41737 - Special Report 3

Plastic Product Design Report

By: Group 07

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The group has shared the work in a fair & equally distributed manner.

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Table of contents

1 Introduction

The following report is a structured design documentation of a phone stand, with an extra function of being a key chain attachment. Through the report the concept is explained and analysed, and a list of requirements for the product is made. The material is then determined with the five-step method and calculations are made in order to assure product stability. Afterwards the product is designed, with the implementation of DFM(Design For Manufacture), to ensure that the product meets the requirements for mass production. The process of mould design is documented and explained, where-from simulations of the injection moulding and specific parameters can be generated. The simulated input parameters are determined with the aim of reducing the cycle time for this mass market product. Lastly, a climate impact investigation is conducted with two different use case scenarios, referencing national waste disposal methods and finally a conclusion of the report is outlined.

2 Methods

The following sections outline the design principles of the phone stand & the intended function of the product. The finalized rendering of both the designed product & mould are depicted in the figure below.

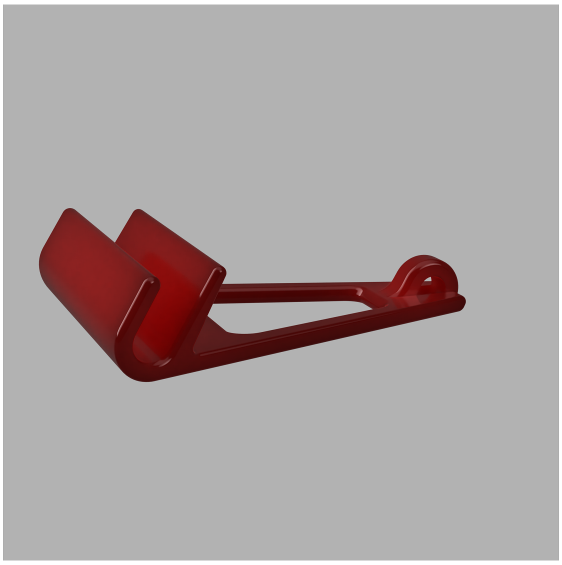

Figure 2.1: A rendering of the finalized cell phone stand component.

Figure 2.2: A rendering of the finalized cell phone stand mould tool.

2.1 Product concept explanation

The cell phone stand is designed with the premise of being a key chain attachment, ensuring that users always have their phone stand conveniently with them, even in cases where users are not making the conscious decision to bring their phone stand along. By mounting it onto a key chain, the phone stand has an emphasis on portability and usability, by integrating itself seamlessly into users' daily routines.

The phone stand is intended to have a minimal profile, preventing it from adding too much bulk to the users already often heavy and cumbersome key chain. By strategically reducing side beams, cutting away the middlemost portion of material, the design achieves a balance between portability, stability, durability and flexibility, allowing the product to bend comfortably in the users pockets whilst also minimizing material usage.

Moreover, the key chain's simple yet robust construction facilitates easy manufacturing via injection molding, enabling a swift path to market with low production costs, given the saturated market the product finds itself in.

2.2 Product function analysis

2.2.1 Primary function:

The products primary function is to securely keep an iPhone 7 plus securely standing on a flat surface (The compatibility of other cell phones is not assessed). Users may still operate their phones and therefore the stand is intended to counteract not only the bending forces resulting from gravity but also withstand user taps and swipes with a sufficiently high stiffness to avoid the phone "bouncing". This is achieved via a frictional fit, wherein the stand has a secure interference fit with the phone, resulting in partial elastic deflection of the plastic flanges contacting the phone.

2.2.2 Secondary function:

The secondary function of the phone stand is the ability for users to utilize the key ring attachment point with any non-proprietary key ring. In doing so, users can keep their phone stand attached to critical items they keep on their person at almost all times: their phone and their keys. The secondary function is also a means of securing the phone stand, as it is a smaller object and easy to lose.

3 Product design

3.1 List of requirements

Based on the product concept explanation in chapter 2, the following product requirements can be notarized:

- Ability to securely envelop a iPhone 7 Plus without cover (selected phone geometry).
- Ability to withstand the assumed forces and associated calculated bending moments, by remaining stable during the subjected user input forces.
- Flat bottom with robust design principles to prevent wobbling on a stable surface.
- The key ring attachment point possess compatibility with majority of key rings.
- Flexible whilst in user's pocket without breaking.
- Low go-to market costs (low development, material, & manufacturing cost).
- Low weight (material savings, user comfort).
- Sufficient wall thickness to prevent phone sidewall play from user input forces.
- Ability to withstand repeated use over an extended period without significant wear and tear.
- Ability to withstand potential creep during prolonged installation under normal operation conditions. Temperatures $-20\,°C$ to $45\,°C$.
- Possess no sink marks in non-descript locations.
- Compliant with DFM rules (as outlined in chapter 4).

3.2 Specified product geometry

From the notarized requirements listed above in section 3.1, the resulting product geometries on basis of the specifications is notarized:

1. The installed phone should have a tilt of 60° from horizontal, as this was found to be ideal angle amongst completed user testing.

2. The the two phone supporting flanges have an acute 1° tilt angle towards each other to ensure secure mounting via interference friction fit.
3. To ensure the minimum pocket footprint, the stand should have a triangular shape as the phone stand narrows towards a singular key ring attachment point.
4. To remain comfortable in pockets the footprint should be constrained to a bounding rectangular volume of 50 mm x 60 mm x 14.5 mm.
5. To be installable onto key rings, a roughly 3 mm ring with a maximum permissible sidewall thickness (resultant key ring deflection) of also 3 mm is necessary.
6. The maximum permitted material volume used (excluding gate - due to ability to be recycled) is 6000 mm^3
7. That the bending beam portion of the design, in order to improve comfort in pocket, based on qualitative testing of 3D printed prototypes in ABS, should have a beam profile as close to 5.0 mm x 2.5 mm x 25 mm as possible permitting DFM considerations.
8. That a customer customizable logo (permitting stationary mould half or insert costs be paid) be applied in a area on the bottom of the product.

Based upon these specified product geometry considerations, the finalized iteratively designed phone stand can be generated in CAD via `Fusion 360`, however, preliminary design work was also performed.

3.2.1 Preliminary design

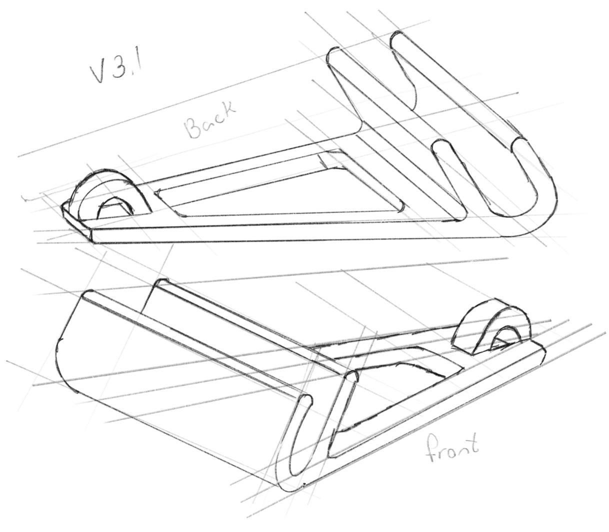

Figure 3.1: Preliminary design sketch.

The preliminary design is crafted to securely hold an iPhone 7 Plus by clamping it between two plastic parts at an angle. The connection from the stand to key chain attachment is purposely made thin allowing the part to flex and prevent permanent deformation and breaking the part in your pocket. Additional design drawings are displayed in appendix A.2.

3.2.2 CAD Adherence to specifications

The following figures depict some of the finalized phone stand CAD model and it's adherence to the laid out product geometry specifications. A detailed technical drawing is outlined in appendix A.3.

Figure 3.2: Adherence of design guidelines #1, #3, & #6.

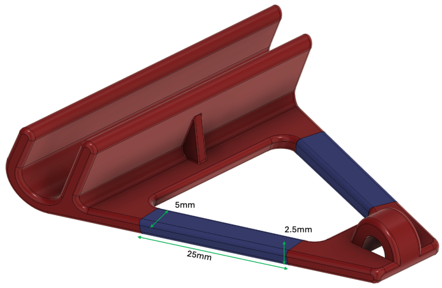

Figure 3.3: Adherence of design guideline #8. The bending beams (to increase comfort) are depicted as blue. The cutaway triangular area reduces volume for adherence to # 7.

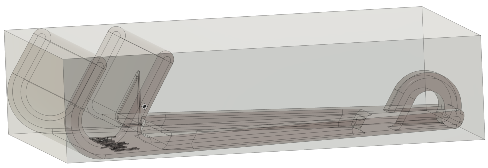

Figure 3.4: Adherence of design guideline #5. The phone stand volume is found to be 5909.948 mm^3 adhering to design guideline #7.

3.3 Systematic material selection

The material has been selected based on the five-step method outlined in the document "Plastics Material Selection" from day 8, which are Establish, Translate, Divide, Eliminate, and Select[1]. The result of the first three steps, Establish, Translate, and Divide, is shown in table 3.1. Due to the demands of the assignment, the material chosen must be formable using injection molding techniques. The phone holder is also expected to act in part as a decoration for the key chain, and the material, as such, should be able to be colored directly, decrease processing steps, and keep the price down. The material should contribute to the phone holder's robustness when it experiences occurrences common for keychains, such as being dropped from hands or from a table and being left out in the sun for longer periods of time when not in use. The results of the fourth step, the elimination, are shown in the Removal of Materials table in table 3.2. Following the elimination of the majority of the materials, only three remain: PPO/PS, PBTOP/PETP, and PTFE. The final selection is then based on the materials' price for a given stiffness and, secondarily, the relative thickness for a given stiffness. According to tables 9 and 10 from the "Plastics Material Selection" document, the amorphous thermoplastic PPO/PS has the best ratio in both categories.

Table 3.1: The part and material demand table made according to Appendix 1 in the Plastics-Material-Selection document from day 8

Demands for the part due to its planned use	Demands for the material	Category
Longevity	High Resistance to UV-radiation	1
Endure Fall from head height to hard surface	-Impact Strength = "good"	2
Minimal deflection when holding phone	-Modulus at 10000 hours greater than 900 MPa at 2 mm thickness	3
Mass producible	-Inject moulding "common"	1
Beautiful Colours	-Bright Colours	1

Table 3.2: Removal of materials table made according to appendix 1 in the Plastics-Material-Selection document from day 8. The X marks denotes a failure of the material to meet the requirement.

Removal of Materials		Amorphous Thermoplastic Materials							Crystallite Thermoplastic Materials					
		ps	abs	sb san	pvc	pmma	ppo/ ps	pc	pe	pp	pom	pa	pbtp petp	ptfe
Demand to material	Table													
High UV-resistance	1	**X**	**X**	**X**	**X**			X	**X**	**X**	**X**	**X**		
Modulus (category 3)														
Good Injection mouldability	1				**X**									
Bright Colours	1													
Impact strength = 'good'	6	**X**				**X**								
Passed all demands		no	no	no	no	no	Yes	no	no	no	no	no	Yes	Yes

3.4 Calculation of functional features

Prior to generating a part within CAD, some simple calculations are necessary to ensure adherence to the outlined requirements in section 3.1.

Due to the fact that the product is designed with a specified clamping fit (interference) to ensure optimal security of the device, however, as there is also an exerted moment aswell as the aforementioned specified deflection, the resultant total deflection is of interest. A diagram displaying these forces is displayed in figure 3.5 denoting a free-body diagram.

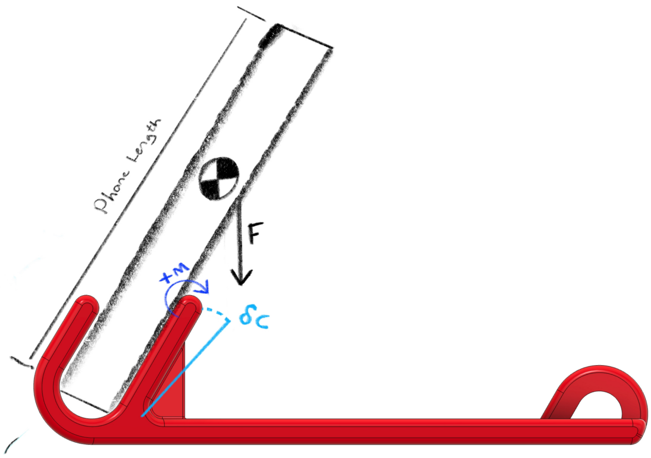

Figure 3.5: A free-body diagram with additional details, describing the forces associated with a mounted iPhone 7+.

Since a iPhone 7+ was the specified product, with the associated parameters:

- **Weight:** W = 0.188 kg
- **Phone Length:** = 158.3 mm
- **Center of gravity** (assumed): $\frac{\text{Phone Length}}{2}$
- **iPhone gravitational force:** F = 0.188 kg · g → 1.846 N

Additionally the associated parameters for the specific ppo/ps, `NORYL™ Resin 731` material based phone mount was set to:

- **Flexural modulus [3]:** E = 2.42 GPa
- **Length:** (recess to tip) L = 0.0115 m
- **Height:** (assumed material thickness) h = 0.0025 m
- **Beam Width:** b = 0.0412 m
- **Mount angle:** = 60°

From the outlined associated parameters, the following calculation of the moment of inertia for a beam is made:

$$I = \frac{b \cdot h^3}{12} \rightarrow 5.36 \times 10^{-11}\,\mathrm{m}^4 \tag{3.4.1}$$

3.4.1 Utilizing the superposition principle

From the free-body diagram, it can be observed that two forces are constituting the forces associated with mounting, namely a applied moment at the tip of the rear phone support flange and a construction defined deflection resulting from the necessary interference fit. Therefore the superposition principle is required to calculate the respective forces combined deflection.

3.4.2 Flange deflection force

Calculating the resultant forces at a specified flange deflection length, defined to ensure a sufficient interference fit was of interest. This is in order to find the associated force resulting from the installed phones point load at the tip of the phone support flange. The engineered deflection length is denoted as δ_c, as seen in figure 3.5. The necessary length for interference was assumed to be:

$$\delta_c = 5 \times 10^{-4}\,\mathrm{m} \tag{3.4.2}$$

It is of interest to find the associated forces with this engineered deflection found via the equation:

$$\delta_c = \frac{\mathrm{F_{flange}}}{\mathrm{L}^3 \cdot 3\mathrm{EI}}$$

Rewritten to finding $\mathrm{F_{flange}}$:

$$\mathrm{F_{flange}} = \frac{3 \cdot \delta_c \cdot \mathrm{E} \cdot \mathrm{I}}{\mathrm{L}^3} \rightarrow 128.04\,\mathrm{N} \tag{3.4.3}$$

3.4.3 Flange moment induced deflection

The unknown contribution of deflection from the resultant moment of the phone installed into the stand is of interest, in order to find the total deflection (via superposition).

The resultant moment generates a deflection via:

$$\delta_{moment} = \frac{\text{Center of gravity} \cdot \mathrm{F} \cdot \cos(60°) \cdot \mathrm{L}^2}{2 \cdot \mathrm{E} \cdot \mathrm{I}} \rightarrow 3.72 \times 10^{-5}\,\mathrm{m} \tag{3.4.4}$$

3.4.4 The total deflection

The total combined deflection is now found via the superposition principle:

$$\delta_c + \delta_{moment} = 5 \times 10^{-4}\,\mathrm{m} + 3.72 \times 10^{-5}\,\mathrm{m} \rightarrow 5.372 \times 10^{-4}\,\mathrm{m} \tag{3.4.5}$$

As shown by equation 3.4.5 a total deflection of 0.5372 mm is present when considering the combined forces as shown in figure 3.5. However, no safety factor is utilized here and user input forces were difficult to calculate or predict. This deflection length ensures a secure fit of the phone and it has been found that the contributing moment, resulting from the phone's weight doesn't significantly increase the deflection when utilizing the given dimensions of the phone stand. Therefore, it is concluded that the "guesstimated" initial dimensions are appropriate for the forces present when a phone is securely installed.

3.4.5 Creep during prolonged usage

Using the values from section 3.4, the force resulting from the weight of the phone is negligible compared to the force of the bending moment resulting from the clamping around the phone. Calculating the strain due to the extreme case of stress caused by the bending moment for 10000 h can be done using the creep modulus of PPO/PS from the Plastics Material Selection document[1] was done.

$$\sigma = 1.28 \cdot 10^{7}\text{Pa} \tag{3.4.6}$$

$$\text{J} = 6.25 \cdot 10^{-10}\text{Pa}^{-1} \tag{3.4.7}$$

$$\varepsilon = \sigma \cdot \text{J} = 0.80\% \tag{3.4.8}$$

After 10000h it is found that there is under 1% of creep. This is an extremely small quantity and would also entail that the phone is constantly installed during the stands lifetime. As in no relaxation of the creep would happen. This means that the creep can be disregarded as a significant factor. However, the utilized creep factor was only at temperatures of 20 °C, however, the product was specified to withstand 45 °C, as it is not expected to be exposed to elevated temperature at prolonged periods of time, allowing for relaxation.

4 Design for Manufacturing (DFM) applied to injection moulding

Designing for manufacturing is not a simple task. There are many different steps to consider and the process of designing such products can be expensive and take a long time. The first step is to figure out which process should be used for producing, e.g extrusion, injection moulding and so on. Next, based on the environment and use-scenario, appropriate materials need to be selected for it to be usable. In the designing steps, iteration is important, and the right answer will usually not be the first one. When designing the product it should be as simple as possible, while maintaining the functional requirements of the specifications. This is done through utilizing standardized components where possible and making the assembly of the product simple and a one-way assembly.

Designing for manufacturing in the application of injection moulding introduces different requirements for the product. The products design must enable proper flow of material, so the mould fills fully with the plastic. It is also important to make the product thin where possible, as warpage increases with thickness. Furthermore, gate placement plays an important role in the optimal flow rate of the material, finding the correct placement together with a product designed for proper flow, will increase the structural integrity of the part.

Whilst this part is required to have little overhead in terms of development costs, the part must still be manufacturable and have a sufficient cosmetic quality. The following analysis outlines the considerations performed and justify the phone stands finalized morphology based on the DFM considerations applied during CAD modelling.

4.1 Considerations pre-simulation

This section outlines general considerations that were continuously implemented prior to the simulation results, presented in chapter 6.

4.1.1 Sink marks

Minimization of sink marks, particularly on external, user facing surfaces is important in order to present a part with a respectable appearance. Minimization of areas that deviate drastically from nominal part thickness or construction of either innovative tooling or part morphologies is crucial to avoid sink marks, especially on highly visible surfaces. Otherwise, some sink marks are also justifiable in areas/surfaces wherein cosmetics is not a consideration (often structural components).

Figure 4.1 & 4.2 shows the finalized part (opaque) in CAD, and overlaid with drawn marker where local deviations to the nominal thickness are and are prime areas where expected sink marks could arise.

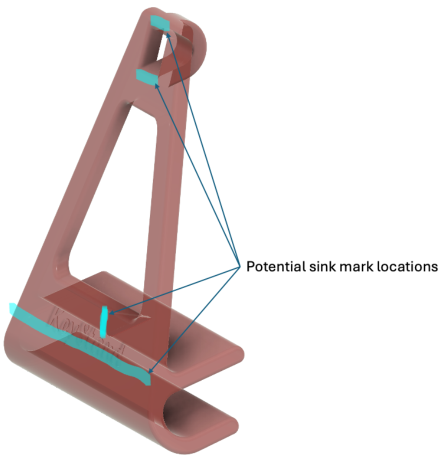

Figure 4.1: Identified sink mark sites (blue) on as seen from the bottom.

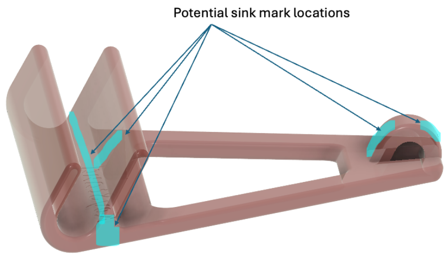

Figure 4.2: Identified sink mark sites (blue) as seen from the top.

As the above figures show, almost all of the potential sink marks are located in areas that are deemed to be acceptable locations, as they are located within the inner "channel", particularly centrally where also a support gusset is located but these sink marks will be occluded by the phone during usage (also not as visible whilst not in usage). The largest expected and visible sink mark will likely be on the external siding (third arrow from left on figure 4.2) due to the 43 mm long section that isn't divided by tooling to prevent the full length wise shrinkage. Considering the comparatively low [2] shrinkage factor as the listed linear shrinkage factor of 0.5%-0.7% for the utilized `NORYL™ Resin 731` [3], the length is still expected to become reduced due to the linear shrinkage (rather than volumetric shrinkage) of:

$$43\,\text{mm} \cdot \frac{(0.5\% + 0.7\%)}{2} = 42.742\,\text{mm} \rightarrow \text{per side shrinkage} = 0.129\,\text{mm} \qquad (4.1.1)$$

The resulting theoretical shrinkage of a 0.129 mm sink mark on each side is far from optimal in terms of cosmetics and would require a new construction morphology by utilizing tooling to subdivide the full length into smaller constituents, to avoid the full length shrinkage. However, moulding simulations will be required to fully evaluate the current sinking effects, particularly packing and assess the congruence of this simplified calculation. This comparison is outlined in subsection4.2.1, where actual simulation results are considered.

The other sink marks were deemed to be sufficiently adequate for the product and aren't warranted for potential re-design compared to that of the "lengthwise sink mark".

4.1.2 Wall thickness optimization

Uniformity of the wall thickness is critical to control homogeneous material shrinkage, reducing internal stress and minimizing the risk of defects such as warping, sink marks, and dimensional inaccuracies in the final moulded part. By striving for consistency in wall thickness aids in uniform cooling rates yielding improved part quality and dimensional stability. Additionally, it facilitates smoother material flow during injection molding, enhancing fill and pack conditions and ultimately leading to more reliable and repeatable manufacturing processes. The utilized nominal wall thickness was selected to be 2.5 mm, however, wherein larger focused forces were expected to be applied on the stand, namely in the key ring loop, the bending beams, and the gusset, the wall thickness was increased to 5 mm.

Figure 4.3: Cross sectional view excluding gusset with a maximum wall thickness found being 0.58 mm above nominal thickness.

Figure 4.4: Cross sectional view including gusset with a maximum wall thickness being 3.356 mm above nominal thickness.

4.1.3 Draft angle implementation

Adequate draft angles prevent friction between the part and tool, reducing the risk of damage during ejection. Draft angles are particularly critical for the two walls that hold the phone, as these parts extend deeper into the mould. When deciding on a specific draft angle there are many factors such as material thickness, material selection, shrink rates, ejection and the texture of the product. As a general rule of thumb, draft angles should be between 0.5° to 2°, but is dependent on the aforementioned factors as well as others. For this project, areas that require draft angles are minimized through design, as such a low 0.5° angle was chosen for most areas. This is in part qualified by draft analysis during CAD-modelling of the part and tool as shown in figure 4.5.

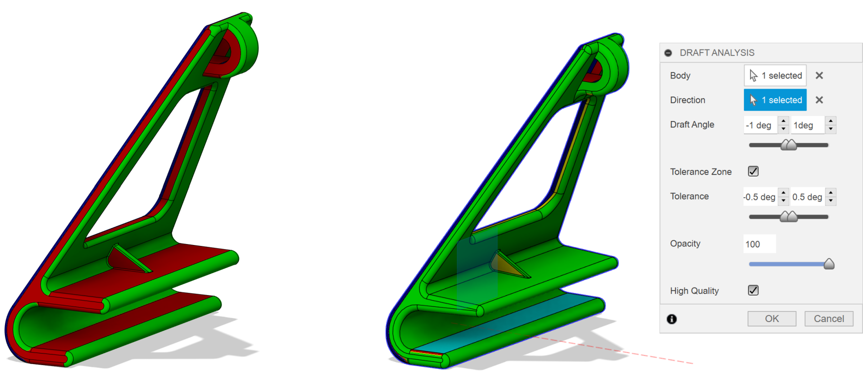

Figure 4.5: Final draft analysis.

4.1.4 Undercuts

Undercuts present challenges in mould design and manufacturing, as they complicate mold release and likely command complex mechanisms such as side actions or slides, increasing tooling costs and lead times. Minimizing undercuts in the design is imperative as it simplifies mould construction, reduces production costs, and reduces time-to-market. Figure 4.6 illustrates undercut analysis in the part design.

Figure 4.6: Part screenshot Fusion 360 - Showing undercuts.

As seen in figure 4.6, there are some portions on the part that are inaccessible (depicted as blue). This is intended to ensure the function of letting the part stick to to moving mould tool partially described in section 4.1.13. This is also necessary for the function of clamping the phone.

4.1.5 Surface finish classification

To save on costs and development time with toolmakers, classification of surfaces allows for quicker turnarounds as attention can be focused solely towards surfaces requiring a high cosmetic finish. As illustrated in figure 4.7, the part is classified into three distinct finish categories:

- **A** - High Cosmetic Finish: Surfaces designated as Class A require a high attention to detail often wire sinking, with either a specified texture or tooling polish. These areas are typically visible to end-users and dictate a high-end surface for aesthetic appeal.
- **B** - No Cosmetic Finish: Class B surfaces do not require any cosmetic

treatment as they are not visible or critical to the part's function. These areas can be left with raw and/or functional finishing without compromising the overall perceived quality of the product. These are often located in non-visible locations.

- **C** - Low Frictional Surface: Surfaces classified as Class C are engineered to have a low-friction finish to aid in the release of the part from the mold, often where undercuts or drafting isn't possible. These surfaces may not require a high cosmetic finish but are crucial for optimizing part ejection and minimizing production challenges.

Figure 4.7 shows a 3D-view of the part within CAD with surfaces categorized into their respective established classifications.

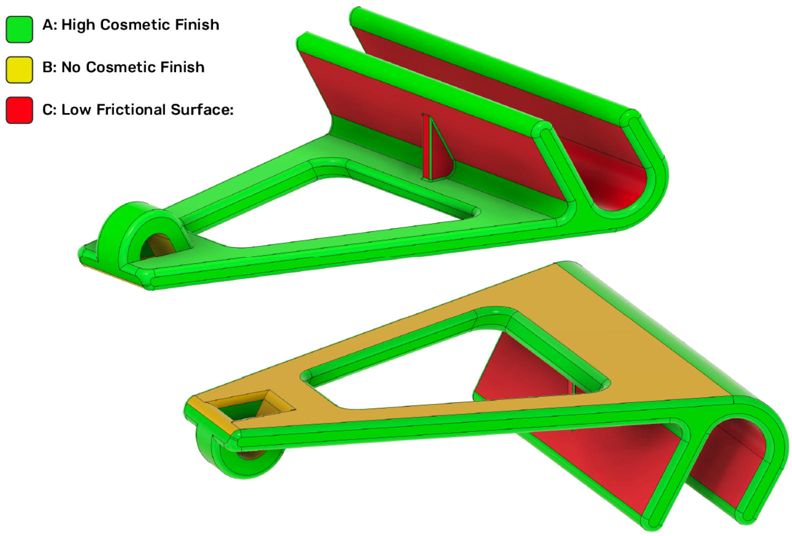

Figure 4.7: Surface finish classifications of the phone stand.

As outlined in subsections 4.1.3 and 4.1.4 the addition of surface class C is due to some areas being difficult to demould (shown in figure 4.6) therefore, utilizing a low friction surface will likely aid in part release and reduce go-to market time spent with testing.

4.1.6 Material selection consideration

Due to unknown manufacturing experience, the material choice will solely be guided by the systematic materials selection process outlined in section 3.3, wherein the mould-ability is included in the evaluation.

4.1.7 Weld lines

Weld lines occur in the injection process when flow fronts merge together, usually in small interface angles. The weld lines are often located near a hole feature wherein the flow front's rejoin after travelling around the hole. Weld lines pose significant problems such as interfering with the cosmetics of the part but also creates weak points if the melt front has begun solidification (even partially) whilst separated, resulting in poor polymer chain cross-linking between the respective fronts.

Removal of these weld lines can be difficult and may require part-redesign if weld lines (solidified melt fronts) occur in sub optimal locations. However, some mitigation is possible by tinkering with the injection moulding parameters, particularly temperature settings. Because of the melt fronts solidification is highly dependent on flow rate and temperature, it is possible to ensure the melt front becomes unified prior to solidification, partially mitigation the weld lines impact on part strength.

As there is only a simplified gate/sprue system in the designed mold for the phone stand, weld lines can only be prevalent in regions with flow front separation. In this phone key chain stand, it can occur away from the selected gate and is expected to occur either around the tip of the material reduction cutaway and/or the key ring loop and the expected region is shown in figure 4.8.

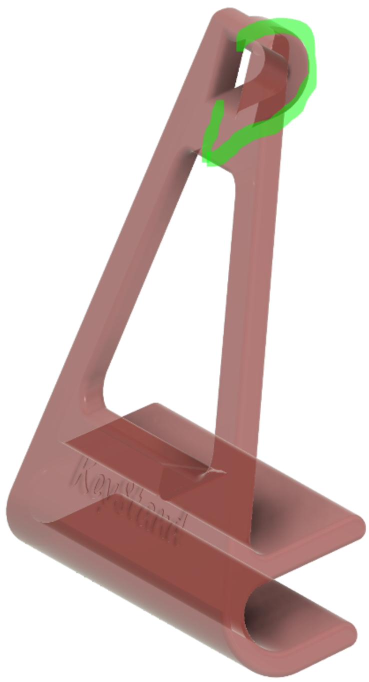

Figure 4.8: Identified weld line regions (green) as seen from the bottom.

As seen in figure 4.8, the region with weld lines is unfortunately located in the same area that is subjected to many of the forces going into the product, namely tension forces from users pulling on their key chain. Therefore, simulation from chapter 6 and the parameter iterations in section 4.2 will be necessary to determine the extent of the weld lines and if it is possible to address problems by tweaking parameters. Otherwise, potential redesign of the part may be necessary in order to tailor the region wherein the weld lines are occurring.

4.1.8 Definition of parting line

The odd shape of the part, including angles between the bottom of the part and the walls holding the cell phone, makes it necessary to implement a somewhat irregular

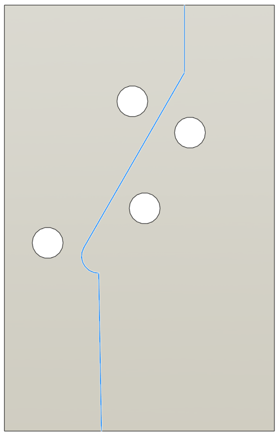

Figure 4.9: Parting line (blue)

parting line. It is designed to mainly follow the center of the side of the product. This is to avoiding undercuts, but also to place the parting line on a surface (center line of the sides of the part), where it will not disturb the aesthetics significantly.

4.1.9 Addition of gussets

Utilization of gussets or ribs to strategically reinforce the structure, enhancing part stiffness, while minimizing material usage is a crucial step in part design. Design considerations, including thickness, height, and spacing, are essential to calculate in order to add them in an optimized manner to heighten the strength-to-weight ratio whilst also preventing sink marks.

A singular rib was strategically placed to further reinforce the central rear phone support flange, as this flange experiences the majority of the bending moment exerted by the phone. Despite calculations presented in section 3.4 demonstrating that it was unnecessary given the selected nominal thickness of 2.5 mm, the decision was made to implement a gusset feature due to its simplistic nature and the potential sink marks being in a allowable area on the product as shown in figure 4.2.

The dimensions of the gusset is governed by the following design recommendations:

$$T_{gusset} = 0.6 \cdot T_{part} \rightarrow 0.6 \cdot 2.5\text{mm} = 1.5\text{mm}$$

and

$$h_{gusset} = 3 \cdot T_{part} \rightarrow 3 \cdot 2.5\text{mm} = 7.5\text{mm}$$

Where t_{gusset} is the thickness of the gusset, t_{part} is the thickness of the part, and h_{gusset} is the height of the gussets most peripheral surface.

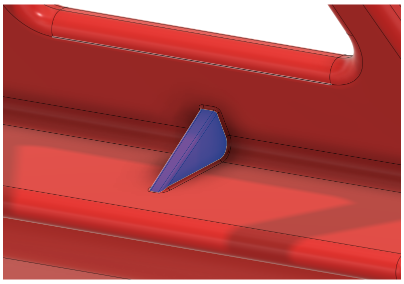

Figure 4.10: The implemented gusset (blue).

4.1.10 Tolerance analysis

Whilst tolerance analysis is still an essential aspect of the design process to ensure that critical dimensions meet functional requirements and that assembly processes are feasible, no notable tolerances were required in this product. This is because of the the compliant nature of the only product feature (phone flanges) that required a close fitment. The analysis can therefore only be performed via simulation results, regarding warpage in the Z-direction, presented in figure 4.17.

4.1.11 Ejector pin locations and rotational fixing

To avoid part deformation during ejection or difficulty in de-moulding the component, evenly spaced ejection pins, placed in strategic locations is necessary. Figure 4.11, depicts the selected four pin locations for this part.

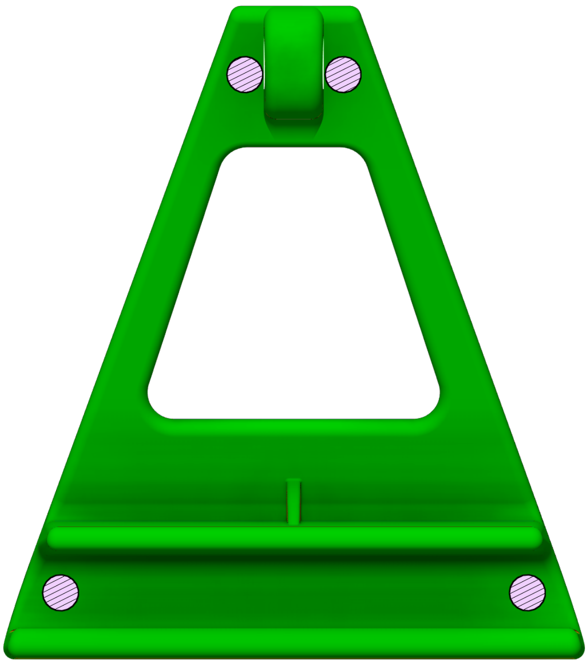

Figure 4.11: Chosen part ejection pin locations.

With this ejection pin layout, the ejection pin marks will remain somewhat obscured from the users, despite being on the upper surface (due to other moulding considerations), the user's key ring and smartphone will cover the marks. Additionally, the pin's are spaced evenly and located in the corners to compensating for warping effects to the best possible degree.

Due to the angle of the part in the mould, machining/grinding of the ejection pins will be performed to mate to the contact surface of the mould due to perpendicular surfaces being incompatible. However, unlike what figure 4.11 shows, the ejection pins will require an additional key way in order to prevent rotation to maintain the translation. Otherwise, the pins may potentially rotate during moulding and cause excess ejection marks on the part or prematurely wear out the pins due to angular forces becoming present. This will increase costs slightly as opposed to using standardized round ejection pins but it is expected that when the added costs distributed over all parts the difference becomes insignificant.

4.1.12 Positioning of the part in mould

Positioning of the part has been achieved in parallel with the part design. It was rather rudimentary, that it needed to be possible to separate the moulding halves and eject the part. Angles were needed in the part to support the cell phone at an angle. This made it straight forward in terms of deciding the angular positioning of the part in relation to the moulds tools linear Y-direction translation. This also governed a design detail - the key-connecting feature. As seen in Figure 5.3 as this feature allows for a key ring to be connected without the need for post processing (drilling a hole), while still achieving ejection.

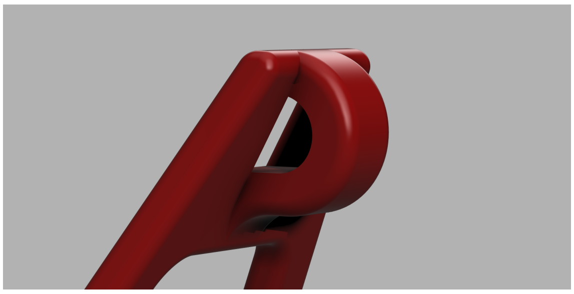

Figure 4.12: Key ring feature with angular feature.

As shown by figure 5.3, the final design of the key ring feature took into account the moulding/ejection orientation, reducing the need for complex tooling features such as sliders or costly post processing.

4.1.13 Part ejection analysis

To avoid unforeseen injection moulding machine downtime, it is imperative to ensure consistent part ejection process. Because unremoved parts can not only cause scrapped parts, but more importantly damage the tool or machine if not properly cleared, which can far-overshadow the upsides in obtaining a optimized cycle-time. Whilst many systems, including vision or robots are present to safe-guard the cyclic process ensuring the part removal, implementing solutions during the design to improve manufacturbility is the simplest & often best method.

An optimized part ejection whilst assessing the part orientation in the mould could be accomplished by positioning the part in the mould so it had either had:

- A strictly vertical drop off from the ejection mould half.
- A simplistic angled slide feature on the ejection mould half, which avoids catching the part during the ejection.

In this case, the later option was selected for this part. Figure 4.13 & 4.14 shows a comparison of the described method implemented to aid in the part ejection.

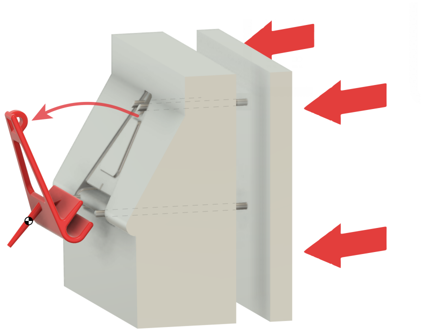

Figure 4.13: Ejected part sliding out of the mould with the attached gate contributing to moving the center of gravity (actual).

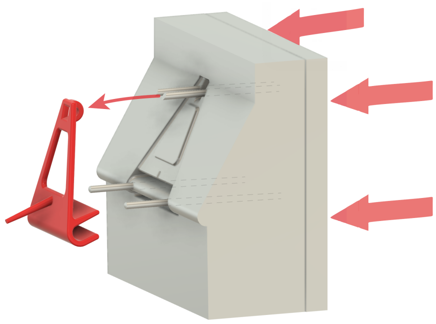

Figure 4.14: Ejector pins pushing the part vertically out of the mould (idealized representation - moulding geometry isn't accounted for).

From the above graphic it is seen that 4.13 was the utilized method for this mould cavity due to the inability for a vertical drop off. The attached gate was advantageously used for its ability to cause a rotational moment to ensure the part is ejected and falls out of the mould without errors, aiding in a robust cyclic process.

Moving & stationary mould halves

In this mold configuration, the fixed half of the tool houses the gate, which is where the molten material is introduced into the mold. This arrangement allows for a controlled and efficient material flow into the mold cavity. The moving half of the mold contains the main cavity and is equipped with ejector pins, facilitating the ejection of the molded part once the injection molding process is completed.

This configuration optimizes the injection molding process by strategically separating the gate and the ejector pins across different halves of the mold. The fixed half's primary function is to manage the entry and initial distribution of the molten material, while the moving half is primarily responsible for shaping the part and ensuring its smooth release. Such a setup is optimal cycle time as it ensures for easy ejection of the finished product from the moulding tool.

4.1.14 Customized text & traceability tooling insert

This phone key chain stand could be utilized as a low cost promotional "freebie" part for companies at events etc., requiring a customized logo. Whilst, an insert could be added with text, the initial manufactured mould design doesn't encompass it. However, given that the insert would require further material subtraction to be implemented (not addition) it is possible to re-work the tooling and incorporate a customized text field for each production run in the future.

Additionally, a numerated traceability insert could also be added, although the reasoning for implementation seems negligible due to not being a part with a very important function or in a highly regulated market (eg. medical or aerospace).

4.2 Considerations post-simulation

Following the outlined simulation runs outlined in 6, review of the results further informed several key factors in terms of assessing the DFM phase, outlined in the following sections. Run 3 is utilized due to being found as the optimal.

4.2.1 Sink marks

As figures 4.1and 4.2 had predicted, sink marks were present in the highlighted areas in the `Moldex` simulation, as depicted in figure 4.15.

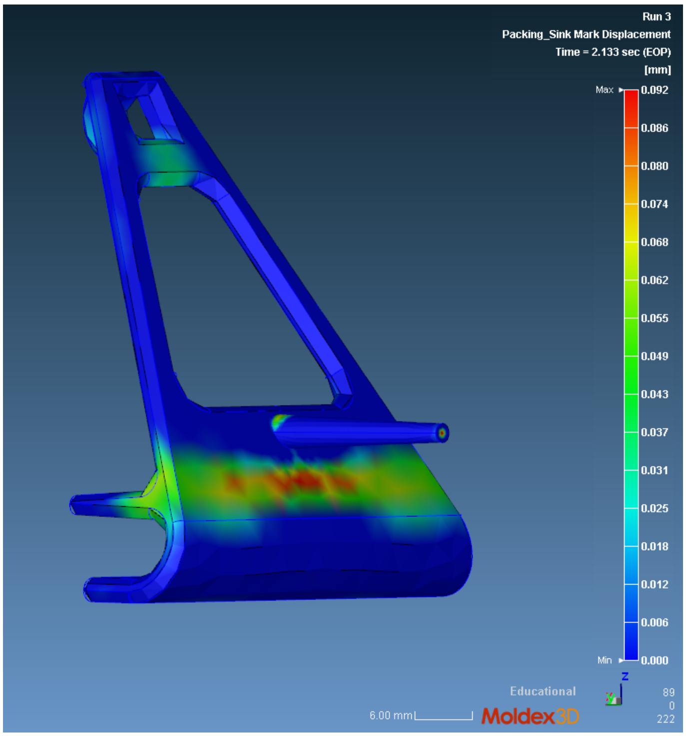

Figure 4.15: Sink mark regions from `Moldex`, showing some congruence with speculated areas.

From figure 4.15 the maximum sink mark of 0.092 mm is found to be occurring in the center, close to the gate rather than on the identified external siding area. Other runs did not posses this central sinkmark. On the identified external siding area a smaller sink displacement of 0.043 mm. The simulated result is roughly a third of the length to the theorized linear shrinkage of 0.129 mm as outlined in equation 4.1.1. It is hypothesized that packing parameters were thus implemented successfully, reducing the linear shrinkage. Although shrinkage is more likely to be volumetric (ie. cubic & not linear) in nature for 3D geometries, the resulting sink marks given such an assumption would result in larger sinkmarks than both the simulated and/or the theorized linear shrinkage, which isn't the case. Therefore, it is speculated that the implemented packing procedure in simulations managed to reduce the sink marks to a satisfactory degree and should be used during production.

4.2.2 Warpage

A critical consideration after running simulations is to evaluate the degree of warpage given it's effect on not only part geometry changes post cooling, but also in terms of part ejectability. Figure 4.16 shows the results of total warpage analysis.

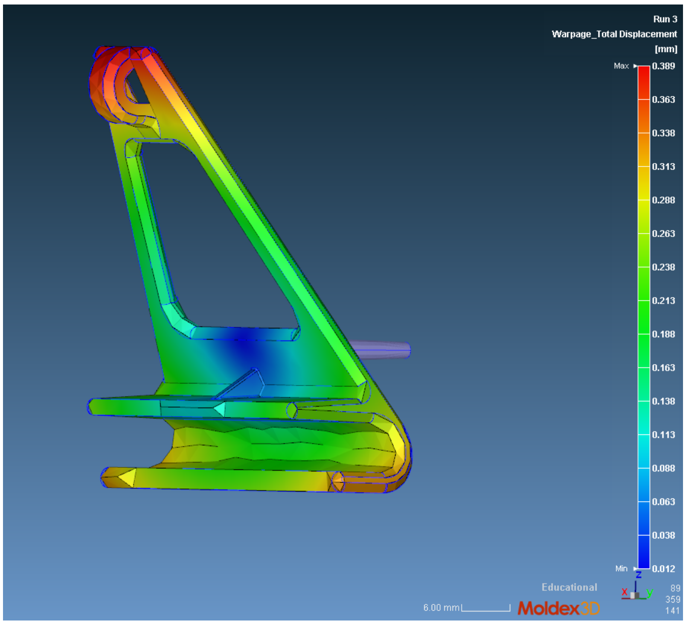

Figure 4.16: Total displacement from `Moldex`.

However, given the aforementioned problems with the ejectability stemming from the acute angled phone "channel" wherein the mould tool uses a undercut, assessing the directional displacement/warpage is also necessary and shown in figure 4.17.

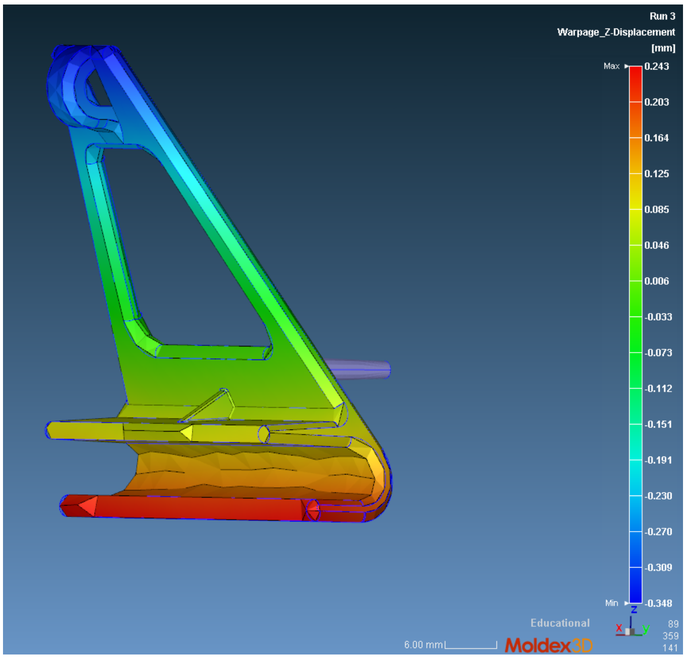

Figure 4.17: Z-direction displacement from `Moldex`.

Figure 4.17 shows a significant warpage on the maximum value of 0.243 mm on the user facing phone flange (bottom in figure). This result is concerning given that it may result in difficulty during part ejection, as the flange could bind itself to the feature that defines this channel. A method of circumventing this would be to eject the part earlier on in the cycle (with the advantage of reducing cycle time), as the thermoplastic would remain hotter and thus be in a more ductile state, however, the risk of causing either permanent part deformation or larger ejection marks during removal of the not-completely cooled part is also a risk. Therefore, either part redesign or actual testing of ejection may be necessary.

4.2.3 Weld lines

From the conducted simulation the found weld lines are presented in figures 4.18 and 4.19. These figures are the weld lines at the top from the two small bending beams that compose an acute angle at the tip near the key ring feature.

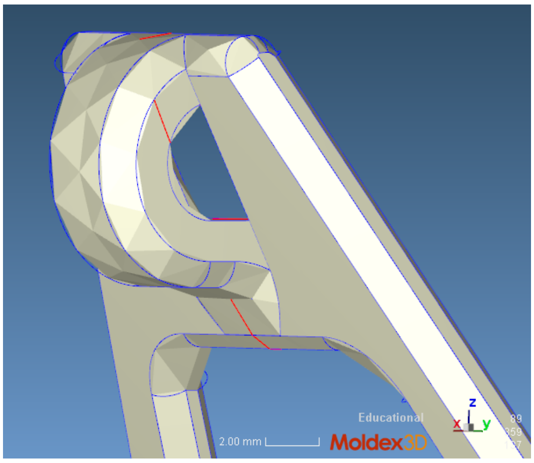

Figure 4.18: Frontal weld lines from `Moldex`, showing two weld lines.

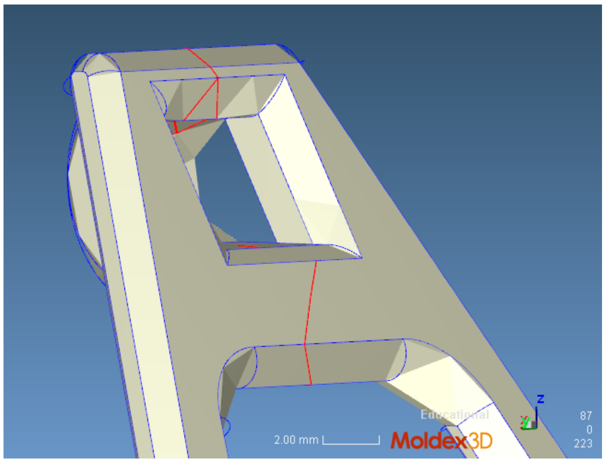

Figure 4.19: Posterior weld lines from `Moldex`, showing two weld lines.

Looking at figure 4.18 & 4.18, it can be seen that the speculated weld lines shown in figure 4.8 are in congruence with the weld lines from the simulation. However, due to inevitable nature of weld lines, they are deemed appropriate given the products intended use case, implying small forces being applied to the keyring feature.

4.3 Conclusion from DFM analysis

Through the DFM analysis performed it was deduced that a re-design of the part/tool wasn't necessary due to an overall adherence to the outlined DFM principles.

The most concerning remaining aspect pertained to the phone support flanges shrinkage due to the 1° undercuts present alongside the 0.243 mm Z-direction warpage (as shown in figure 4.17) would cause adherence to the moving mould half. More analysis with advanced multi-physics simulation would be required in order to determine part ejectability.

Furthermore, if this undercut problem were to be present, the temperature at ejection could be increased due to polymers being having improved elastic behaviour at elevated temperatures. However, this would likely also entail deeper ejection marks on the upper (user visible) surface, which isn't ideal.

Another way of addressing the potential undercut issue is to further remove tool steel on the moving mould half via an EDM machining process, as there is surplus material available. This machining would result in a reduction the undercut angle, with the impact of longer tooling development time and a slightly increased part volume.

A final concern was the present weld lines in the most mechanically critical area, namely, the keyring feature. While these weld lines would cause separation of the melt front due to the keyring exerting a force along the weld front, it was suspected that adjusting the input temperatures such as melt and/or mould temperature and conducting tensile testing could be implemented to determine the extent of this concern.

A way to address this problem would be to move the gate position towards the key ring feature, away from the centralized location, causing weld lines to instead be formed near the phone support flanges. However, the impact of deviating from a central area may entail other filling issues, especially when utilizing lowered temperatures as outlined in chapter 6. Further analysis towards changing gate position will be necessary if weld lines are too be avoided.

5 | Mould Design

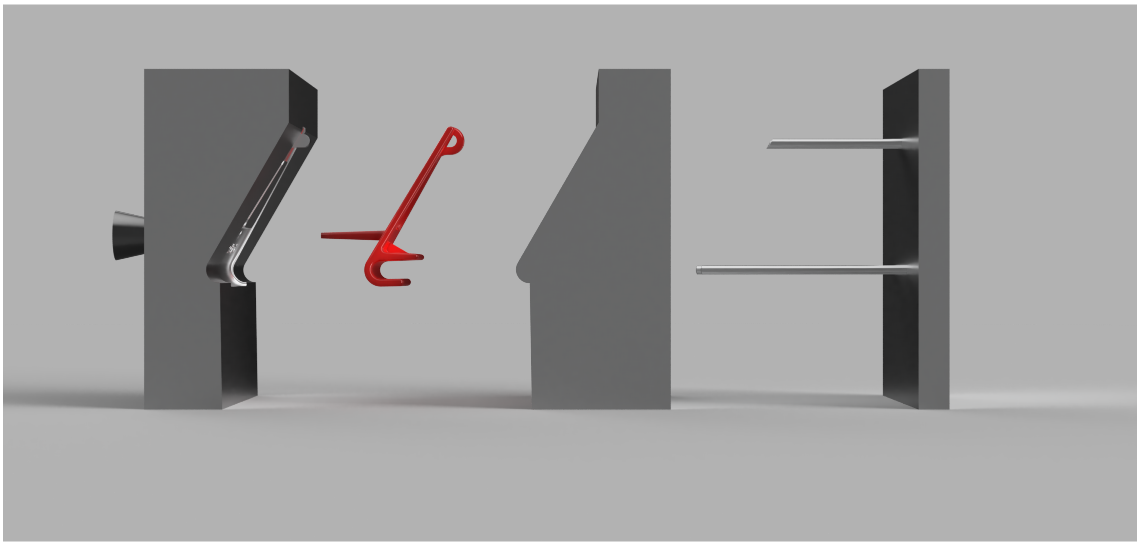

Figure 5.1: Exploded render of the mould design.

5.1 General remarks

For this mould, a fairly simple two part mould design with a parting line that roughly follows the center of the part thickness, has been designed in `Autodesk|Fusion 360`. It is assumed that the shrinkage and the few areas without draft angle will facilitate that the part will remain stuck to the moving part during separation of the mould halves but still be ejected once subjected to the equally spaced four ejector pins. A few fillets have been omitted, as to not over complicate the CAD-modelling. All of these edges should be assumed to have a radius of $\approx$ 0.1mm and can be found in detail in appendix A.3. While this chapter outlines many of the designed implementations, many are also outlined in chapter 4 due to the significant overlap between them.

5.2 Outer dimensions, material, and description

The part can be constrained into a bounding rectangular volume of 50 mm x 53 mm x 35 mm.

The complete mould dimensions when both halves are connected are 70 mm x 110 mm x 110 mm. This leaves the necessary space for bushing, sprue, cooling, ie. the mould's operational features, enhancing the efficiency of cooling and the ease of material handling.

As section 3.3 outlines, the selected material for the part is a blend of Polyphenylene Oxide and Polystyrene (PPO/PS). The properties of this materials is important for products requiring high durability under the operational stresses, which is expected for small pocket gadgets.

The mould parts and ejector pins are crafted from P20 (specified via `Moldex`) tool steel, as this "hard-tooling" is necesary due to the high part count required, making "soft-tooling" via aluminum in compatable due to the sub-1000 cycles it is capable of handling. Ejector pins are speculated to be standard components, ground on one side, in order to have the same angle as the mould/part.

5.3 Injection molding machine selection

Usually, at this point in the process, a specific machine will be chosen. The choice will depend on mould size, material, economy, availability just to mention a few important factors. The machine selected was the `Arburg allrounder 370A Alldrive (1000kN)`, due to it being the machine utilized in DTU building 427 plastics labs, which would then come with specific dimensions for cooling tubings, fittings, nozzle, ejector module size etc. To keep a reasonable scope for this report, all these dimensions have been assumed and the smallest screw diameter (18 mm).

Figure 5.2: Arburg allrounder 370A Alldrive (1000kN)
[4].

5.4 Positioning the part

Positioning of the part has been achieved in parallel with the part design. It was rather rudimentary, that it needed to be possible to separate the moulding halves and eject the part. Angles were needed in the part to support the cell phone at an angle. This made it straight forward in terms of deciding the angular positioning of the part in relation to the moulds tools linear Y-direction translation.

5.4.1 Key ring feature

This also governed the design detail for the key-connecting feature. As seen in Figure 5.3, this feature allows for a key ring to be attached without the need for post processing, while still achieving ejectability.

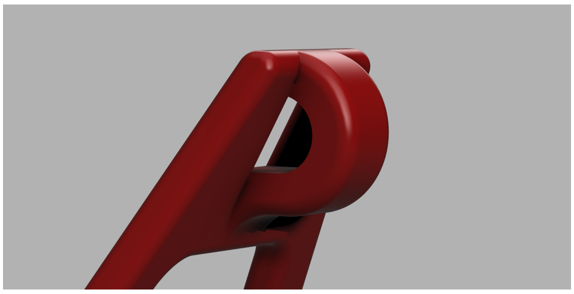

Figure 5.3: Key ring feature with angular feature.

5.5 Shape of mould core and mould cavity

The parting line had to follow the parts general shape for much of the part length, to ensure ejectability. There is only one cavity and undercuts are completely avoided. This also removes the need for complex tooling features such as sliders.

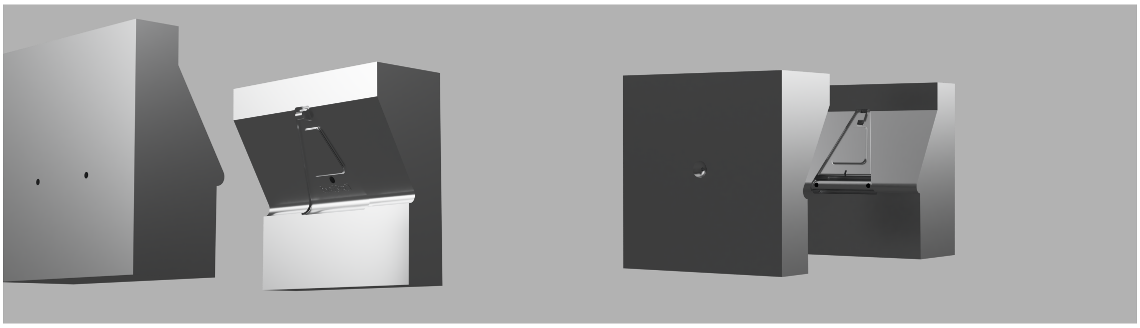

Figure 5.4: Mould Cavity

5.6 Gate and runner system

This subsection outlines the design rationale and mathematical relationships involved in configuring the runner system for the injection molding process, specifically focusing on a sprue-gate system.

5.6.1 Selection of the sprue gate system

The gate selection for the part was determined based on placing it in a central location to aid in a homogeneous material flow towards the mould sides.
The choice of a sprue-gate system is driven by the simplicity and effectiveness in the injection molding process, while also avoiding runners and a separate gate. Sprue-gates are straightforward to design and implement, making them a favorable option for streamlined production - especially when working with a single very simple part.

5.6.2 Sprue gate location

The gate location has been selected based on the following parameters:

1. Symmetry in the center line.
2. A centralized position for optimal outwards flow.
3. Position the bottom surface for aesthetic reasons & due to being on the fixed mould side.

Figure 5.5 depicts the selected gate location.

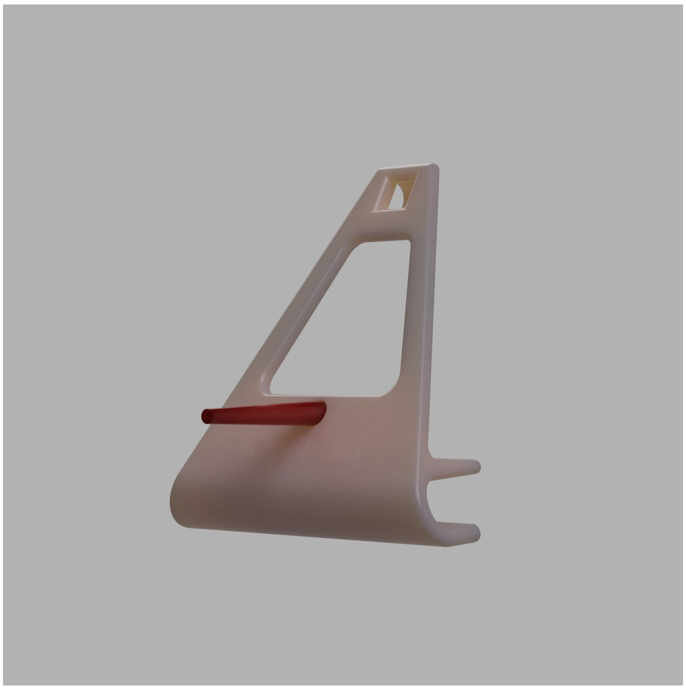

Figure 5.5: The selected gate location on the part.

Whilst the part could have implemented a recessed pocket in order to mitigate the wobble from the gate mark, this was omitted due to added complexity, requiring additional post processing.

Air flow/ venting and weld lines has not been considered in the selection of gate location due to the products symmetry and centralized gating location placement available. However simulation results outlined in chapter 6 will confirm this notion.

5.6.3 Nozzle, sprue bushing, and sprue gate dimensions

As aforementioned, the specific dimensions for the nozzle are assumed. These dimensions influence the design parameters of the sprue bushing, specifically, the inner orifice diameter of the nozzle d_N and the spherical radius R_N of the nozzle are critical. The design ensures that the sprue bushing's spherical radius R_A and inner initial orifice diameter d_S accommodate the nozzle's dimensions plus an additional clearance to facilitate material flow and thermal expansion.

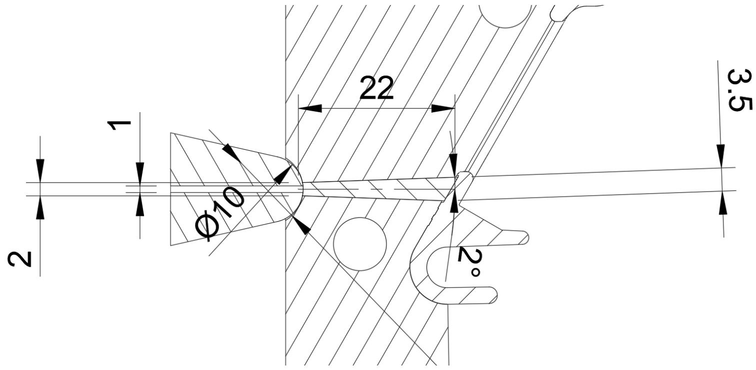

Figure 5.6: A full size technical drawing of the sprue gate shape is listed in appendix A.1.

Sprue bushing Dimensions

The known (assumed) dimensions are as follows:

- $R_D = 10\text{mm}$
- $d_N = 1\text{mm}$

Mathematically, the relationships are defined as follows:

Relationship between spherical radius of the nozzle (R_N) to the spherical radius of bushing (R_A)

$$R_A \geq R_N + 1(\text{mm}) \tag{5.6.1}$$

$$\Rightarrow R_A \geq 10\text{mm} + 1\text{mm} \Rightarrow R_A \geq 11\text{mm}$$

Relationship between inner orifice diameter of the nozzle (d_N) to the inner initial orifice diameter of the bushing (d_s)

$$d_s \geq d_N + 1(\text{mm}) \tag{5.6.2}$$

$$\Rightarrow d_s \geq 1\text{mm} + 1\text{mm} \Rightarrow d_s \geq 2\text{mm}$$

Sprue Dimensions and Taper Angle

The dimensions of the sprue bushing directly affect the runner's sprue dimensions—specifically, the length L and diameters d_S (start) and d_F (finish) of the sprue. These dimensions are important for determining the taper angle α of the sprue, which influences the flow and cooling of the molten plastic within the runner system. The taper angle is calculated to ensure that the sprue can be ejected and to ensure efficient material flow and minimize the stress and heat concentration during the molding process.

The known (assumed) dimensions are as follows:

- $L = 22\text{mm}$
- $d_A = d_s = 2\text{mm}$
- $\alpha = 2°$

The geometric relationship of the sprue's dimensions are as follows:

$$\tan(\alpha) \geq (\frac{d_F - d_A}{2 \cdot L}) \tag{5.6.3}$$

It is optimal to have $1^\circ \leq \alpha \leq 2^\circ$ in order to facilitate smooth material flow from the nozzle through the bushing into the mold cavity. We assume $\alpha = 2^\circ$, and thus solve for d_F

$$\tan(2^\circ) \geq (\frac{d_F - 2\text{mm}}{2 \cdot 22\text{mm}}) \Rightarrow d_F = 44\text{mm} \cdot 0.035 + 2\text{mm} \approx 3.5\text{mm}$$

To facilitate proper cut off of sprue, as to have a flat bottom surface, the sprue area is submerged 0.5mm into the part surface.

Figure 5.7 shows the finalized runner system implemented.

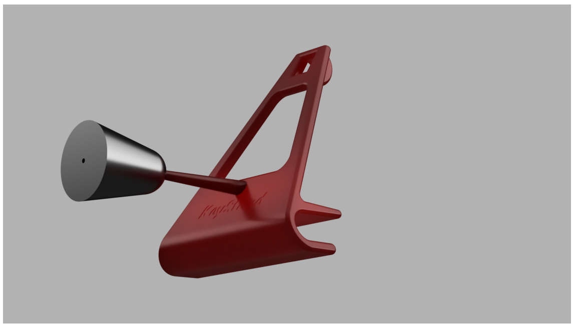

Figure 5.7: Runner design - Render

This comprehensive approach to designing the runner system ensures that all components are optimized for both functional performance and manufacturability.

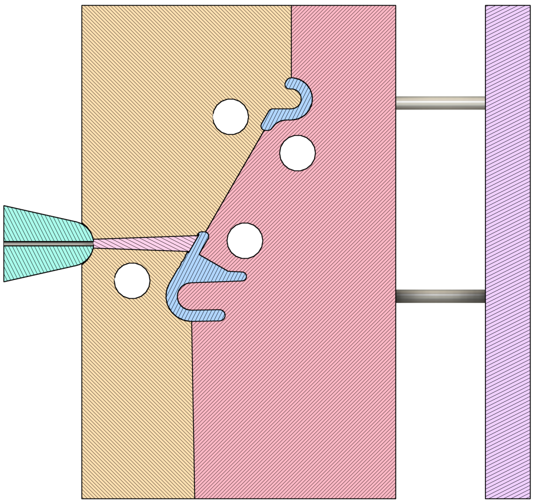

Figure 5.8: Cross sectional view of the implemented sprue-gate system.

5.6.4 Zebra Analysis

A Zebra analysis of the part was made, to ensure continuity in the surface interfaces. This was was done for both the component and the moulding halves.

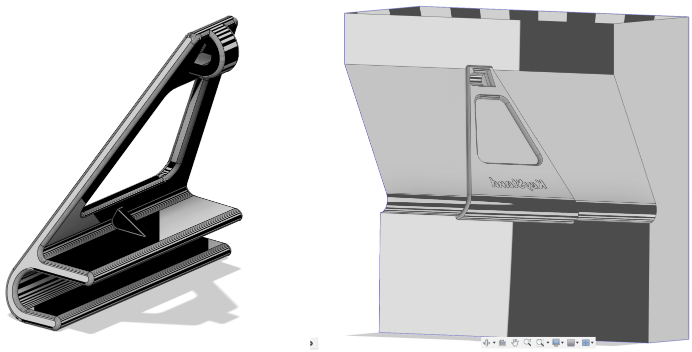

Figure 5.9: Zebra analysis - part and mould - CAD

5.6.5 Draft analysis

Draft angles are carefully considered in the design to facilitate the ejection of the injection moulded piece. Implementing a draft angle of min 1° (4.5) significantly reduces the force required to eject the part from the mould. This not only minimizes the friction between the mould and the part but also helps in maintaining the surface finish of the product. A minor area of non-drafted angles are accepted, as minor undercuts - along with warpage and shrinkage. This ensures a higher friction between the moving half and the part than between the fixed half and the part. Thus, it is ensured that the part (incl. sprue) will be pulled out of the fixed half. Because the areas are minor, and because ejection happens while the part temperature is still higher (≈ 70℃), the part kan still be ejected.

5.6.6 Cooling Channels

The cooling channels are positioned by assumption, and further included in the simulations, as to assess their effectivity.

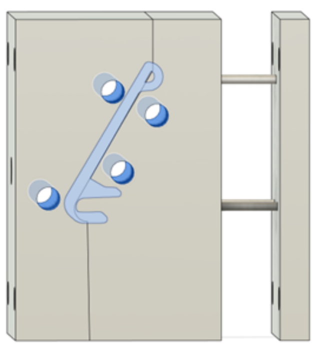

Figure 5.10: Illustration of chosen cooling channels

5.6.7 Ejector pins

The ejector pins are designed to be flush with the part surface. The should of course be constructed with minimal tolerance, but with a focus on allowing the movement of them. The design specifics are further elaborated on in 4.1.11.

6 Simulation of injection moulding process

Finding the right parameters for a given injection moulding process is often a process done with some trial and error wherein operators change/tweak input parameters and consider the outputs in order to find the most suitable parameters based on their needs, such as cycle time, sink marks, machine capability (such as tonnage or cooling capabilities). This factory floor tweaking often results in scrapage of material and waste of time. However, utilizing digital twins for manufacturing, via software such as `Moldex`, allows for simulation of the injection moulding process, wherein the utilized material, designed mould tool, part, and selected injection moulding machine are inputted and the injection process can then be simulated, predicted, and adjusted.

This chapter summarizes the setup steps required to conduct a simulation within `Moldex`, as well as outlining the experimentation steps performed with the aim of reducing this low-cost products cycle time through the power of simulations in order to reduce both the setup time and find the limits of the process parameters.

6.1 Inputs & setup of simulation

Setting up the simulations required a few simplifications of the part CAD model. During meshing of the part several problems were occured. The part had, at the time, text (a logo) displayed on the front. This did not play well with the meshing as it had many sharp and oblique angles. Additionally these letters were not optimized for injection molding and were scrapped by taking them out of the CAD-model. Another problem of meshing was attempting to incorporate the nozzle of the injector. Here meshing made the union with the mold very undefined, as such it was removed to save time and complexity. This means that the mold does not have the heated nozzle providing an additional heat source, which may potentially affect the temperature gradients in the mould and consequently the filling and warpage simulations. However, it is assumed that it the contribution is negligible.

Cooling channels were simplified in the simulation as five channels running though the moulding tool. See figure 6.1 for the setup. This was done as the cooling channel design had not been concluded in the mould design process as simulations took place.

As a PPO/PS was the selected material, outlined in section 3.3, a commercially available blend, that also was available within `Moldex` was necessary to find. The resultant PPO/PS polymer material was `NORYL™ Resin 731` from `Sabic`.

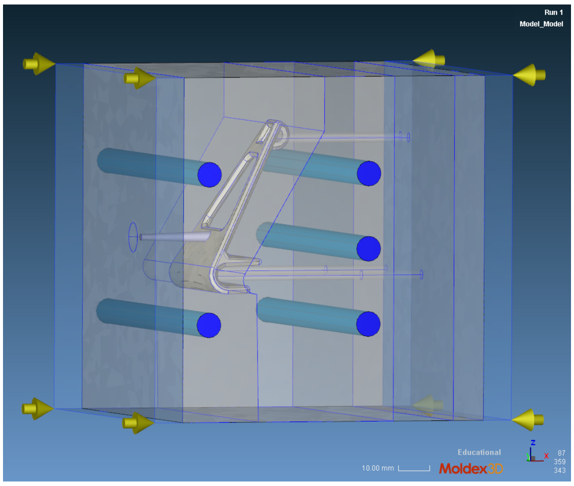

Figure 6.1: The cooling channel system used in the Moldex simulation. This differs slightly from the final CAD-model.

The machine selected for the simulations in Moldex was Arburg 370A-700-18. This machine selection provides the injection behaviour to Moldex.

Lastly the analysis mode used was FPCTV. Filling, packing, cooling and warpage simulation. This would give all the information needed in the decision making as to what process parameters were suitable as described in section 4.2.

6.2 Experimentation via 3 runs

Utilizing `Moldex`, parameters were optimized to reduce cycle time and thereby increase production throughput, whilst still having a part that wasn't noticeably worse off in terms of sink marks, volume, etc. For the injection mould parameter testing, `Moldex` and the provided data sheet for `NORYL™ Resin 731`[3] were used to simulate the three different runs via the following method:

1. **Run 1:** Centre of recommended parameters
2. **Run 2:** Lowest recommended parameters
3. **Run 3:** Under recommended parameters

The parameters for each run is tabulated in table 6.1. The packing pressure is set to 80% of the injection pressure. Since the injection time is defined the injection pressure is just what is needed to move in that time. This makes the packing pressure dependent on the injection time and temperature of the melt, or said in a different way the packing pressure is not directly defined.

The strategy of three runs were not formulated from the beginning. After an initial test of "Run 1" run, all three runs was performed. Run 1 and Run 2 revealed no large problems with the mould filling or warpage. Finally Run 3 (at much lower temperatures to really push the envelope) was performed, also with success.

Table 6.1: The injection moulding parameters set for the simulation runs

Parameter	**Run 1**	**Run 2**	**Run 3**
Melt Temperature	290 °C	280 °C	270 °C
Mould Temperature	100 °C	75 °C	50 °C
Injection Speed	0.1 s	0.1 s	0.1 s
Maximum injection pressure	61.630 MPa	66.288 MPa	71.514 MPa
Packing Pressure	16.995 MPa	9.159 MPa	15.753 MPa
Packing Time	5 s	5 s	2 s
Cooling time	8 s	5 s	4 s

6.3 Results and discussion

The result of running the three simulations were a substantial reduction in cycle time. The initial goal of investigating warpage and sink marks became less important as the simulations indicated that these would not be a problem. In table 6.2, selected results and parameters are presented.

Table 6.2: Different parameters and results from the three simulation runs.

Parameter	**Run 1**	**Run 2**	**Run 3**
Packing Time	5 s	5 s	2 s
Cooling Time	8 s	5 s	4 s
Cycle Time	18.01 s	15.01 s	10.01 s
Volumetric Shrinkage - Avg	4.084 %	3.751 %	5.080 %
Sink Mark Displacement	0.0108 mm	0.096 mm	0.092 mm
XY_Clamping Force - Max	7.283 t	7.868 t	8.294 t
XY_Max Displacement	0.389 mm	0.395 mm	0.389 mm
Density - Max	1.082 g cm^{-3}	1.086 g cm^{-3}	1.090 g cm^{-3}

The first run had an appropriate cooling time and an non optimised packing time. The two additional iterations with lower cooling and packing time got similar if not better results. Based on the results from three runs of the `Moldex` simulations, it is evident that staying within the confines of manufacturer recommended parameters would be costly in terms of production throughput. Whereas, by altering the injection molding parameters, a significant impact on cycle time has been shown, whilst not undermining part quality. Run 1, with a cycle time of 18.01 s, achieved a volumetric shrinkage of 4.084 % and a minimal sink mark displacement of 0.0108 mm. In contrast, Run 3 stands out as the optimal configuration, achieving a remarkable reduction in cycle time of 44.42%, to 10.01 s. Despite the slight increase in volumetric shrinkage (5.080 %), this was balanced by a negligible sink mark displacement (0.092 mm) as well as a increased density of 1.090 g cm^{-3}, likely due to cooler mould tooling, resulting in less shrinkage. Therefore, Run 3 presents an optimal compromise, achieving faster cycle times with minimal trade-offs in terms of part quality, making it the preferred configuration for our production process, especially considering the headroom provided by the selected 1000 kN $\Leftrightarrow$ 225 t clamping force capabilities of our machine when compared to the tonnage required (8.294 t), showing that flashing will likely not be drastically affected despite the higher forces arising from the more viscous (due to lower temperature) polymer.

The main design parameter enabling these lowered cycle times is the injection sprue. The large inlet enable the plastic to be injected at a very high rate, filling the mould before the mould has the chance cool the melt front. As such the mould temperature only starts to cool the melt during the packing stage.

6.3.1 Other considerations

From Run 3 several other figures were extracted. Sink mark analysis is presented in figure 4.2. Total and z-direction warpage was presented in figure 4.16 and 4.17 respectively. Weld line analysis was also considered, and this is presented in figure 4.18 and 4.19.

6.4 Process parameter conclusion

In conclusion the parameters in run 3, in table 6.1, are the most desirable as they produce a good enough part with a much lowered (approx. 44.4%) cycle time. This is despite the process running at lower than manufacturer recommended process conditions, emphasizing the value that simulations can have towards profitability.

7 | Sustainability

A life cycle assessment analysis of the product is relevant to identify where there are areas of improvement in the environmental impact of the product. In order to be sustainable the impact of products need to be minimized if not eliminated. For this analysis the EcoAudit tool in Granta Edupack is used. It provides a full material database together with transport and end of life impact assessments. Two use scenarios are analysed for a single product.

7.1 Materials and manufacture.

The phone holder is principally made of plastics polymer PPO+PS. This is a non recyclable polymer and as such will be 100% virgin. The primary process is injection molding, Granta calls this polymer molding. A seconday process of cutting and trimming is added to remove the injection sprue. The sprue weighs roughly 20% of the final product. Secondly a metal key ring is also included. It is made from stainless steel by wire drawing. A conservative (overestimating) estimate of 10% removal is made, furthermore the recycled content is set to the typical amount in the GRANTA database. Last material is the packaging. Here cardboard is used with 10% removed.

For joining and finishing, the process of construction was selected as the most appropriate for the assembly of the parts. All the choices discussed here are presented in table 7.1.

Table 7.1: The choices made in term of material, manufacture and joining.

Material and manufacture						
Component	Material	Recycled content	Mass [kg]	Primary process	Secondary process	% removed
Phone Holder	PPO+PS	Virgin	0.006	Polymer molding	Cutting and trimming	20
Key ring	Stainless steel	Typical	0.01	Wire drawing	Cutting and trimming	10
Packaging	Cardboard	Virgin	0.05		Cutting and trimming	10
Joining and finishing						
Name		Process			Amount	Unit
Assembly and Packaging		Construction			0.066	kg

7.2 Two use and EoL scenarios

Two scenarios are constructed and presented for the use and end of life (EoL) phase. The secondary scenario is in some cases made different for the sake of differentiation.

7.2.1 Scenario 1

In the first scenario the product is manufacture in China and used in Denmark. The designed product life cycle is five years, however since it is designed for a single model of Iphone, and people replace these at a high rate to get the latest model, the estimated use life will be 3 years.

Distance to manufacturer: Made in Guangzhou, China. Transported by truck to port, quick estimate of 100 km. From port in Guangzhou, China, to Antwerpen, Belgium, by container ship with a journey length estimated to 18000km. It is then deliver to at warehouse in Kolding, Denmark, the truck journey being 800 km. Lastly the part is delivered to the consumer by light commercial vehicle as part of a parcel delivery, here an estimate of average delivery distance is 150 km. This is presented in table 7.2.

Table 7.2: Transport conditions in scenario one. China to Denmark via Belgium.

Name	Transport type	Distance [km]
Factory to port, CN	Truck > 32t, EURO 3	100
Port to port, CN/BE	Sea container ship	18000[5]
Port to warehouse, BE/DK	Truck 16-32t, EURO 6	800
Final delivery, mail order	Light commercial vehicle	150

EoL: In Denmark there is a relatively robust recycling network. However the polymer chosen, PPO+PS, cannot be recycled. Therefore it will go to incineration. Incineration in Denmark is done with thermal recovery. The metal key ring will be recycled and the cardboard packaging will also be recycled. In these cases we consider 100% recovery. These considerations are presented in table 7.3.

Table 7.3: The product life and EoL for scenario one.

<table>
<tr><td colspan="4">Use</td></tr>
<tr><td colspan="2">Product life cycle</td><td colspan="2">Country of use</td></tr>
<tr><td colspan="2">3 years</td><td colspan="2">Denmark</td></tr>
<tr><td colspan="4">End of Life (EoL)</td></tr>
<tr><td>Quantity [kg]</td><td>Component name</td><td>EoL Type</td><td>% recovered</td></tr>
<tr><td>0.006</td><td>Phone Holder</td><td>Combustion</td><td>100</td></tr>
<tr><td>0.01</td><td>Key ring</td><td>Recycle</td><td>100</td></tr>
<tr><td>0.05</td><td>Packaging</td><td>Recycle</td><td>100</td></tr>
</table>

7.2.2 Scenario 2

In the second scenario the product is manufactured in China and used in the USA. In order to narrow the scope of the transport distance investigation this product is sold and used in California. The designed product life cycle is five years. For the sake of variety the use life of the product will also be five years.

Distance to manufacturer: Made in Guangzhou, China. Transported by truck to port, quick estimate of 100 km. From port in Guangzhou, China, to San Francisco, USA, by container ship with a journey length estimated to 11600km. It is then deliver to a warehouses in the state, an average truck journey of 250km. Lastly the part is delivered to the consumer by light commercial vehicle as part of a parcel delivery, here an estimate of average delivery distance is 150 km. This is presented in table 7.4.

Table 7.4: Transport conditions in scenario two. China to California in the USA.

Name	Transport type	Distance [km]
Factory to port, CN	Truck > 32t, EURO 3	100
Port to port, CN/US	Sea container ship	11600[5]
Port to warehouse, US CA	Truck 16-32t, EURO 6	250
Final delivery, mail order	Light commercial vehicle	150

EoL: The polymer chosen, PPO+PS, cannot be recycled. In this scenario it goes to landfill together with the cardboard. The metal key ring will be recycled, we consider 100% recovery. These considerations are presented in table 7.5.

Table 7.5: The product life and EoL for scenario two.

Use			
Product life cycle		Country of use	
5 years		United States of America	
End of Life (EoL)			
Quantity [kg]	Component name	EoL Type	% recovered
0.006	Phone Holder	Landfill	100
0.01	Key ring	Recycle	100
0.05	Packaging	Landfill	100

7.3 Results

The summary results for the climate change impact are presented in figure 7.1 and 7.2 for scenario one and two respectively. Additionally the breakdown for each phase in terms of CO2eq and energy is presented in table 7.6 and 7.7 for scenario one and two.

The material contribution is the largest contributor. Looking further into the numbers it turns out that the metal key ring is very expensive in sustainability terms. The EoL potential is almost identical between the scenarios in terms of climate change impact. This is because the metal key ring is so expensive to manufacture and has a large EoL impact. The recycling of the plastics and cardboard in scenario one only provides a small reduction in the overall environmental impact of the product.

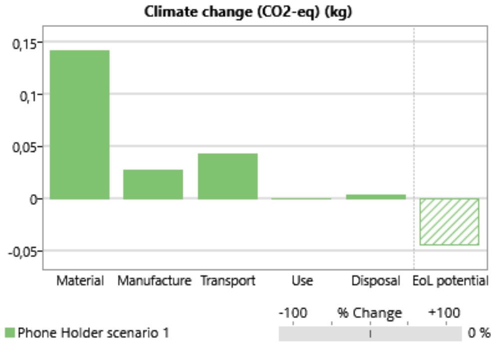

Figure 7.1: Scenario 1

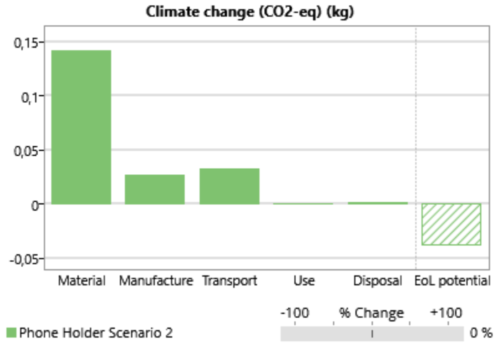

Figure 7.2: Scenario 2

Table 7.6: Summary: Scenario 1

Phase	Energy (MJ)	Energy (%)	Climate change (CO2-eq) (kg)	Climate change (CO2-eq) (%)
Material	2,697	72,3	0,142	66,0
Manufacture	0,361	9,7	0,027	12,6
Transport	0,628	16,8	0,043	20,0
Use	0,000	0,0	0,000	0,0
Disposal	0,045	1,2	0,003	1,5
Total (for first life)	**3,731**	**100**	**0,216**	**100**
End of life potential	-1,051		-0,045	

The transport cost is different but not as much as expected. The largest contributor for both scenarios is the final delivery by light commercial vehicle which is set to the same distance. This is a transport mode where the parts are not well packed in a large consignment. This makes the transport stage very inefficient.

Table 7.7: Summary: Scenario 2

Phase	Energy (MJ)	Energy (%)	Climate change (CO2-eq) (kg)	Climate change (CO2-eq) (%)
Material	2,697	76,4	0,142	70,6
Manufacture	0,348	9,9	0,026	13,0
Transport	0,469	13,3	0,032	15,9
Use	0,000	0,0	0,000	0,0
Disposal	0,018	0,5	0,001	0,6
Total (for first life)	**3,532**	**100**	**0,202**	**100**
End of life potential	-0,440		-0,038	

7.4 Sustainability conclusion

The most significant contributor to the environmental impact is the initial material use. The use of a stainless steel for the key ring is the most significant contributor, and also provides the greatest EoL recovery potential. The two transport scenarios, while quite different in scope, are not very different in contribution. The largest contributor are in both cases the identical final delivery.

8 Conclusion

In the report, several important requirements have been outlined for the design of the plastic part, mould, and polymer selection. The chosen polymer, a blend of PPO/PS, offers a lightweight yet durable material that ensures the product remains flexible in the users pocket without breaking while also resisting creep under prolonged use. The robust mechanical properties help the product withstand the calculated installation forces, providing a high degree of the devices stability during usage.

The triangular bottom design provides stability on flat tables. This is achieved by submerging the sprue-gate mark to achieve a flat surface during moulding. The key ring attachment point is compatible with a wide variety of key rings, and the triangular shape ensures the stand tapers neatly to this point, minimizing bulk.

Throughout the mould design process, Design for Manufacturing (DFM) principles have been applied to, among others, minimize sink marks, ensure consistent wall thickness, and to prevent sidewall bending, while also reducing development/production costs.

The injection moulding process has been iteratively designed to achieve a fast cycle time, decreasing the production cost, and thus ensuring a low price to market.

By implementing these parameters and designing the mould around them, the final product embodies both form, function, and manufacturability, providing a convenient and practical solution that securely envelops an iPhone 7 Plus and remains durable over time.

8.1 Future work

There are many possibilities for further development of the product. The focus areas would then be governed by desired product updates and a business plan.

8.1.1 Finalizing mould for production

Using the mould in a specific injection moulding machine requires a redesign of the mould, as for example alignment pins are placed differently in the current design. In general, a lot of different specifics will need to be changed before it can be implemented into a machine.

The mould design could (and should) be upgraded to contain several cavities (likely 4, 8 or more), with an adjusted runner system to make it easier to mass produce the product via multiple cavities. Furthermore, venting for each cavity should also be designed.

8.1.2 Further part refinement

The extent that weld lines have on the key ring feature may cause poor mechanical structure, therefore tensile testing is required with the specified moulding parameters found via three iterative cycle time optimization runs.

Additionally, the release of the part in terms of the undercut mould feature will have to be evaluated experimentally, as it is difficult to assess the part ejection success.

The part could also be upgraded with for a universal fit for different smart phones, ensuring a secure fit would however, present a challenge.

Bibliography

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[3] MatWeb, *Datasheet for SABIC NORYL 731* https://www.matweb.com/search/datasheet.aspx?matguid=83edf7884ea8466aab3cb2895b37fd2f&ckck=1

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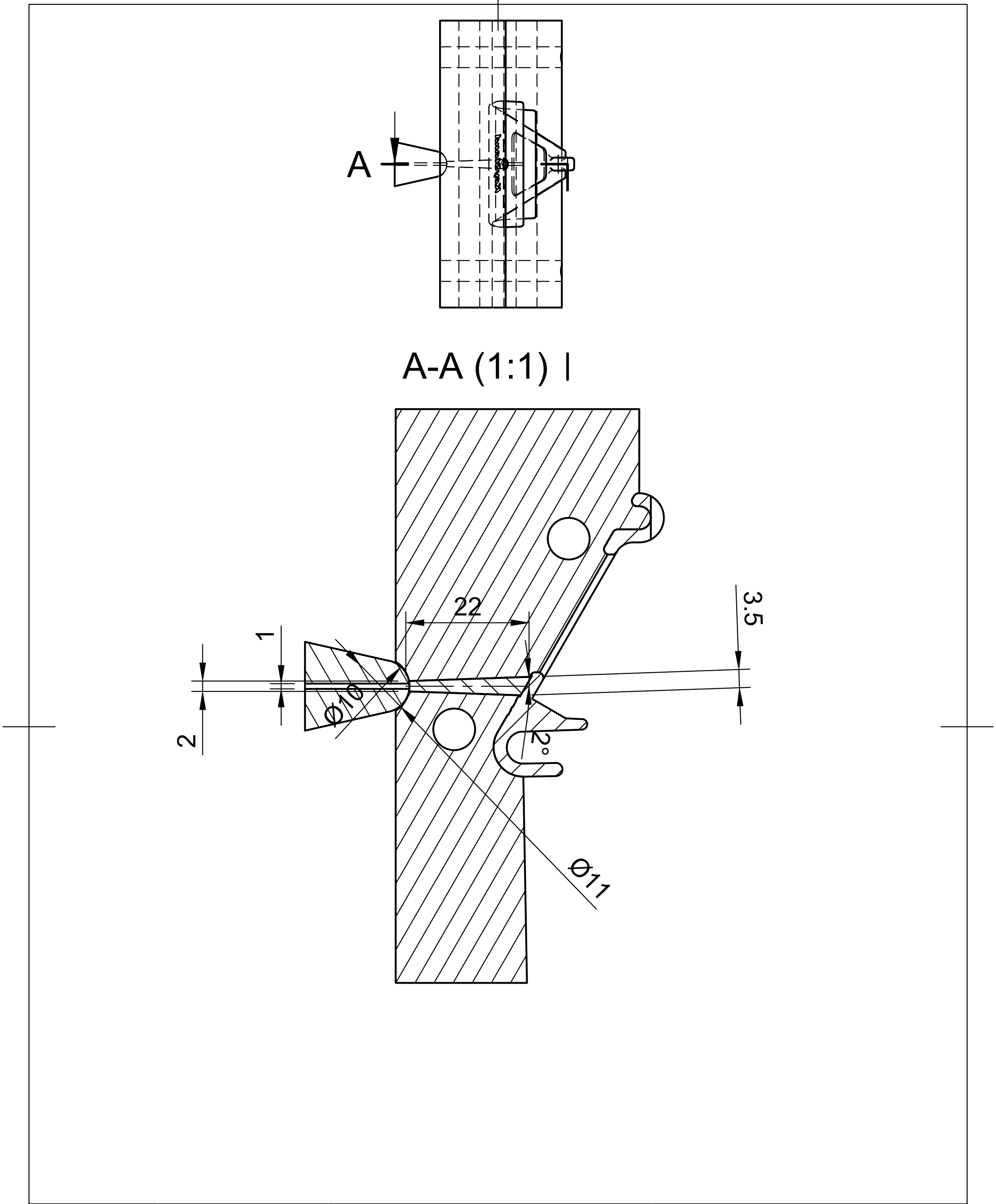
A | Appendix

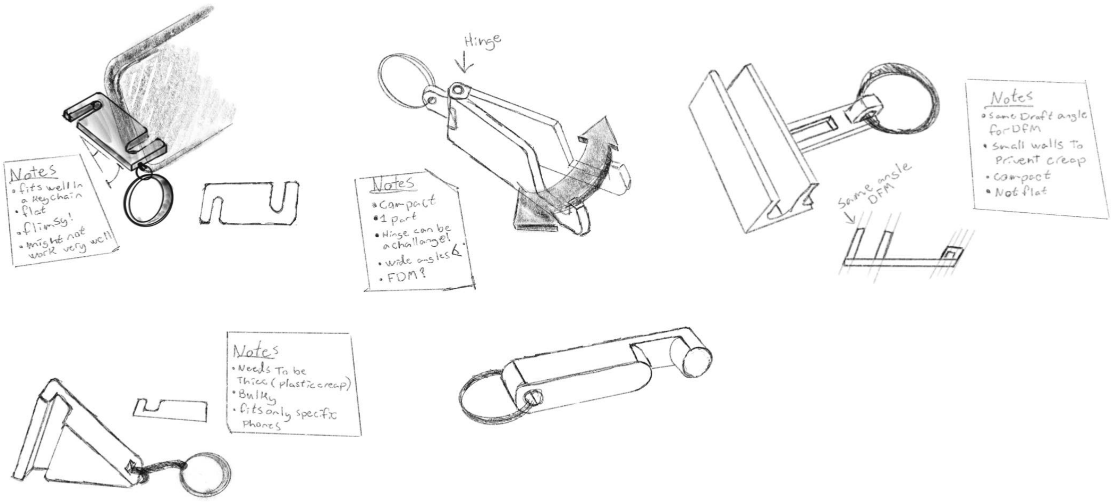
A.1 Appendix A - Sprue gate technical drawing



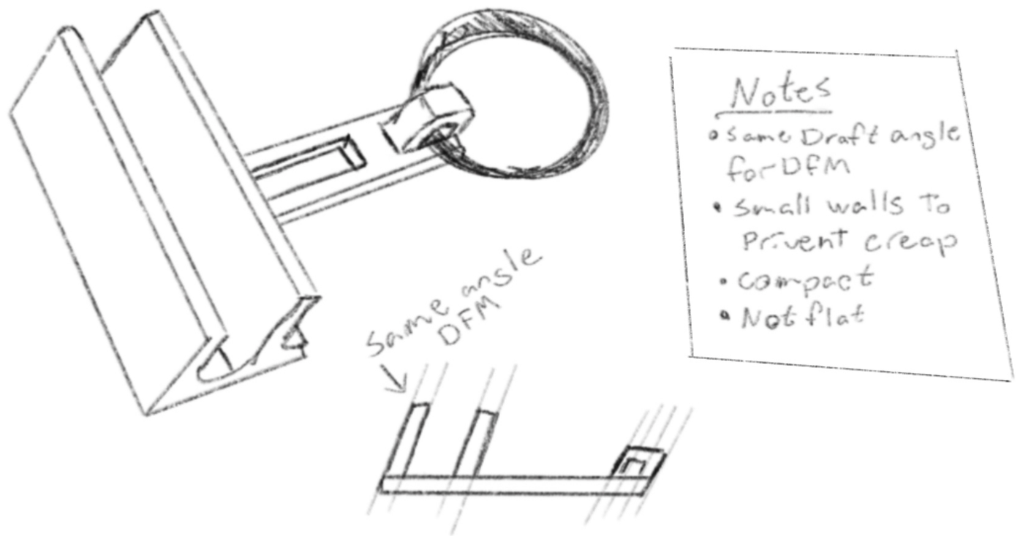
Dept.	Technical reference	Created by	Approved by		
	Phone Stand	Morten Deurell 04-05-2024			
		Document type: Cross section	Document status		
		Title: Cell Phone stand v6.1 Bushing and sprue	DWG No.: 1		
			Rev.	Date of issue	Sheet: 1/1

A.2 Sketches

A.2.1 Concepts - sketches



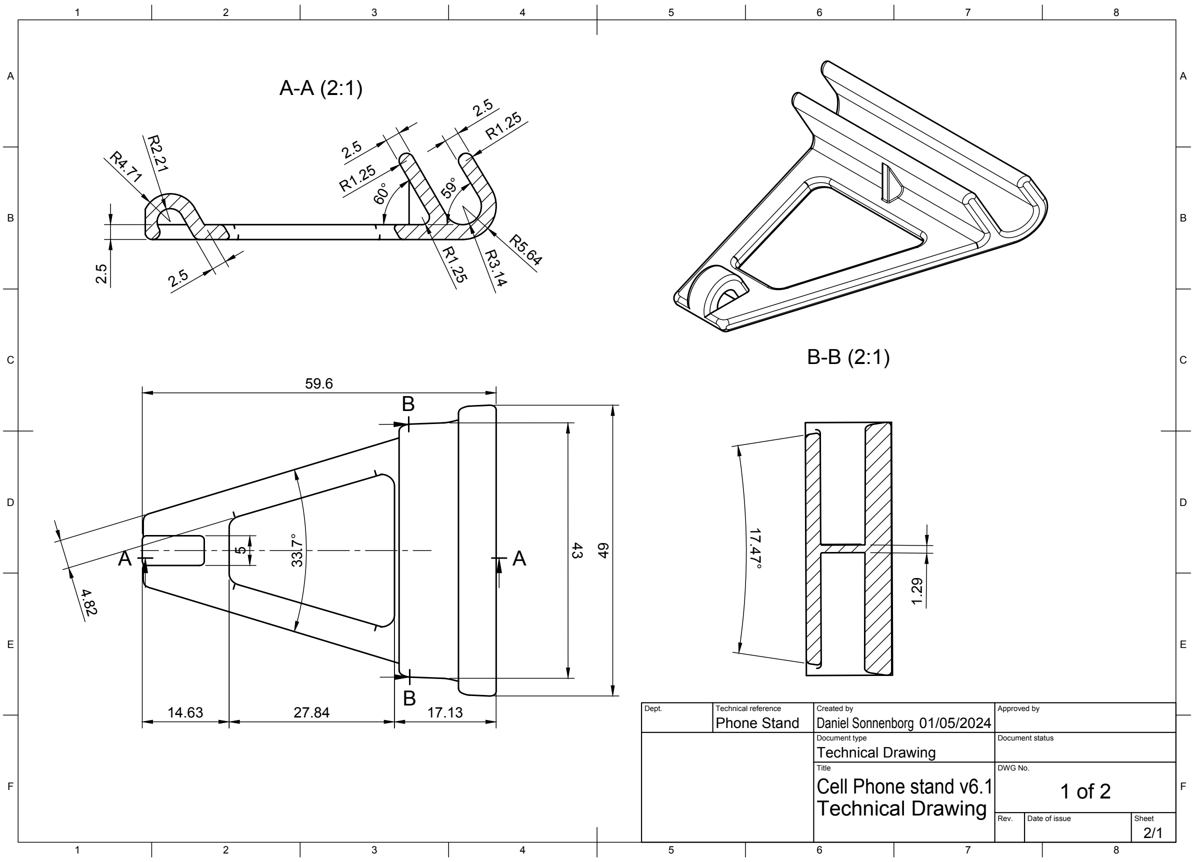
A.2.2 Final concept



A.2.3 Concepts - CAD

A.3 Technical drawings

A.3.1 Technical drawing - measurements



A.3.2 Technical drawing - fillets