & Therkildsen, M. (2013). How product trial changes quality perception of four new processed beef products. *Meat Science, 93(1)*, 119-127.

Scaffaro, R., Lopresti, F., Maio, A., Sutera, F. & Botta, L. (2017). Development of polymeric functionally graded scaffolds: a brief review. *Journal of Applied Biomaterials & Functional Materials, 15(2)*, 107-121.

Shahzad, A. (2016). Biofiber-reinforced biopolymer composites. In Thakur, V.K. & Thakur, M.K. (Eds.), *Handbook of sustainable polymers: structure and chemistry.* Boca Raton, Florida: CRC Press.

Tech21 (2020). T*he power of plant based.* Retrieved on February 2 2020, https://www.tech21.com/en_au/the-power-of-plant-based/.

Texier, B.D., Cohen, C., Quéré, D. & Claneta, C. (2012). Shuttlecock dynamics. *Procedia Engineering, 34(2012)*, 176-181.

Thompson, A. (n.d.). *Minimum temperature iPad can tolerate.* Retrieved on January 7 2020, https://itstillworks.com/minimum-temperature-ipad-can-tolerate-19173.html

Tveito, O.E., Førland, E., Heino, R., Hanssen-Bauer, I., Alexandersson, H., Dahlström, B., Drebs, A., Kern-Hansen, C., Jónsson, T., Vaarby Laursen, E. & Westman, Y. (2000). Nordic temperature maps (DNMI KLIMA Report 09/00). Retrieved from Meteorologisk institutt, https://www.met.no/publikasjoner/met-report/met-report-2000/_/attachment/download/fd5c813f-c990-4701-b32d-1cd5739366b4:3c546bbb335949d58fdeb1e043bb335a9ee3a6fa/MET-report-09-2000.pdf.

UAG (2019). *What material is used to manufacture UAG cases?* Retrieved on February 17 2020, https://urbanarmorgear.zendesk.com/hc/en-us/articles/211238323-What-material-is-used-to-manufacture-UAG-cases-.

Unipipes (2019). *Insert molding – All you need to know.* Retrieved on March 8 2020, https://www.unipipes.com/blog/insert-molding-design.

Vaidya, A. & Pathak, K. (2019). *Applications of Nanocomposite Materials in Dentistry*. Woodhead Publishing.

Varghese, A.M. & Mittal, V. (2018). *Polymer composites with functionalized natural fibers. Biodegradable and biocompatible polymer composites* (157-186). Woodhead Publishing.

Williams, A. (2019). *Is Modern Technology Too Fragile?* Retrieved on February 16 2020, https://inews.co.uk/ibuys/tech/best-tablets-samsung-galaxy-amazon-fire-apple-ipad-reviews-634744.

Wypych, G. (2016). *Handbook of fillers 4th edition.* ChecmTec Publishing: Canada, Toronto.

Yang, C., Ngo, T. & Tran, P. (2016). Influences of weaving architectures on the impact resistance of multi-layers fabrics. *Materials and Design, 85(2015)*, 282-295.

**Images**

Alpha Coders (n.d.). *Wallpaper puzzle.* Retrieved on March 5 2020, https://wall.alphacoders.com/big.php?i=810904&lang=Dutch.

Bispo, S.J.L., Freire, R.C.S. & Aquino, E.M.F. de (2015). Mechanical properties analysis of polypropylene biocomposites reinforced with curaua fiber. *Material research, 18(4)*, 833-837.

Chess.com (2019) *Do You Know This Rare Chess Fork?* Retrieved on February 20 2020, https://www.chess.com/article/view/rare-chess-fork.

DIT (2019). The principle of PURE®. Retrieved on January 25 2020, https://www.ditweaving.com/about_pure.php?page=pure_technology.

Gecko Covers (2019). *About us.* Retrieved on February 15 2020, https://www.geckocovers.com/nl/About-us.

Ghavami, K., Rodrigues, C.S. & Paciornik, S. (2003). Bamboo: functionally graded composite material. *Asian Journal of Civil Engineering (Building and Housing), 4(1)*, 1-10.

Gizmoslip (2018). *iPad Pro 2018 Drop Test! You're Gonna Want a Case With This One...* Retrieved on March 5 2020, https://www.youtube.com/watch?v=YoU2QnhjwXQ.

JerryRigEverything (2018). *iPad Pro Bend Test! - Be gentle with Apples new iPad...* Retrieved on March 3 2020, https://www.youtube.com/watch?v=hUBsxCcJeUc.

Lastu (n.d.) Salmon skin hardcase. Retrieved on February 10 2020, https://lastu.co/collections/all-cases/products/salmon-skin-cardcase-by-lastu?variant=12012998393898.

Kmetty, Á., Bárány, T. & Karger-Kocsis, J. (2010). Self-reinforced polymeric materials: a review. *Progress in Polymer Science, 35(2010)*, 1288-1310.

Native Union (2020). *Clic terrazzo.* Retrieved on February 18 2020, https://www.nativeunion.com/collections/iphone/products/clic-terrazzo.

NDT Resource Center (n.d.). *Fracture Toughness.* Retrieved on November 17 2019, https://www.nde-ed.org/EducationResources/CommunityCollege/Materials/Mechanical/FractureToughness.htm.

Okumoto, Y., Takeda, Y., Mano, M. & Okada, T. (2009). *Design of ship hull structures: a practical guide for engineers.* Heidelberg, Berlin: Springer.

Pela Case (2020). *Honey bee edition.* Retrieved on February 18 2020, https://pelacase.com/products/honey-bee-edition-eco-friendly-iphone-11-pro-max-case?variant=20466587402328.

Plati, E. & Williams, J.G. (1975). *Effect of temperature on the impact fracture toughness of polymers.* Polymers, 16(12), 915-920.

Polymer database (2015). *IMPACT TESTING AND DUCTILE-BRITTLE TRANSITION.* Retrieved on March 1 2020, http://polymerdatabase.com/polymer%20physics/ImpactTest.html.

PragasitLalao (2016). *Carbon fiber composite raw material.* Retrieved on March 1 2020, https://www.istockphoto.com/nl/foto/carbon-fiber-composite-raw-material-gm622210776-108909901.

SolStock (2016). *Using digital tablet on the train.* Retrieved March 5 2020, https://www.istockphoto.com/in/photo/using-digital-tablet-on-the-train-gm504490064-83171043

Statista (2018). *Distribution of plastic waste treated between 1980 and 2015, by disposal method.* Retrieved on February 18 2020, https://www.statista.com/statistics/960146/plastic-waste-treated-by-disposal-method/.

STL Testlab (n.d.). *Izod Impact Strength Testing.* Retrieved on February 13 2020, https://info.stltestlab.com/product/izod-impact-strength-testing/.
Texier, B.D., Cohen, C., Quéré, D. & Claneta, C. (2012). Shuttlecock dynamics. Procedia Engineering, 34(2012), 176-181.

Weefgetouwen meta (n.d.). *Keperbindingen en afleidingen.* Retrieved on February 15 2020, http://www.weefgetouwenmeta.be/weven/keperbinding.php.

Vector used in Acknowledgements:
Andypp (n.d.). *Hummingbird Particle Vector Illustration.* Retrieved on March 8 2020, https://pngtree.com/freepng/hummingbird-particle-vector-illustration_4140440.html.