CHALMERS

Structural Strength in Thin Phone Design

Master's Thesis within the Product development programme

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MASTER’S THESIS

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ABSTRACT

All handsets used today in the industries and by consumer market face an upgrade at certain period of time in their lifecycle. In this thesis an attempt is made to examine the consequences of building a thin phone by evaluating different Structural and system architectures, cross sections and different possible materials. The test results demonstrate the need for better architecture for a thin phone in order to withstand the bending and torsional load requirements. Materials used today in the handsets could be replaced with hybrid materials such as ABS/PC, ABS/PA etc. At the same time use of sheetmetals in the frame drastically improves stiffness which leads to a composite architecture for the frames and covers for the handsets. A selection method is defined according to the requirements of Ascom handsets which includes cross sections and material properties. Selection charts can be wisely used to identify and compare the new concept cross sections with those of existing handsets. The concepts proposed in the project are all with different system architecture using hybrid structural design and better distribution of materials which addresses the need for a thinner phone that meets the requirements. The proposed solutions has thickness of 14,6mm to 16,3mm when compared to existing thickness of 25mm and stiffness approximately 1,4 to 4,9 times stiffer than the existing phone.

Key words: Compact handset design, Structural strength, Material selection

Strukturell hållfasthet vid konstruktion av tunna telefoner
Examensarbete inom masterprogrammet

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SAMMANFATTNING
Alla telefoner som idag används inom industrin och konsumentmarknaden behöver en uppgradering efter en viss tidsperiod. I denna avhandling görs ett försök att undersöka konsekvenserna av att bygga en tunn telefon genom att utvärdera olika konstruktioner, system arkitekturer, tvärsnitt och material. Testresultaten visar på behovet av bättre arkitektur i tunna telefoner för att klara de böj- och vridande belastningskrav som ställs. De material som används i dagens telefoner skulle kunna ersättas med hybridmaterial såsom ABS/PC, ABS/PA etc. Samtidigt kan ramar av metall drastiskt förbättra styvheten, vilket leder till en kompositkonstruktion av ram och kåpa. En urvalsmetod som innefattar tvärsektioner och materialegenskaper är framtagen enligt Ascoms krav för handenheter. Urvalsdiagram kan användas för att identifiera och jämföra nya tvärsnittskoncept med befintliga telefoner. De koncept som föreslås har alla olika systemarkitektur med hybridkonstruktion och bättre val av material som klarar de krav som ställs på tunnare telefoner. De föreslagna lösningarna har en tjocklek mellan 14,6 mm och 16,3 mm, jämfört med befintlig en tjocklek på 25mm, samtidigt som de är cirka 1,4 till 4,9 gånger styvare än nuvarande telefon.

Nyckelord: Kompakt telefonkonstruktion, hållfasthet, materialval

CONTENTS

PREFACE

In this thesis project, an attempt has been made to evaluate the implications of building a thin handset that should maintain the existing requirements from Ascom. The thesis work has been carried out from September 2011 to February 2012 as part of the Masters program in Product Development at Chalmers University of Technology. The thesis work is carried out at Ascom Wireless Solutions located in Gothenburg, Sweden.

The thesis work is carried out in guidance from Mr. Robert Holmberg, Manager-Mechanical design and Mr. Nermin Hromic, Engineering Project Manager from Ascom Wireless Solutions and Associate Professor Mr. Magnus Evertsson from Chalmers University of Technology as supervisor.

All the studies and tests have been carried out in the laboratory of Ascom. My colleague at Ascom, Stefan Högberg, Mechanical Test engineer is highly appreciated for his help in carrying out the tests and sharing his experience in handset testing. I would like to thank Ulf Westberg, Ulf Berg, Joakim Axelsson, Jaana Olesen and Thomas Björkman in sharing their rich experience during my study at Ascom.

Finally, I would like to thank Mr. Robert Holmberg and Mr. Nermin Hromic for giving an opportunity to carry out a thesis work at Ascom Wireless solutions without whom the project would have not been possible.

I would like to thank Associate Professor Mr. Magnus Evertsson for his guidance in this project.

Göteborg, February 2012
Mohan Raj Manoharan

NOTATIONS

VoIP	Voice over Internet Protocol
WiFi	Wireless Fidelity
DH	DECT Handsets
VoWiFi	WiFi based VoIP service
IP	Internet Protocol
DECT	Digital Enhances Cordless Telecommunications
IP-DECT	Internet Protocol - Digital Enhances Cordless Telecommunications
LCD	Liquid Crystal display
PCB	Printed Board Circuit
PCBA	Printed Board Circuit Assembly
CAD	Computer Aided Design
CES	Cambridge Engineering Selector
USB	Universal Serial Bus
FPC	Flexible Printed Circuit
LED	Light-Emitting Diode
DFA	Design for Assembly
PTC	Parametric technology Corporation
Windchill PDMLink	A Web-based PLM-PDM program from PTC for handling Product data throughout its life cycle.
ProEngineer	Creo elements/Pro.5 CAD program from PTC
RoHS	Restriction of Hazardous Substances
ABS	Acrylonitrile Butadiene Styrene
ABS/PC	Acrylonitrile Butadiene Styrene/PolyCarbonate
SAN	Styrene Acrylonitrile
PA	Polyamide
PSU	Polusulfone
PES	Poly Ether Sulfone
PET	Polyethyleneterephthalate
PMMA	Polymethylmethacrylate
PC	PolyCarbonate
PVC	Polyvinylchloride
PP	Polypropelene
ASA	Acrylate styrene acrylonitrile
PS	Polystyrene
PEI	Polyetherimide
ETFE	Ethylene-tetrafluoroethylene
PEEK	Poly Ether Ether Ketone
POE/POP	Thermoplastic Polyolefin Elastomer/Plastomer
TPO	Thermoplastic Polyolefin Elastomer
TPV	Thermoplastic Vulcanizate
SEBS	Styrene Ethylene Butylene Styrene Block Copolymer

1 INTRODUCTION

1.1 BACKGROUND

Handheld and fixed line communication has been an integral part of business and has improved a lot in recent days. The information flow between departments is very essential in order for an organization to take lead against the competitors by launching products well ahead of others. In this context communication devices such as telephones have been widely used in industries for very long time to communicate the information from one part of the industry to another.

As time evolves the telephone as a product has evolved into mobiles from fixed lines. These industry specific devices should meet the stringent requirements which are specific for each type of industry. These devices have been widely used in hospitals and offices as well with a different form factors and with lower requirements. These devices have been often called as “Mission critical communication” (6) since information shared is critical at the moment.

Ascom Wireless Solutions is one the international provider of handsets in this business with focus on wireless solutions which are customizable for specific types of industry, security communication and reliable for alerts, mobilization and network testing. Ascom wireless product line DH3, DH4 and DH5 addresses the needs of heavy industries, hospitals and office communication and is one of the world leaders in this business segment. Wifi and DECT network technology is used by these handsets to communicate and transfer data. Today these handset has been in the market for 22 years and have been considered for an update considering design as well as due to the demands from the market. (6)

As a thumb rule for any mobile device, the market has now demanded a phone with a thinner profile with the same performance as before and even better in certain ways. Ascom has thus decided to research and investigate on thinner phone concepts and its implication on structural strength, design, cost and manufacturing.

1.2 ASCOM WIRELESS SOLUTIONS

Ascom Wireless Solution is a telecom company based in Switzerland and is a leading provider of enterprise mobility offering voice and messaging solutions with a broad range of purpose built handset for each industrial requirement. The company specializes in VoWiFi and IP-DECT technology handsets which increases the employee mobility and connectivity.

The handset solution is characterized as “Mission critical communication” since the information flow is very critical at the moment for any industry to become a leader in its business. Ascom products are widely used in heavy industries, hospitals and for office communication.

1.3 PROBLEM DEFINITION

Today Ascom products have been in the market for 22 years and have met with a demand from the market to make a product with thinner profile at the same time maintaining the aspects of the existing product such as ruggedness, reliability and IP rating. A thinner profile for a mobile device implies tightly packed electronic components within the defined volume, thinner walls, more risk of reliability issues during various test simulations. In theory, thin cross sections are comparatively weaker than thicker sections which has to be overcome by better structural design and materials.

1.4 AIM AND OBJECTIVE

The thesis aims to develop and analyze compact mechanical design concept for wireless telephones which meets Ascom requirements. Structural strength of the phone will be tested by developing new test methods derived from Svensk standard (1). A recommendation for potential concept designs will be the result of the project with an in depth analyses of different materials and cost.

The main objectives of the project are

1. Identifying requirements for the new concepts through benchmarking of the existing products from Ascom as well as from the competitors.
2. Identify structural strength and stiffness testing requirements for existing and or for the new concept phones.
3. Identify possible better materials, production methods and its implications for use in future handsets.
4. Propose detailed mechanical design concepts that are thinner and aimed to be 15 to 18mm in thickness.
5. Test and verify concepts using prototypes.

1.5 LIMITATIONS

The project boundaries have been set inorder to limit the scope of work as listed below.

1. Hardware (electronics) design and development is limited to placement of large components such as microphone, LCD, connectors, audio components etc. PCB routing, antenna placement and design are beyond the scope of the project.

2. Manufacturing process information is included in the material selection as reference details but design of tools will not be considered for the project.

3. Industrial design is considered to be out of scope since the project is a preliminary study of structural strength for a thin phone design.

2 METHODOLOGY

A well-defined methodology is set in the early phase of the project in order to plan and execute work in a structured way. The project is a preliminary work for mechanical design and development and so it is necessary to capture as much information as possible in early stage and analyze different possible design concepts. That is why this methodology is adopted for this project. The project is divided into three segments as shown in the fig.1. Each segment is carried out by sub dividing it into various topics.

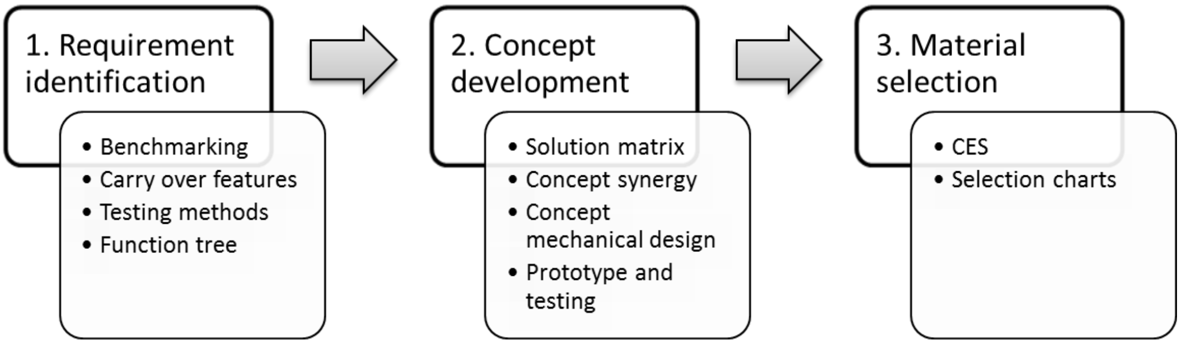


Figure 1 - Methodology for the project

1. The first step of the project is proceeded by identifying the requirements for a thin handset. Benchmarking is carried out to understand the competition and to develop inner knowledge of handset architecture. Existing Ascom handsets were also involved in this study to compare the position of the handsets against the competition. During this study, typical characteristics of Ascom products are identified and carried forward for the new concepts. New testing methods were defined to meet the structural requirements of a thinner phone. All the requirements are captured in a Function tree model which is suitable for visualizing the information about the many different requirements.

2. The requirements are translated to sub solutions in a matrix model during the concept development phase. This is done by organizing a workshop for brainstorming new solutions involving all the members from the mechanical team. The various sub solutions are combined together using a concept synergy method to form complete concepts. The generated concepts are ranked and some are combined together to form three different mechanical concepts. The complete concept solution is realized using CAD and prototypes for further testing and proof of concept.

3. The third step is carried out by identifying possible better materials using methods proposed by Material selection and design literature (2). Cambridge Engineering Selector (CES) (3) software is used to plot the material properties and chose the best fit for major components such as frames, battery cover, attachment clip, window and sealing gaskets. As a part of material selection, a selection chart was defined to relate cross sections along with material properties. The aim of this chart is to select and compare the new cross sections against different materials and its properties.

3 REQUIREMENTS IDENTIFICATION

Requirements for the concept phones were derived out of three stages; Benchmarking, identifying carry over features and developing new testing methods.
A Function tree model was developed in order to capture all stages of requirements for the phones.

3.1 BENCHMARKING

For identifying requirements, a market study was made in the form of benchmarking the existing products from Ascom as well as from competitors. Ascom products DH4 and DH5 were studied to identify possible improvements and to identify the best practices that are followed in the mechanical design at the same time to create a basic understanding about hardware components. A system architecture model was developed to quickly grasp the built up architecture in thickness for both the models. The model captures the main components of the handset along with its relative position inside the assembly. Side view of the handset is set as the default view for this model.
The model was developed during every phone study event to capture the Structural architecture. The model gives a visual picture of high level component placement inside the phone. Although the model is not exact replication with dimensions, it provides the reader of this report a clear understanding of the phones architecture.
Ascom’s DH3 and DH4 handsets are aimed for customers in light weight industries, offices and in hospitals.

The fig.2 shows the Ascom DH3 handset and its internal components.

Figure 2 - DH3 handset disassembled parts

Fig.3 shows the system architecture model of DH3. The left side view of the handset is shown and its ma
jor internal components that drives the thickness is shown along with the dimensions.

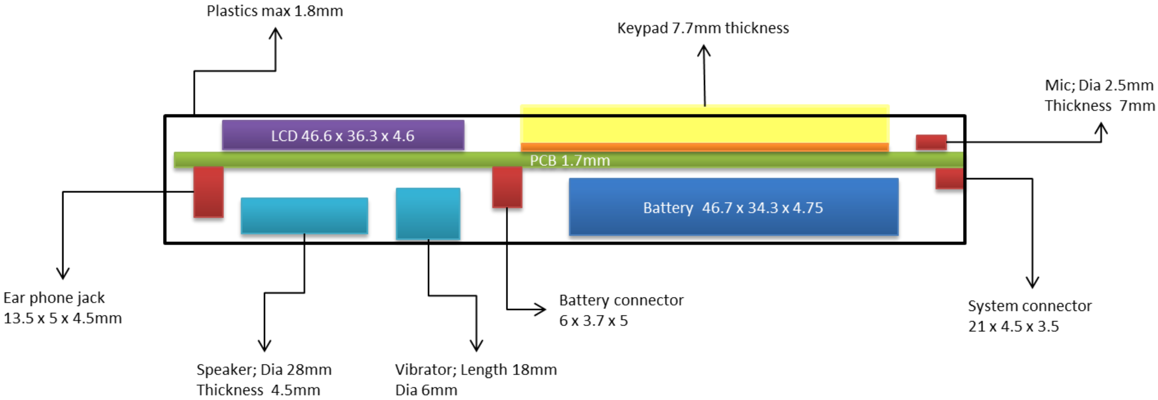


Figure 3 - DH3 System architecture

Fig.4 shows the Ascom DH4 handset and its internal parts

Figure 4 - DH4 handset disassembled parts

Fig.5 shows the Ascom DH4 handset's system architecture model

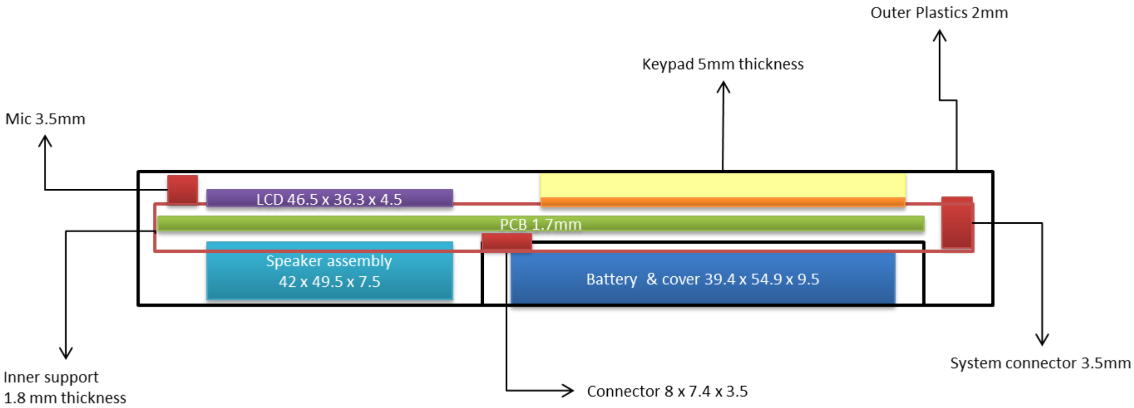


Figure 5 - DH4 System architecture

Some of the major improvements that can be made in current design are listed below

1. The phone has empty space that can be effectively used to place components by tightly packing it together.
2. Since the phone is designed few years ago, the component technology chosen is outdated. i.e. over the time almost all of the components have reduced in size. By using new versions of the components, it would be possible to reduce the thickness of the phone drastically.
3. The curved shape on top and bottom of the phone, occupies space where components which are mostly prismatic in shape are not possible to be placed. Industrial design with more square like shape would give more volume space efficiency. But the new concepts have to be balanced between industrial design and volume space efficiency.
4. Few large components like vibrator, microphone are housed in the front and rear cover connected to the PCB through wires. This method could be replaced by placing the component directly on the PCB to save space in thickness.
5. Thickness of the keypad can be reduced to a minimum. The existing keypad is designed to occupy space due to phone thickness. In future the reduced thickness for keypads will save space in thickness.
6. A plug-in type battery is used which occupies more space when compared to batteries used in smartphones such as Sony Ericsson Xperia S. Batteries with side wall connections can be chosen for the future concepts.
7. Battery door and battery are integrated as one unit due to requirements. Alternate methods such as phone without battery door, battery door that is hinged to the rear cover can be investigated for future concepts.

3.1.1 COMPETITOR ANALYSIS

Sonim and Siemens have given direct competition with Ascom in their phone business. Sonim XP3.20 is considered one of the rugged phones in the market while Siemens SL78H and SL400 are used in offices. These two competitors were included in benchmarking to create a basic understanding of a rugged phone built up.
The study also included consumer market phone providers such as Sony Ericsson and Samsung. These two phone brands were included to develop knowledge about thinner phone design and to understand more about small size components since these manufacturers use large number of components that are very latest in the industry.

SONIM XP3.20

Sonim Techonoliges, has the reputation of building handsets that are rugged in construction and durable for long life time and intended to be water and dust proof. The fig.6 shows the Sonim XP3 2.0 handset with its internal components.

Figure 6 - Sonim XP3.20 disassembled parts

A system architecture model was developed as shown in fig.7 to make it easy for future reference.

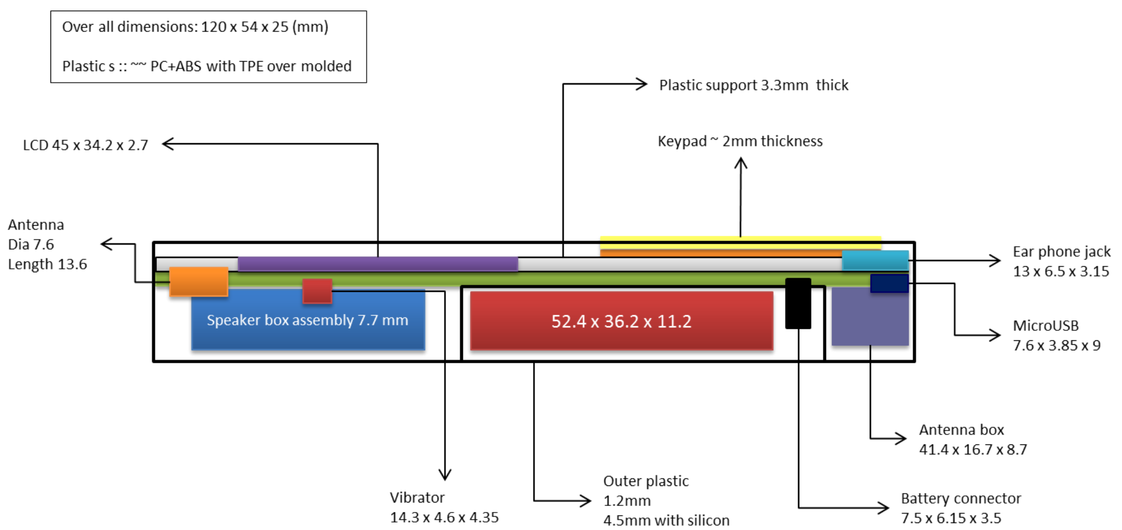


Figure 7 - Sonim XP3.20 System architecture

The Sonim phone holds design features that can be considered for future concept phones. Some of the important aspects of Sonim are:

1. When compared to Ascom phones, relatively thinner components are used that have led Sonim to build a phone that is thinner in total size. This depends on the time period of both the phones. In future concepts, thinner components can be implemented.
2. Components which have connectors mounted on Flexible Printed Circuits (FPC) are placed on either side of the board as shown in the fig.8 and fig.9. This method saves space in thickness direction.

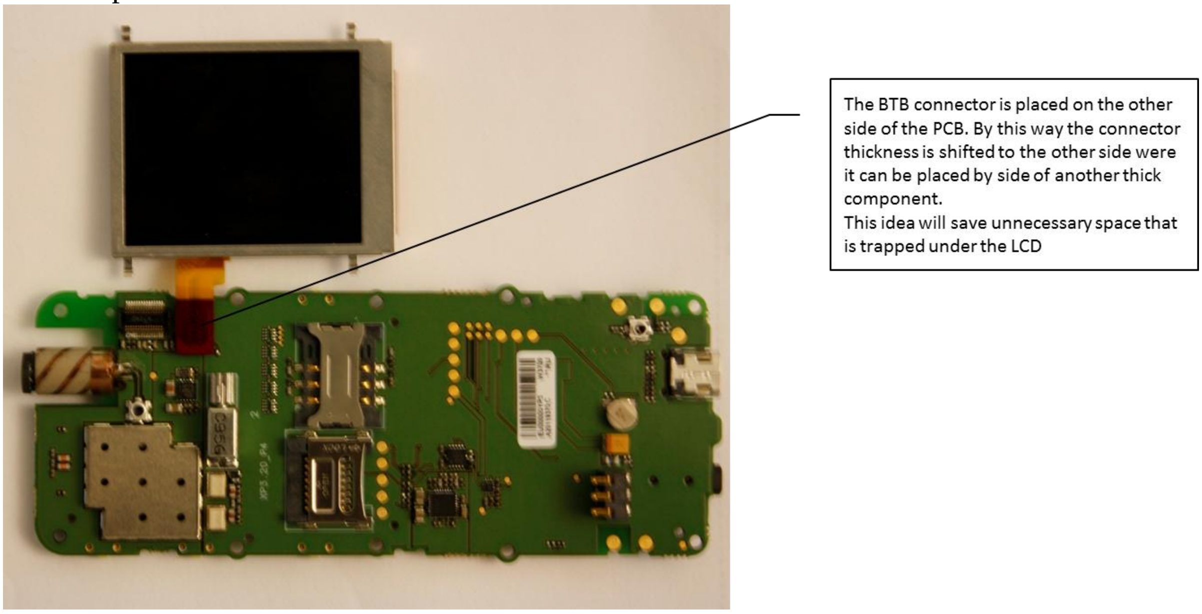


Figure 8 - LCD connector placement in Sonim XP3.20

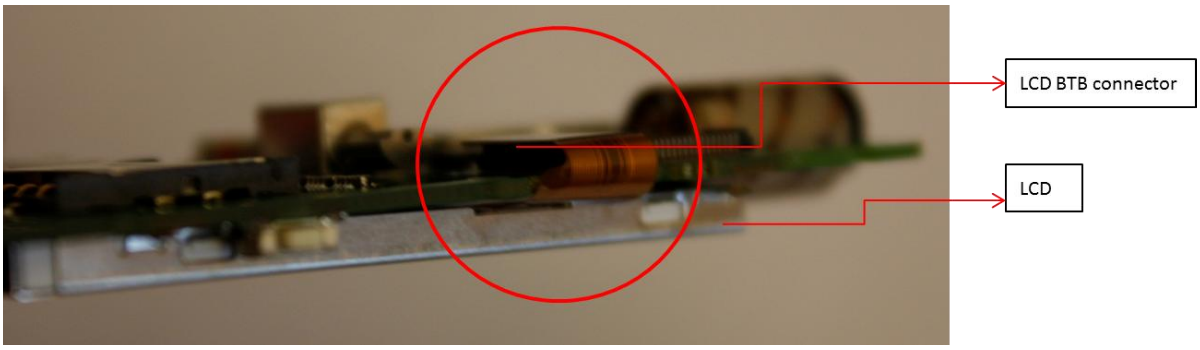


Figure 9 - LCD connector in assembled position in Sonim XP3.20

3. The keypad is designed with a thinner profile and mounted on the front cover which could be considered and adopted for future concepts.
4. A standard mini-USB connector is used and mounted on the middle of the PCB as shown in the fig.10 to save space in thickness.

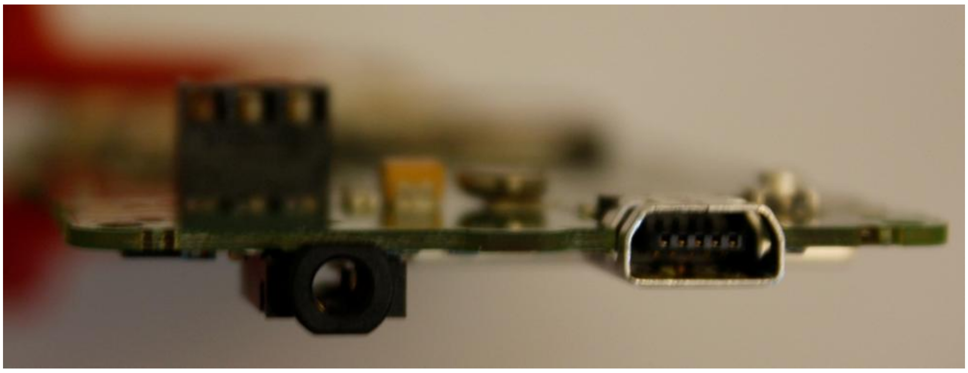


Figure 10 - USB connector position in Sonim XP3.20

5. PCB assembly is mounted on to a plastic frame to create support and at the same time to reduce thickness.

A more detailed report of Sonim phone is included in Appendix.G in CD-ROM.

SIEMENS SL400 AND SL78H

Siemens phones are widely used in light industry and in office and homes. These phones are built with good aesthetics and high surface finish. Fig.11 shows the Siemens SL78H handset with its internal components.

Figure 11 - Siemens SL78H disassembled parts

The system architecture model for the phone was developed as shown in fig.12

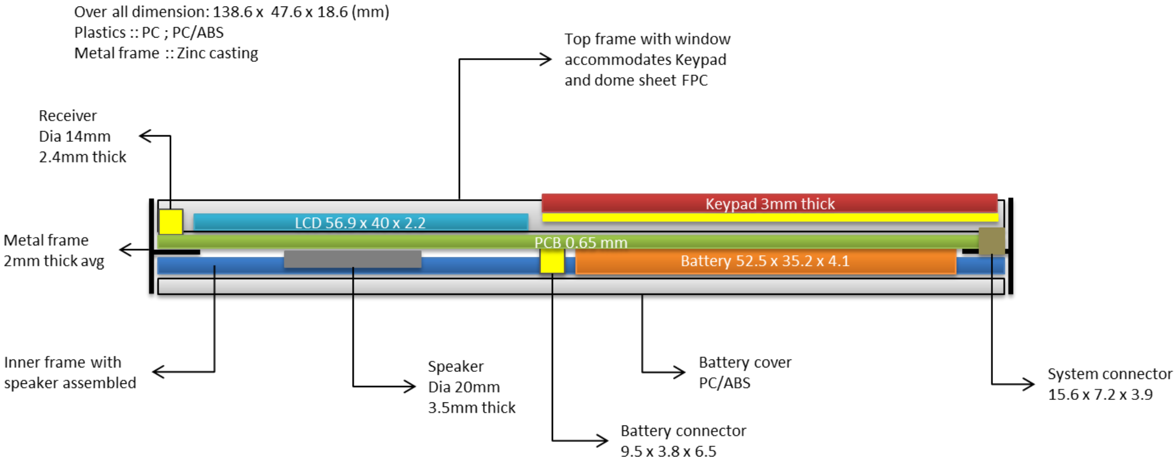


Figure 12 - Siemens SL78H System architecture

Fig.13 shows the Siemens SL400H handset with its internal components.

Figure 13 - Siemens SL400 disassembled parts

The system architecture model for the phone was developed as shown in fig.14

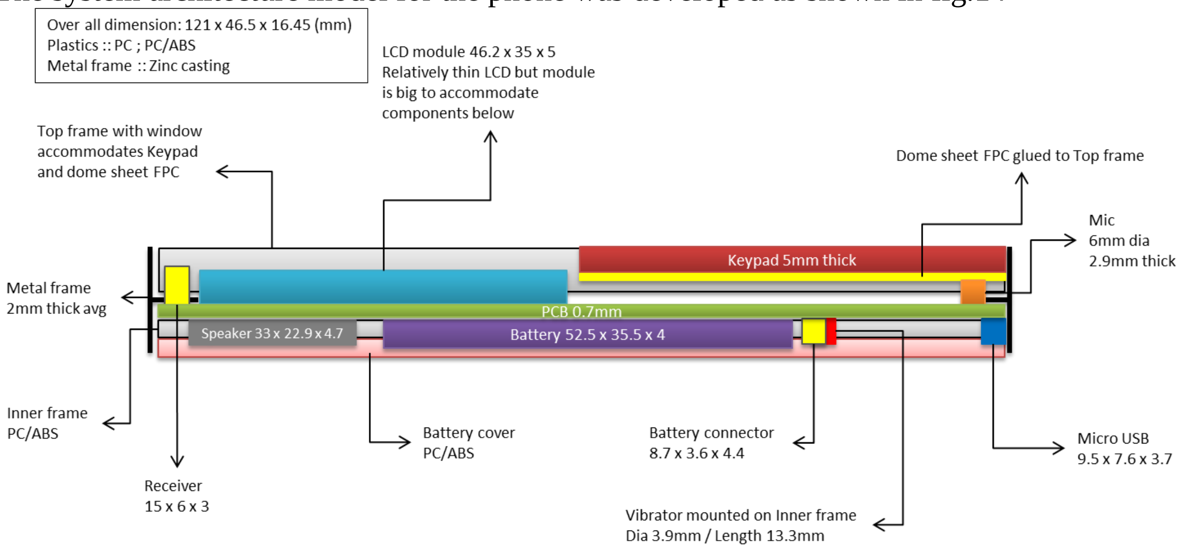


Figure 14 - Siemens SL400 System architecture

Some of the best design features of the Siemens phones are:

1. The main frame is made by Metal injection molding which adds extensive stiffness to the phone structure. The cost of manufacturing metal injection molded part could be high which is compromised with thinner architecture with better stiffness.
2. Major components are used with thinner profile which reduces the overall thickness for the phone.
3. The Printed Circuit Board (PCB) along with front window is designed together to become a sub assembly that is stronger. See fig.15 for details

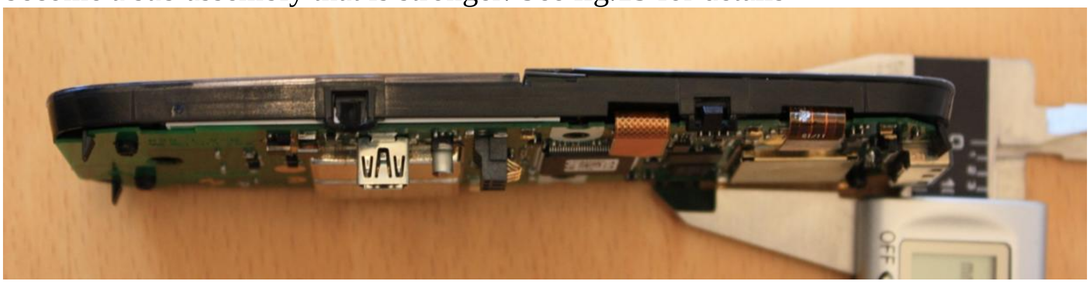


Figure 15 - Siemens SL78H PCB & Frame assembly

4. The battery thickness is very small compared to the existing Ascom phone which reduces the overall thickness.
5. Some of the components, for instance the speaker, is submerged inside the rear cover to save thickness.

More detailed benchmarking report is included in the Appendix.G in CD-ROM.

SONY ERICSSON M600I AND SAMSUNG B2100

Sony Ericsson and Samsung are one of the leading handset manufacturers addressing the consumer market. Both of these phones were selected for the study to capture the handsets compact design.

The fig.16 shows the Sony Ericsson M600i phone with its internal components.

Figure 16 - Sony Ericsson M600i disassembled parts

System architecture model was developed as shown in fig.17.

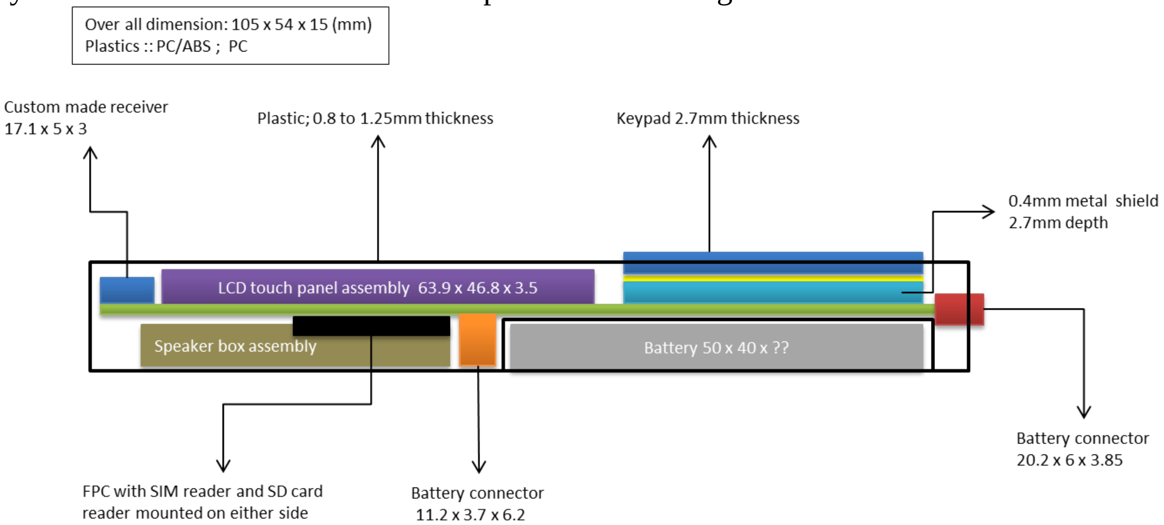


Figure 17 - Sony Ericsson M600i System architecture

The fig.18 shows the Samsung X2100 and its internal components

Figure 18 - Samsung X2100 disassembled parts

System architecture model for Samsung X2100 is shown in fig.19.

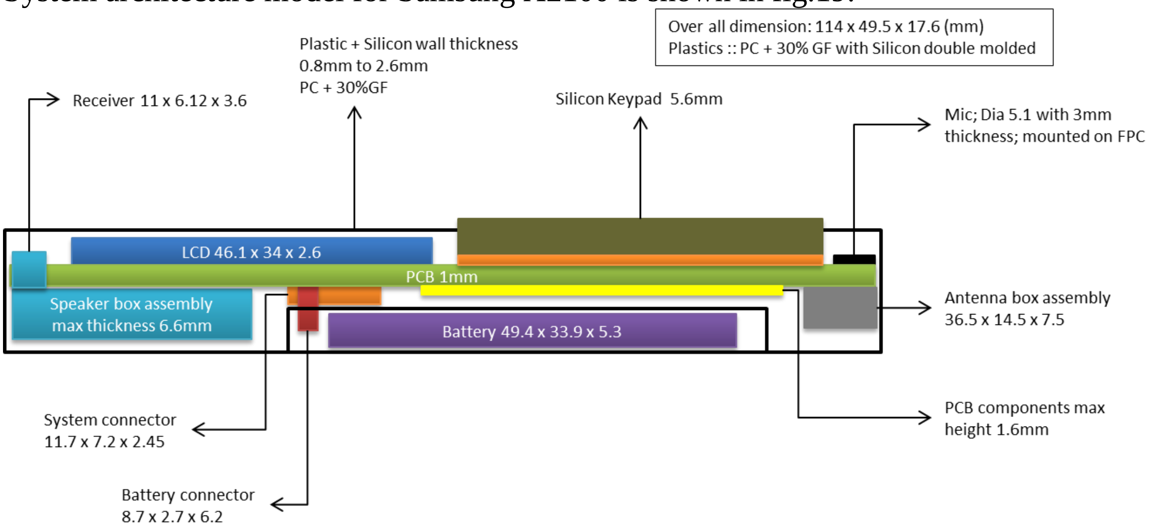


Figure 19 - Samsung X2100 System architecture

Both the handsets possess some of the industry standard thin components along with compact design methodology. Some of the best aspects are listed below.

1. As an alternative to sheetmetal-plastic hybrid parts, Sony Ericsson has used protective shield cans that provide stiffness and protecting the hardware components underneath. This design strategy can avoid the keypad forces directly impregnating the PCB and its component.
2. Flexible Printed Circuits (FPC) has been used in these phones. Using FPC makes it possible to optimize the space available within the phone their by increasing volume space efficiency.

A more detailed benchmarking report is included in the Appendix.G in CD-ROM.
The benchmarking of the competitor phones have provided valuable information about building handset that addresses ruggedness, compactness and knowledge about component placements and component thickness. These aspects will be considered during the concept generation and included as much as possible in the future concept to reduce the thickness of the phone.

3.2 CARRY OVER FEATURES

By benchmarking the predecessor phones from Ascom, the information about the features that should be carried over to the upcoming concepts were provided. Some of the trademark features that are identified as important carry over are:

1. The alarm button
2. The side mounted mute button
3. The attachment clip at the rear cover
4. The integrated battery and battery door

The fig.20 shows the images of the features in DH4 handset.

Figure 20 - Carry over features from existing DH4 handsets

The identified features will be included in the concept design. This is important in order to maintain the same customer perspective on Ascom products.

3.3 STRUCTURAL STIFFNESS OF HANDSETS

3.3.1 TESTING METHODS

For identifying the structural strength and stiffness of the phone, a more severe testing method has to be defined. The 3-point bending test from Svensk standard (1) was selected to bend the phone up to 600N. The test is a standardized method defined by above standard to test any type of product. This method is chosen to simulate the usage condition that the phone will need to withstand in the industrial environment and to some extent in office environment. A torsional test was discussed and defined within the team to test the phone up to 6Nm torque. Prototype fixtures and glass fiber inserts were developed for each type of phone for this test.

3-POINT BENDING

The 3-Point bending standard test defined in Svensk standard (1) was modified and adopted for Ascom requirements and to match the phone geometry. Fig.21 below is a representation of the testing method with dimensions and loading conditions.

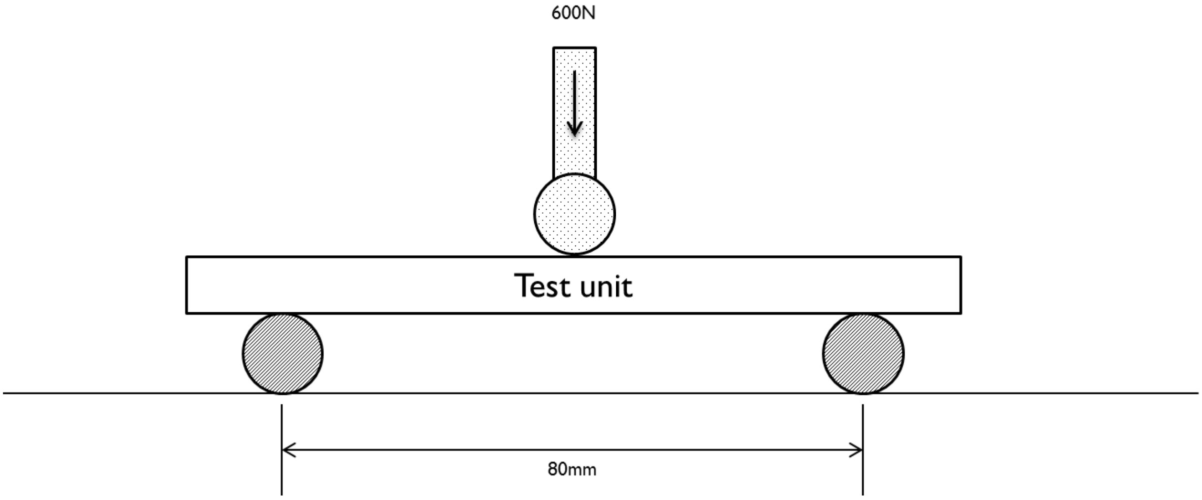


Figure 21 - 3-Point bending test illustration

A prototype probe for bending was developed for this test as shown in the fig.22. The test was developed to imitate the severe bending condition a phone may experience during its use in heavy duty industries. A 600N load is applied at the middle of the phone and deflection is measured to check the phone strength. A measurement is noted for every 100N to analyze the behavior as the load is gradually applied. A hold time of 5 seconds is given at the 600N load to increase the severity of the test. This is to check the behavior of PCB components and its soldering rigidity. The bending test is also carried out for each individual part such as PCB, front cover, rear cover to study the contribution of each part towards the deflection.

Figure 22 - DH4 tested with the Bending test probe

TORSIONAL TEST

Torsional test is developed at Ascom to verify the torsional stiffness of the phone geometry. The fig.23 represents the method of testing but the actual test varies.

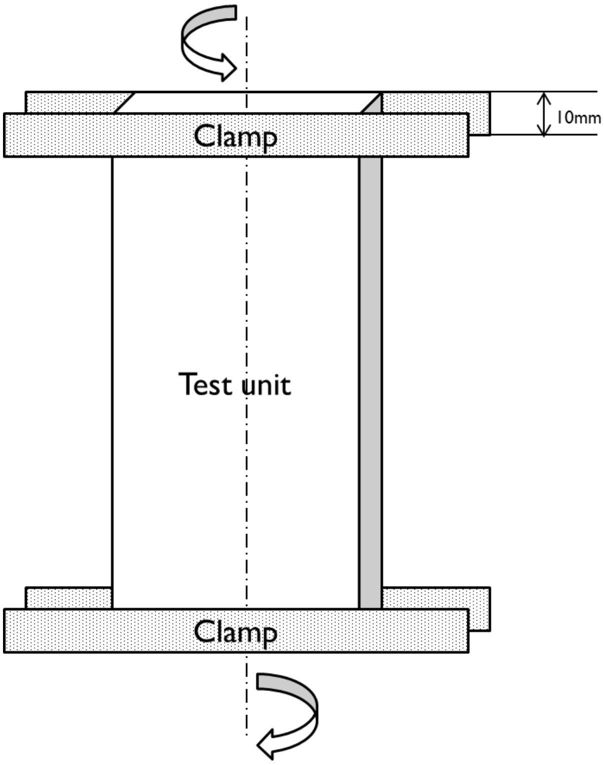


Figure 23 - Twisting test illustration

A prototype cavity, see fig.24 was developed to hold one side of the phone firmly while the other side was twisted using a torque screw driver with torque values that can be varied from 0 to 6Nm. Glass fiber inserts for cavity to fit each phone variant were manufactured. One end of the phone will be held in a wise while the other end will be twisted using a hand held torque screw driver.
A torque of 6Nm was applied to the phone and angular deflection is measured. The test is performed at 6 stages starting from 0Nm with a unit increment of 1Nm to study the behavior of the phone geometry. The test is developed to simulate day to day usage of phone in a human hand. Although 6Nm torque is considered to be higher value and cannot be normally twisted using hand, it is set as severe load condition to study the effects on PCB and its components.

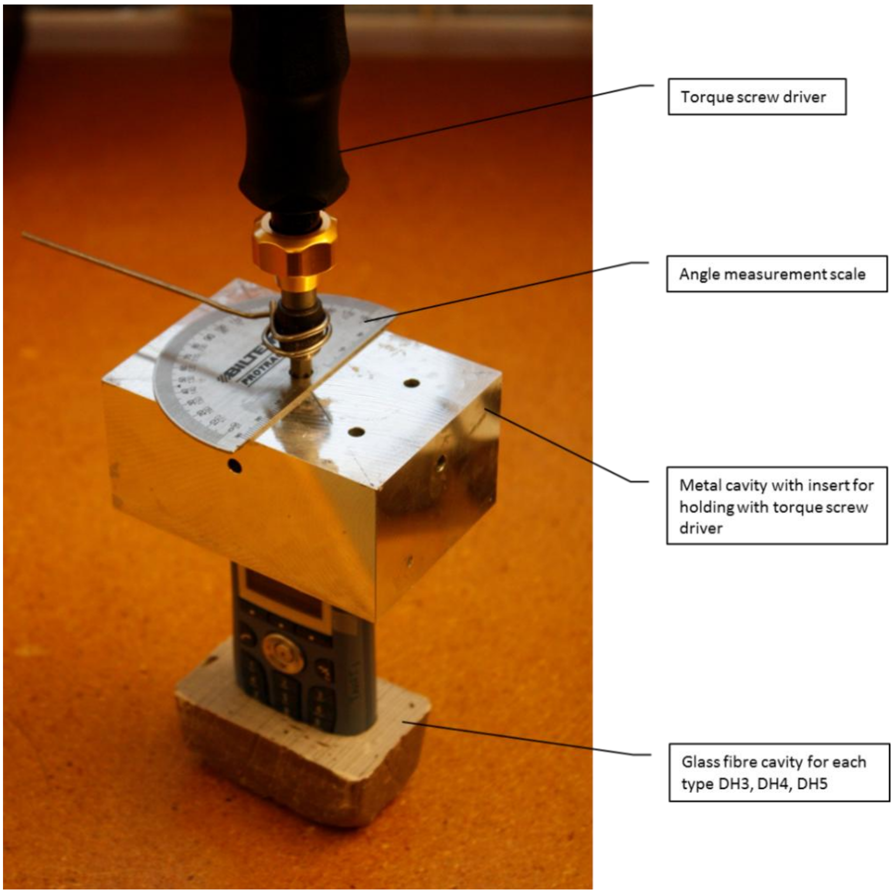


Figure 24 - Twist test set up showing Metal cavity on top and Glass fiber cavity on bottom

Fig.25 shows the torsional test setup held in position in a wise

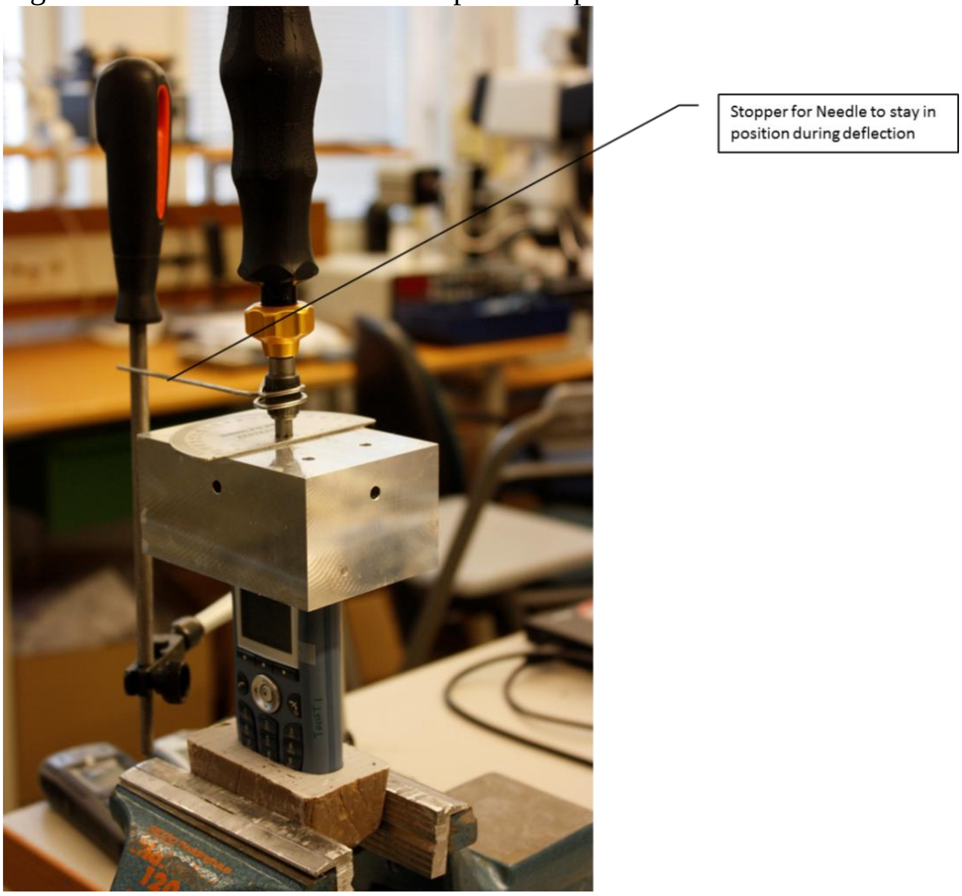


Figure 25 - Twist test set up in hold position

3.3.2 TEST RESULTS

BENDING TEST

The graph, see fig.27 below show the results of each phone when it is bend both on front side and rear side. The phone geometry and the mechanical design contributes to the deflection. Due to the simple design of DH3 it has shown a deflection of 4.8mm to 6.5mm at 600N load. DH4 has shown better values due to its inner frame which holds the PCB and sandwiched by front and rear cover. The addition of thin inner frame dramatically increases the bending strength of the phone.

DH5 on the other hand has shown deflection of 2.7mm on either side and is the strongest phone on Ascom series. This is due to the bigger inner frame which houses the PCB and LCD and forms a strong inner unit. The front and rear cover has considerable wall thickness when compared to the other phone which also contributes to the phones strength.

Figure 26 - Front side loading on DH4 handset

The Siemens SL400 and SL78H phones show considerable strength which comes from the metal frame that supports all the components. The initial bending values of these phones are caused by compression of plastic towards the loading direction and thus unaccountable for deflection. The geometry shape of each part plays vital role in deflections.

Name	Max_Force (Preset to 600N)	Disp at 100N	Disp at 200N	Disp at 300N	Disp at 400N	Disp at 500N	Disp at 598N
Unit	N	mm	mm	mm	mm	mm	mm
DH3-Front	601,02	1,36	2,31	3,03	3,67	4,26	4,82
DH3-Back	599,42	2,26	3,37	4,19	4,98	5,75	6,52
DH4-Front	602,30	1,36	2,23	2,97	3,61	4,21	4,77
DH4-Back	602,58	1,31	2,29	2,95	3,52	4,07	4,57
DH5-Front	603,01	1,03	1,44	1,80	2,14	2,46	2,77
DH5-Back	608,63	0,90	1,43	1,81	2,14	2,44	2,71
SL400-Front	602,09	0,85	1,44	1,88	2,28	2,60	2,87
SL400-Back	620,36	1,48	1,94	2,26	2,52	2,73	2,92
SL78H-Front	614,10	0,53	0,82	1,10	1,39	1,85	2,10
SL78H-Back	600,72	0,43	0,69	0,92	1,16	1,40	1,64

Table 1 Bending test results

The Table.1 shows the phones performance against each step of load condition.

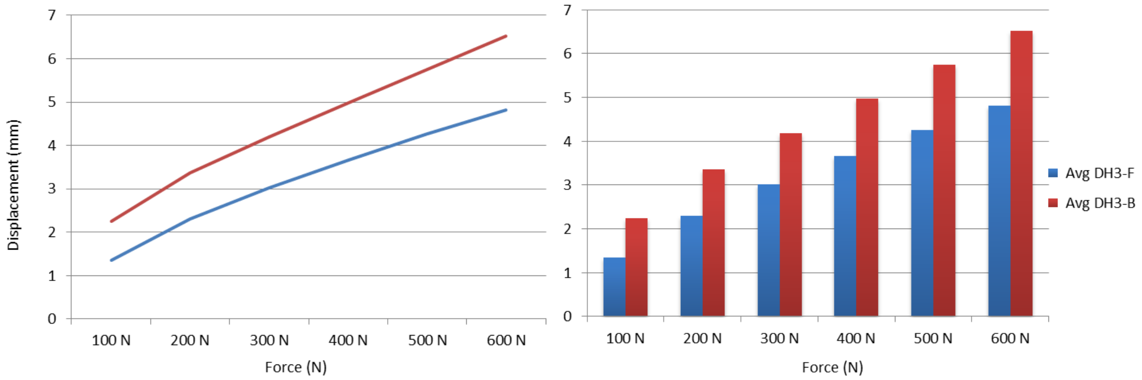


Figure 27 - Front and Rear loading result plot of DH3 handset

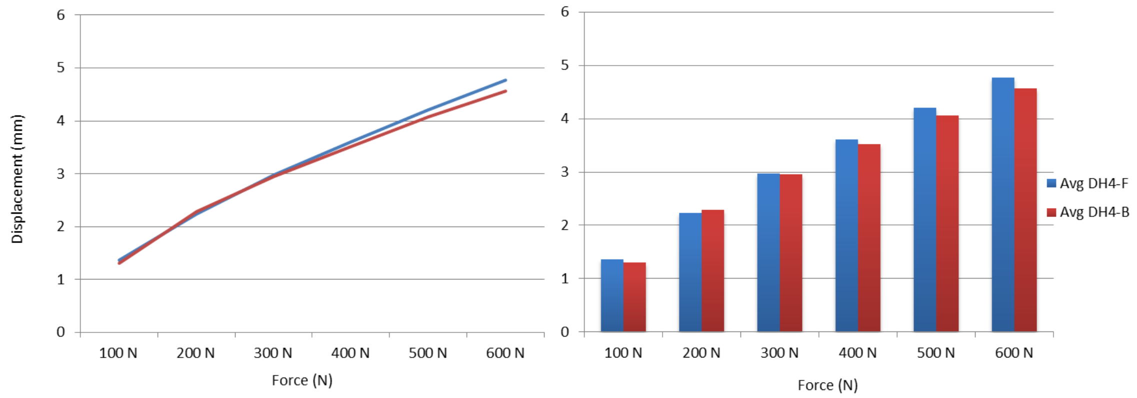


Figure 28 - Front and Rear loading result plot of DH4 handset

INDIVIDUAL BENDING TEST OF PARTS

Bending tests are applied for major contributing parts of the phones such as front cover, rear cover, inner frame (in DH4 and DH5) and PCB. These parts are tested with 3-point bending test to identify the contribution of each part over the load condition. Although there are many factors that drive the phone strength and these individual part tests cannot be compared to that of the whole phone, the test is carried to identify the part which is strongest and determine what drives the stiffness of the entire structure. The fig.29 and 30 shows the graphical plot of individual component contribution of DH3 and DH4.

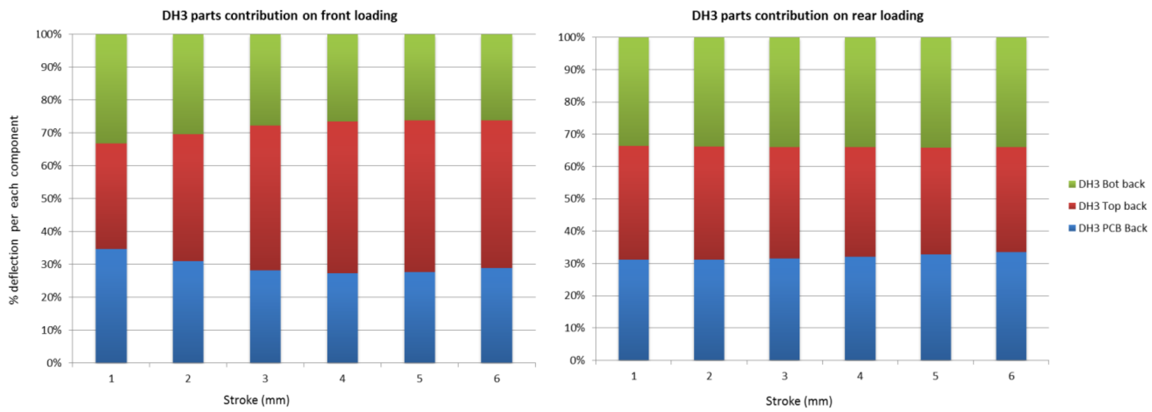


Figure 29 - Individual part contribution of DH3 handset

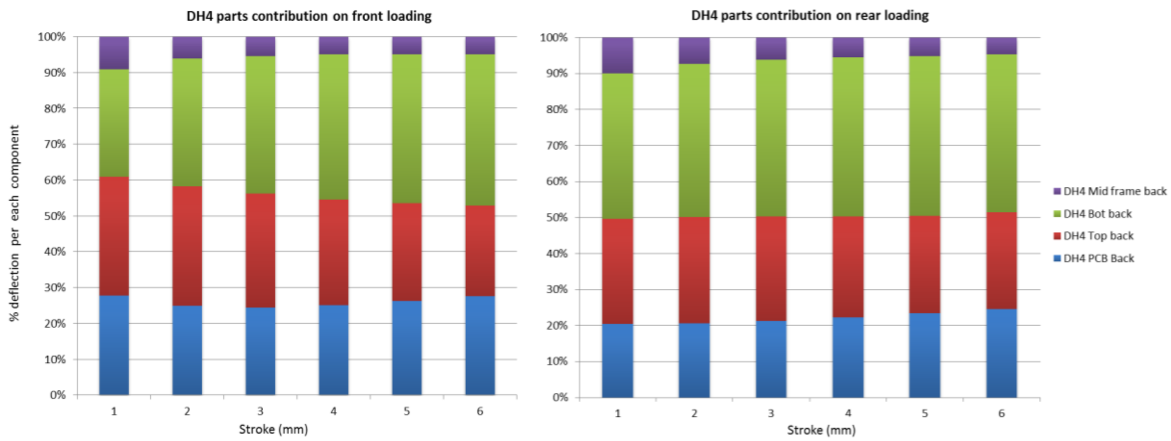


Figure 30 - Individual part contribution of DH3 handset

The test results show the plastic covers take on the bending load very well. Depending upon the geometry and direction of loading the stiffness varies and shows the importance of geometry towards a bending load. Although the PCB is fragile in nature, due to its thickness (1,6mm) it takes up partial load.

TORSIONAL TEST

The test shows the DH3 phone is the weakest phone with highest angular deflection of 9.5^{o} at 6Nm. This is due to its design that is intended to be low cost because of the market it addresses. DH5 on the other hand shows a value of 5^{o} which is again its design that is intended to be in heavy industry. The competitor phone from Siemens showed although it is designed with metal frame. This is due to the plastic geometry deflecting while the torque is applied and metal frame remains stable without any deflection.
Siemens SL78H phone shows more deflection than SL400 although the length is longer. This shows the length of the phone plays important role in deflection i.e. more the length of the phone, more prone it is to deflection. Table.2 shows the torsion test results of DH3, DH4, DH5 and Siemens SL400 and SL78H.

Torque (Nm)	Angle (deg)														
	DH3			DH4			DH5			Siemens SL400			Siemens SL78H		
	I	II	avg	I	II	avg	I	II	avg	I	II	avg	I	II	avg
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	2	2,5	2	2	2	0	1	0,5	0	0	0	1	1	1
3	5	4	4,5	3	3	3	1	2	1,5	1	1	1	3	3	3
4	6	5	5,5	4	4	4	3	3	3	2	2	2	4	4	4
5	7	7	7	5	5	5	4	4	4	3	3	3	6	6	6
6	10	9	9,5	7	6	6,5	5	5	5	4	4	4	7	7	7

Table 2 Torsion test results

The fig.31 below shows the graphical plot of deflection of the phones.

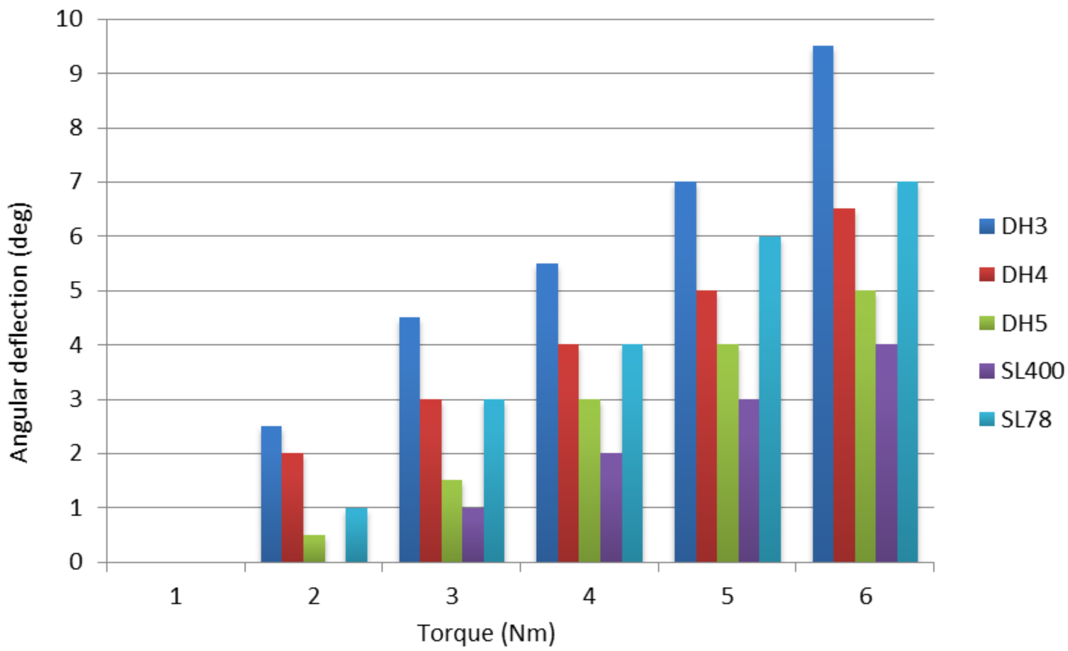


Figure 31 - Twist test results of Ascom and competitor phones

OBSERVATIONS

During the testing process, careful observations and images were made to capture the behavior of the phone and individual parts. The observations play a vital role in understanding how the geometry works during load conditions and later can be implemented during the mechanical design of components to avoid potential failures.
The observations are documented and listed.

1. The vertical walls as highlighted in the fig.32 which connects the side walls add strength to the front cover. During the bending load condition, the side walls tend to buckle. The presence of the intermediate wall that connects the two side walls prevents the side wall from buckling. The same type of geometry can be implemented in the future concepts for a stronger cross section.

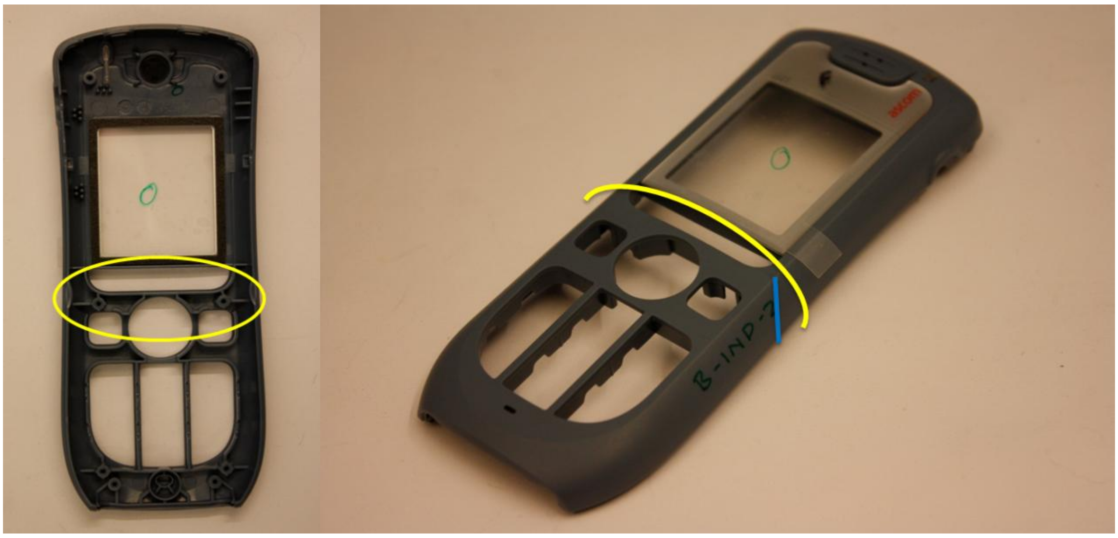


Figure 32 - DH4 front cover

2. The front cover of DH3 has a curvature shape on the front side with two almost vertical side walls, see fig.32. The combination of shape and side wall structure increases stiffness when considering the other parts. This kind of geometry could be carried forward to the next generation handsets.

3. The position of the battery and its cavity in the rear cover plays a vital role in the stiffness of the part. From the results, DH3 rear cover is weak when compared to the DH4 rear cover. This is due to the battery positioned exactly in the middle of the phone which tends to create a weak spot. This weak spot lowers the strength of the cover during bending loads. Thus it is advisable to place the battery in the middle of the phone although there should be a compromise with the hardware design. The fig.33 and fig.34 shows the battery positions and its weak spot in the rear cover of DH3 and DH4.

Figure 33 - DH3 Rear cover

Figure 34 - DH4 rear cover

4. The absence of the intermediate wall in the DH4 makes it weak as discussed in point 1. During the bending test of DH4 front cover, the side wall tends to buckle and thus losing stiffness. This design can be improved by adding intermediate walls like in DH3. The fig.35 below shows the buckling shape of the DH4 front cover.

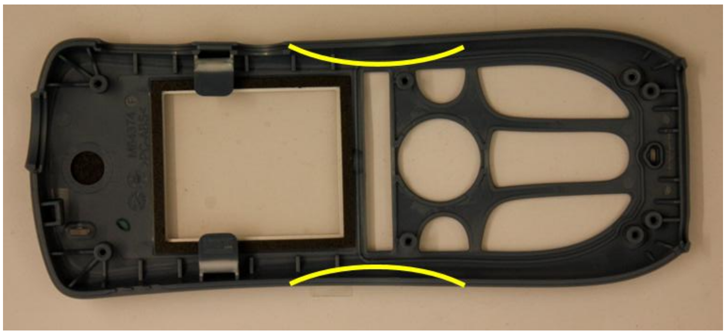


Figure 35 - DH4 front cover

5. The DH5 phone shows good results due to its very thick walls as well as with its additional inner frame that adds twice the strength when compared with other phones. The width of the phone increases with these double protected walls which is a needed design for rugged phones. The same concept can be carried forward at the same time possible hybrid materials which possess higher stiffness values can be investigated for future design. The fig.36 shows the front and rear cover of the DH5 phone. The position of the battery for DH5 is not in the middle which stiffens the geometry by avoiding the weak spot with low stiffness in the middle.

Figure 36 - DH5 front and rear cover

6. The fig.37 shows the inner protective cover of the DH5 which houses the PCB along with other components. This adds twice the strength to the DH5 phone. The vertical walls of this inner cover with stands high load during front loading in the bending test due to its C-shaped cross section. At the same time the rear side buckles due to high load fig.38. The advantage of the C-section can be carried forward in the design for a stronger cross section.


Figure 37 - DH5 Inner frame front side

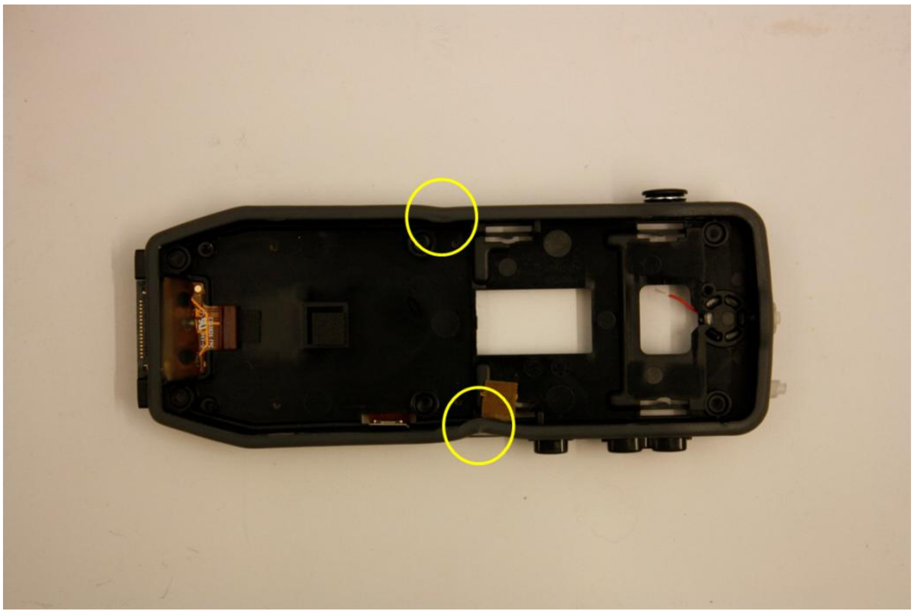


Figure 38 - DH5 Inner frame rear side

3.4 FUNCTION TREE MODEL

In order to clearly identify the different requirements, a function tree method proposed by Ulrich and Eppinger (4) was adopted and developed according to Ascom's requirement. The function tree gives a visual layout of the requirements divided by main functions and sub-functions followed by their specific requirements. The fig.39 represents the Ascom function tree with four levels of details included.

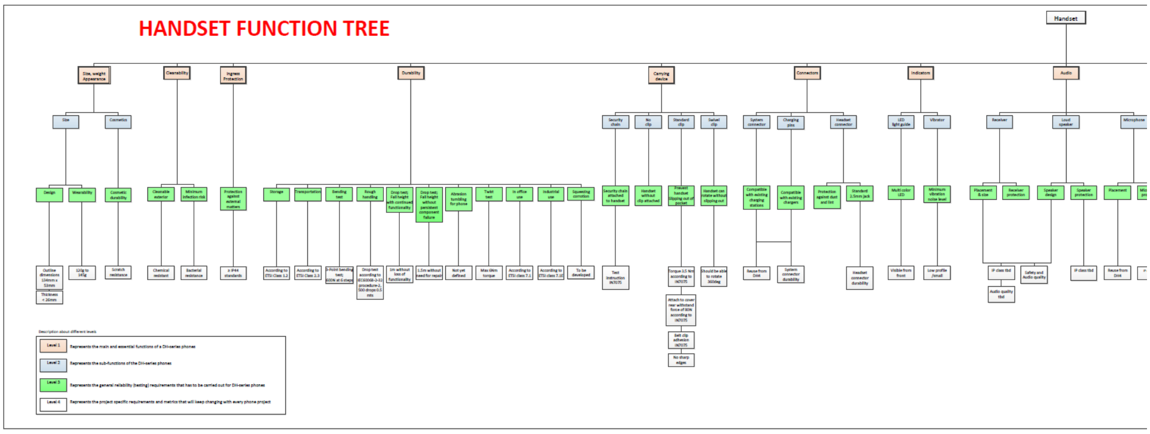


Figure 39 - Ascom handset function tree model

The Top level represents the Black box. The first level represents the main functions of a DH4 phone capturing all the high level functions that contributes to the phones functionality. The second level represents the sub function of the main functions adding up with more detailed component level functionality of the phone. This level captures all the necessary components that are mandatory for a phone to operate. The third level represents the general requirements of the sub functions that are mostly derived from the reliability documents of Ascom. Additional requirements that are new and yet to be added are captured along with the old requirements. Thus the function tree model evolved as a new standard for visualizing the Functions along with the requirements. The bottom level represents the project specific requirements that are only specific to each project and thus keeps changing according to each project.

The function tree has evolved into Ascom version as the project team saw the potential to capture functions, sub-functions and requirements in one document that is visually clear to read, easy to identify the details and more appealing to project and marketing team.

The function tree document is developed as detailed level by splitting the main functions to each page with more details explained. Due to its large size the actual function tree is included in the Appendix.C as split up into different pages.

Fig.40 shows a single sub-function “Carrying device” from the Function tree model.

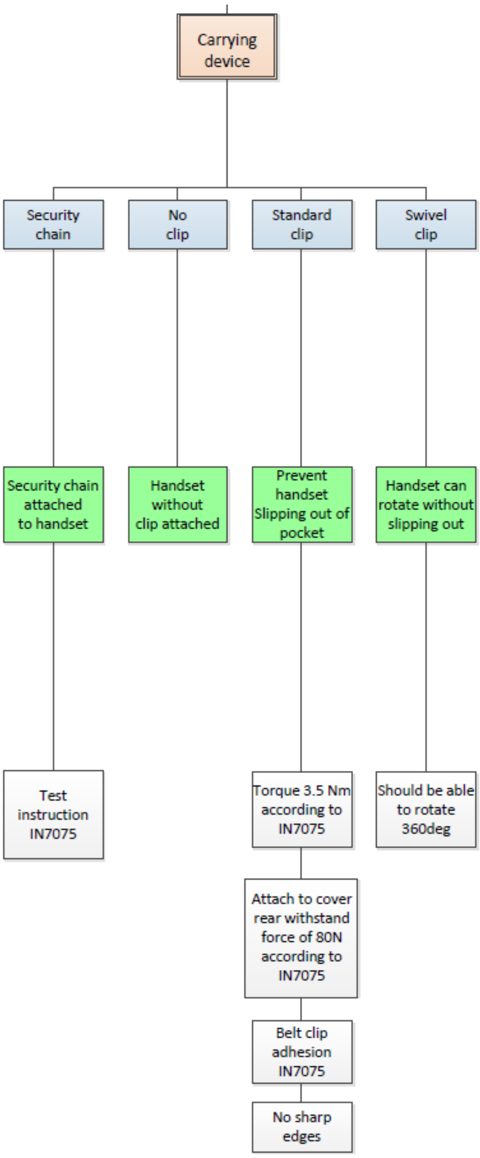


Figure 40 - Part of Function tree model showing "Carrying device"

The fig.41 shows the detailed view of the “Carrying device”. The full detailed document is included in the Appendix.C for reference.

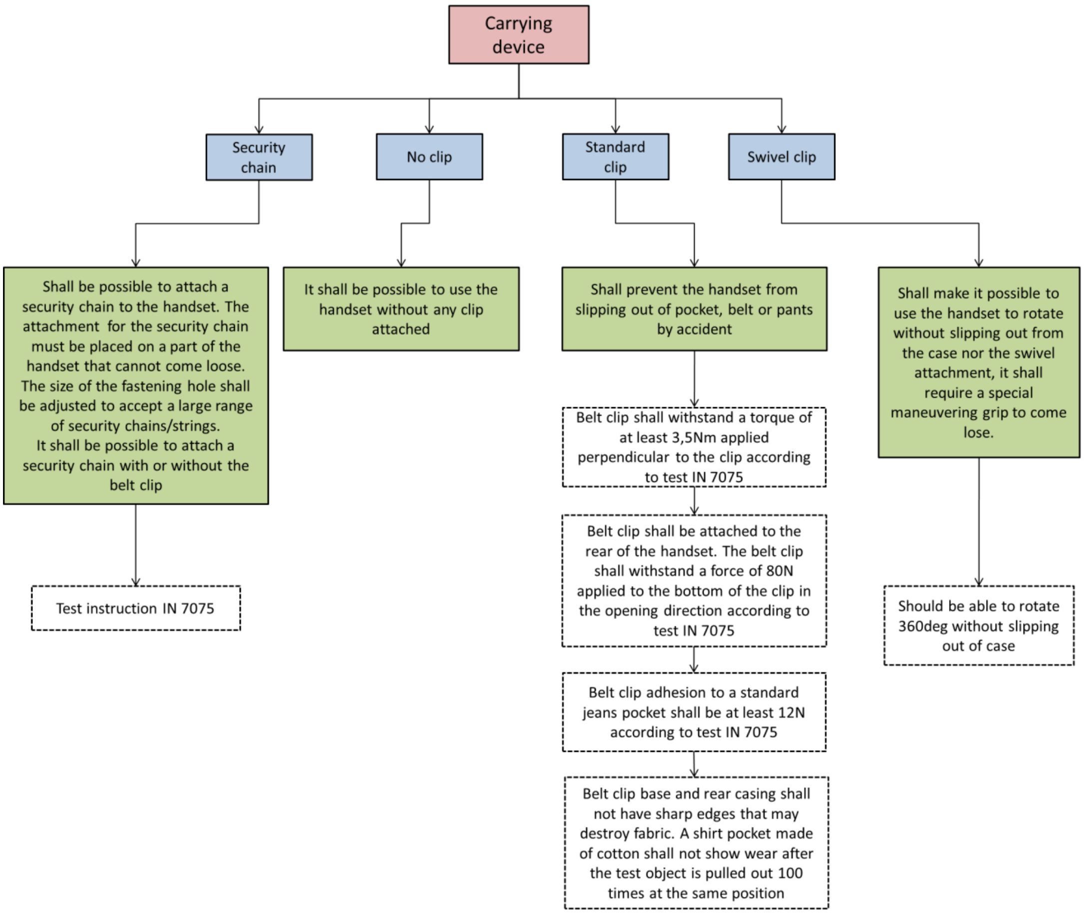


Figure 41 - Detailed view of "Carrying device"

4 CONCEPT GENERATION

The project work is carried out as a preliminary evaluation of mechanical design for thin phones and hence only the basic requirements were fixed such as overall dimensions and major functionalities. With this in mind the concept generation phase is proceeded by identifying solutions for the sub-functions and is developed as a solution matrix. Fully developed concepts that are combinations of different sub-solutions are then developed using the concept synergy method and ranked based on experience of the design team. The finalized concepts were then developed with CAD system to develop detail models for assembly and testing. The concept development started with the solution matrix which progressed as described below.

4.1 SOLUTION MATRIX (MORPHOLOGICAL MATRIX)

A morphological matrix or a solution matrix is the next step in a product development process after Function tree model (4) (5). It is a well-known method in product development which identifies and combines different sub-solutions for a product concept and delivers a complete solution that has all the requirements captured from function tree. This method is applied in this project in order to not miss any important functionality and its requirements.

The solution matrix was developed by listing the individual sub-functions in a row and different possible solutions in the respective columns. The solutions for various sub-functions were created by a brainstorming workshop session involving the entire mechanical design team. Simple hand sketches were generated and placed in a matrix as shown in the fig.42 and shows only part of the matrix. The full version is included in the Appendix.D. Collective experience of the individual team members were gathered and a goal was set to come up with solutions that are simple, cost effective at the same time in line with Ascom's business goal and requirements.

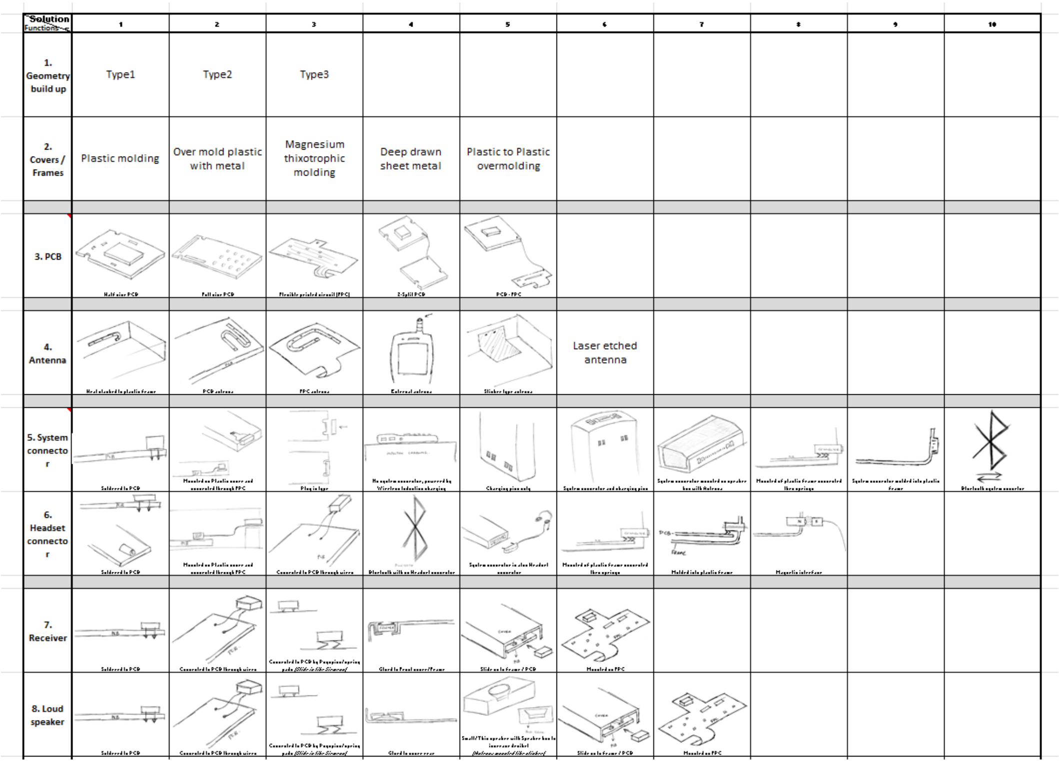


Figure 42 - Solution matrix

Among the sub functions, three main driving sub functions were identified which had the ability to define the characteristics of the phone. Those were,

1. Structural architecture (Geometry) – Type 1, 2 & 3 (fig.43, 44 &45)
2. Type of Frames/covers (refer to solution matrix)
3. PCB size (refer to solution matrix)

Three main types of structural architecture along with PCB size were proposed as listed below:

TYPE 1:

Type 1 represents a concept with half size PCB which packs components on both sides of it. This concept is utilized in most of the smart phones to reduce the thickness of handset. The available area for hardware component placement is reduced and routing for the PCB becomes complex. Fig.43 shows the Type 1 structural architecture.

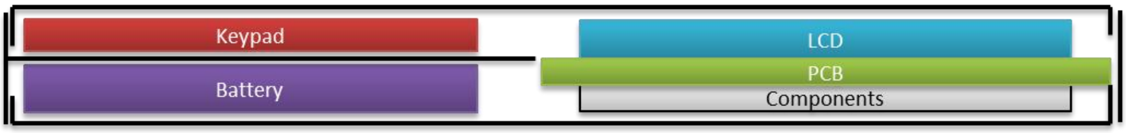


Figure 43 - Type 1 structural architecture

TYPE 2:

Type 2 represents a conventional design with full size PCB. It is hardware friendly and has more real estate for components to be placed freely. Handset thickness has to be compromised for hardware friendliness since the PCB runs throughout the length of the phone. Fig.44 shows the Type 2 structural architecture.

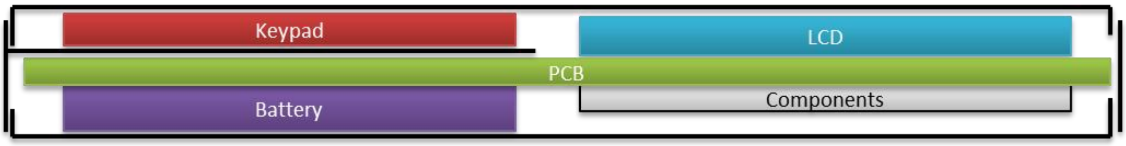


Figure 44 - Type 2 structural architecture

TYPE 3:

Type 3 represents a split PCB design placed on top and bottom side of the phone. The secondary PCB can be made of FPC to optimize shape and space. The cost of the product might increase due to FPC but could be a good compromise for handset thickness. Fig.45 shows the Type 2 structural architecture.

Figure 45 - Type 3 structural architecture

The above mentioned sub-functions were placed in the top row of the matrix in order to define a character for the concepts at the first place and then various sub function-solutions were added to obtain a complete concept.
All the sub-functions that are listed in the function tree model combined with the above provided 22 sub-functions in total that are listed in the matrix. The 22 sub-functions are listed in order as in Table.3

1	Structural architecture	**12**	Battery connector
2	Covers / Frames	**13**	Battery
3	PCB	**14**	Battery door
4	Antenna	**15**	Keypad
5	System connector	**16**	Side buttons
6	Headset connector	**17**	LCD
7	Receiver	**18**	Window
8	Loud speaker	**19**	Security chain
9	Micro phone	**20**	No clip
10	LED light guide	**21**	Standard clip
11	Vibrator	**22**	Swivel clip

Table 3 - Sub-functions from Function tree model

4.2 CONCEPT SYNERGY METHOD

Concept synergy is the next step to the morphological matrix in product development process (4) (5). The concept synergy method combines each selected sub-function solution and ranks it. The total rank is achieved by summing up the individual rank which is then used to select top rated concepts among others. In this case, criteria based on important life cycle phases of a product were set including Ascom's business needs.

The five concepts are then transferred to concept synergy template and ranked based on criteria as below:

A. Design/Technology/Strategy
   The solutions are to be ranked based on how well the design will work when it is implemented. Feasibility of technology was considered at the second level when combining the solutions and finally ranked against whether the solution is in line with Ascom business goals.
B. Manufacturing of parts
   Manufacturing feasibility weighed against existing Ascom supplier base and their technological capabilities.
C. Assembly
   Design For Assembly (DFA) is considered
D. Repair
   The solutions are combined by keeping in mind about serviceability and its implication of parts that need to be replaced.
E. Cost
   Final criteria is set as cost that decides the solution over all the above.

The ranking grade was given as shown in the table.4

Grade	
●	Adds high value
◑	Fits well
○	Does not add value
⊗	Conflict

Table 4 - Grades for Synergy

The workshop resulted with five concepts that differed by their structural architecture. They were named after the weather condition on the day and are Rainy, Foggy, Windy, Snowy and Mechy.

Concept Rainy:
The concept contains type 2 geometry with PCB and FPC for keypad. Full size PCB gives flexibility in component placement as well as antenna integrated in the board itself.

Concept Foggy:
The concept houses a combination of half size PCB along with FPC using type 1 geometry. The component placement for hardware will be comparatively complex for this concept on the other hand the thickness of handset is reduced.

Concept Snowy:
The concept is a follow up of Foggy with new methods of antenna placements were introduced instead of placing it on the PCB. This saves space in PCB at the same time gives flexibility for antenna placement.

Concept Windy:
This concept houses type 3 having a split PCB design. FPC is selected to be used for keypad for more flexibility. Advanced functionality such as Bluetooth, vibrating loudspeaker instead of normal vibrator were considered for this concept.

Concept Mechy:
As the name implies, the concept was developed by the Mechanical team anticipation of a future phone. This concept includes some of the advance technologies used in handsets and out of the box design strategies.

Although the concept synergy gave a good foundation for converting the sub functions to a complete concept, at the early stage of the project it was decided to develop and test as much as solutions as possible to understand the different way of structural layout that adds strength to the handset at the same time reduce its overall thickness.

Concept Rainy was selected due to its simplicity and proven design built up. Remaining concepts were combined by picking the best parts. Concept Foggy and Snowy were combined together and conceived as one concept. Some of the characteristics of Windy and

Mechy were combined together to form a third concept. Fig.46 shows part of the synergy method for Concept Rainy. The full versions of synergy of all concepts are included in the Appendix.E.

Criteria for Synergy	
A	Design/Technology/Strategy
B	Manufacturing of parts
C	Assembly
D	Repair
E	Cost

Grade	
●	Adds high value
◑	Fits well
○	Does not add value
⊗	Conflict

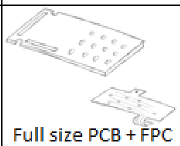
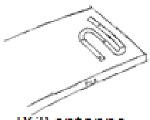
Functions	Solution	Criteria	Grade	Description of synergy
1. Geometry build up	Type2			Rainy
		A	◑	
		B	◑	
2. Covers / Frames	Over mold plastic with metal	C	●	
		D	◑	
		E	⊗	
		A	◑	
		B	◑	
3. PCB	 Full size PCB + FPC	C	○	
		D	◑	
		E	⊗	
		A	◑	
		B	●	
4. Antenna	 PCB antenna	C	●	
		D	●	
		E	●	
		A	◑	
		B	◑	
5. System connector	 Soldered to PCB	C	○	
		D	○	
		E	◑	
		A	●	
		B	◑	
		C	●	
		D	●	

Figure 46 - Concept Rainy formation using Concept synergy method

The five concepts were then developed in the CAD system ProEngineer in the concept design and development phase.

5 CONCEPT DESIGN AND DEVELOPMENT

The combined three concepts were selected to the CAD development phase of the project. Creo elements Pro5.0 (ProEngineer) was used to design the CAD models. All the CAD data were maintained in Windchill PDMLink for managing revisions and updates. The standard Ascom part and assembly templates were followed for future use of the CAD design.
Most of the standard components were reused from old phone development projects, while some of the components which could be made thinner were custom designed according to supplier standards. Components such as loudspeaker, vibrator, LCD were some of them which faced a thickness reduction. By achieving smaller thickness in these components, the thickness of the handset was reduced to 16,5mm from 25mm. Hybrid architecture for frames were introduced instead of plastic type of materials to increase the stiffness at the same time maintaining a thin profile. The frames are made of a combination of sheet metal and plastic molded together and is intended to be manufactured using over molding technology. The concepts are discussed further below.

5.1 CONCEPT RAINY

Over all dimensions: 133,7 x 52,3 x 16,3 (mm)
Strength and stiffness are the two main properties that are targeted when designing the concepts. Concept Rainy was given an I-section shaped main frame to with stand the bending and torsional load from the reliability tests see fig.47. The main frame houses all the main components such as PCB assembly (PCBA), LCD, LCD window, keypad, keypad FPC as shown in the system architecture see fig.51. The rear cover is designed as a C-section to cover the components and seal it from the back side. The main frame and rear cover are fastened together using standard screws on top, bottom and middle of the phone. The knowledge gained from initial tests was implemented in this concept such as, vertical walls as much as possible, stronger I-section and battery cover that is attached to the rear cover while removing the battery. The illustration in fig.47 shows an I-section that is closed by the rear cover. This closed section increases stiffness for torsional loading.

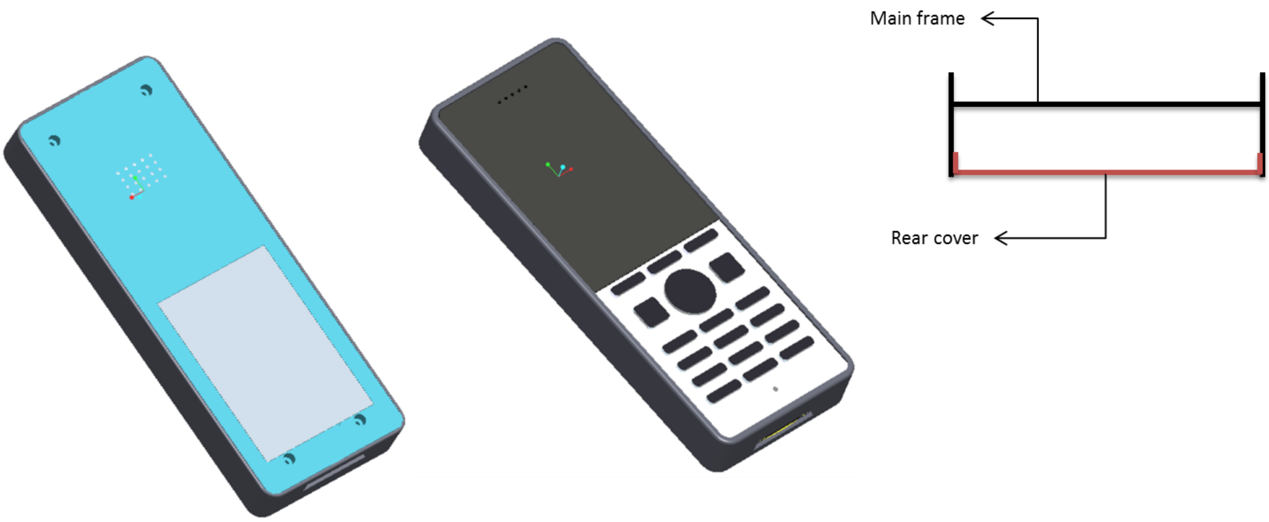


Figure 47 - Concept (1) Rainy front and Rear view

Fig.48 shows the length wise cross section of Concept Rainy with its internal assembly and components.

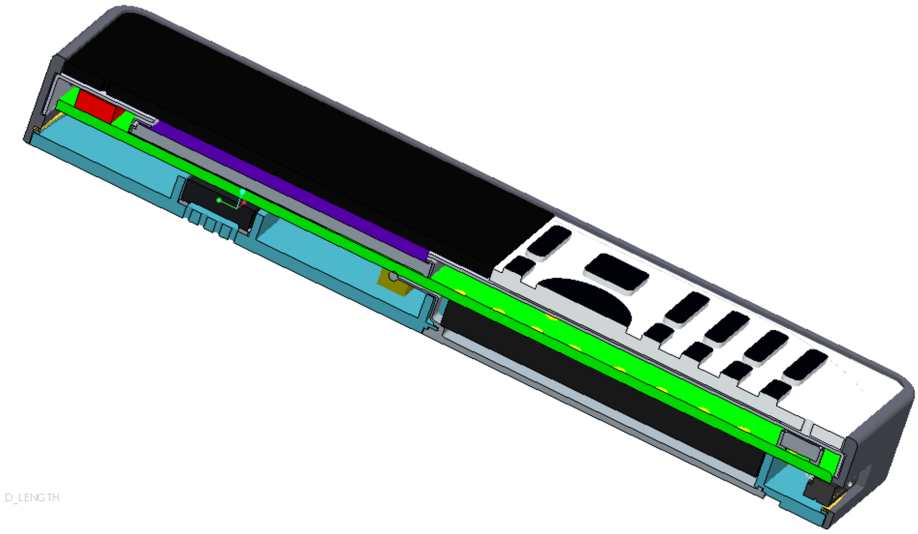


Figure 48 - Concept (1) Rainy cross section view

The Fig.49 shows the exploded view of the concept in the order of its assembly steps. Possible manufacturing methods are discussed in the information bubble for each component.

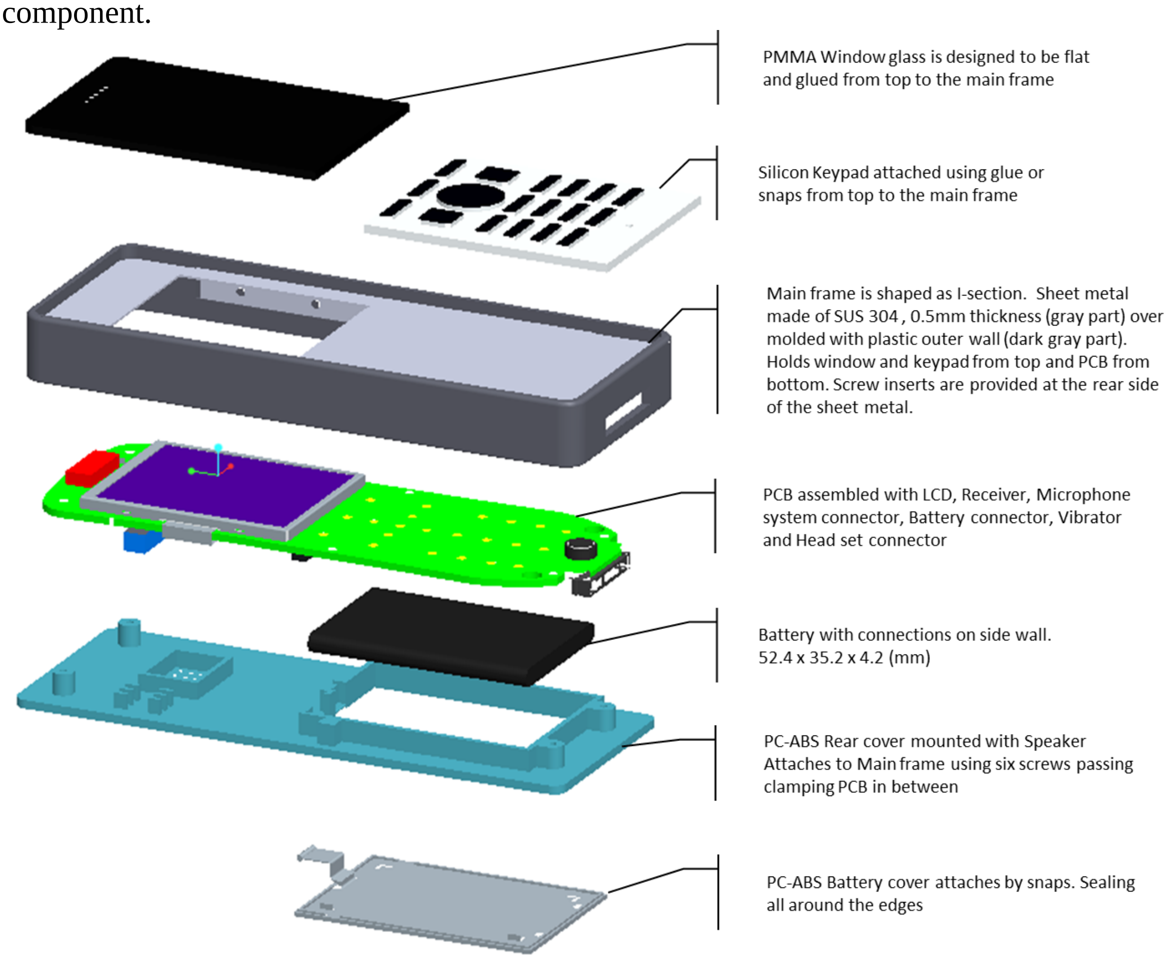


Figure 49 - Concept (1) Rainy exploded view with details

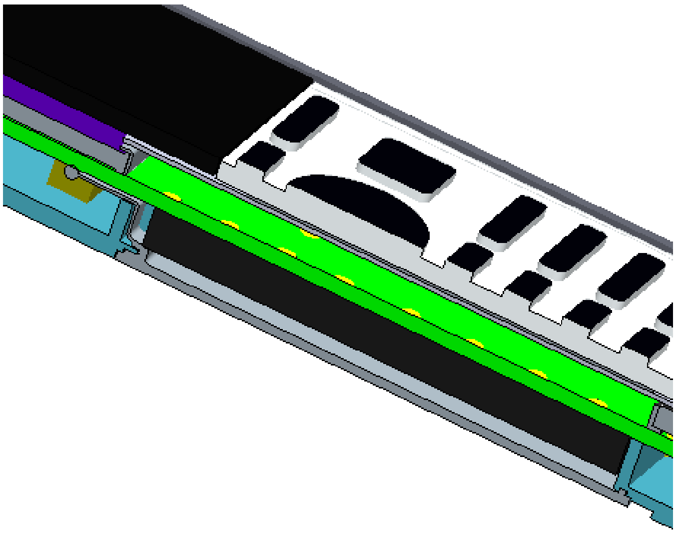


Figure 50 - Detail view of battery door attached with main body

The fig.50 shows the details of the battery door hinged to the rear cover during assembly. This idea is implemented in order to have two pieces of the handset when replacing the battery. The battery door has a thin flexible strip that is locked during assembly with the rear cover. The battery door is able to losely hang during battery replacement and can be snapped again.

A system architecture model was developed for each concept to quickly learn the major component position inside the handset. The fig.51 shows the concept Rainy's system architecture.

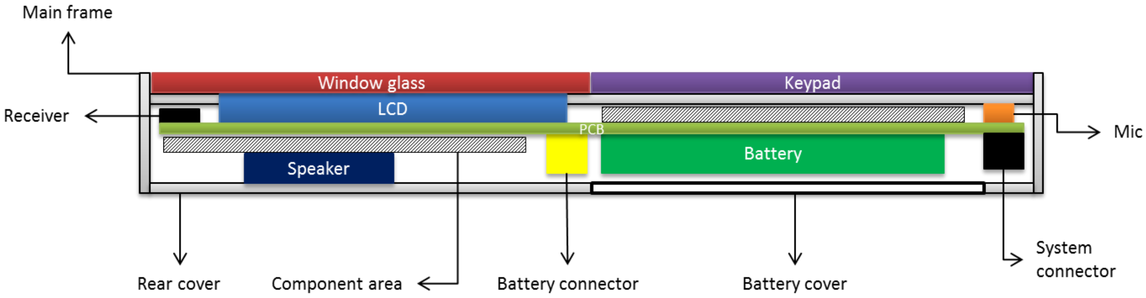


Figure 51 – Concept (1) Rainy System architecture

5.2 CONCEPT FOGGY + SNOWY

Over all dimensions: 133,7 x 52,4 x 15,5 (mm)
The concept was conceived with two C-Sections joined together to form a strong structure. This is a more traditional way of building a handset at the same time the components were placed to optimize the volume occupied by each of it. This way a handset thickness of 15,5mm is achieved. The components on the PCB Assembly (PCBA) are protected against the keypad forces by introducing a shield can made of sheetmetal that prevents the key press forces to be transferred to the PCB components see fig.54. The concept involves simple parts that makes it possible candidate for low end phone. Fig.52 illustrates the structural cross section, front and rear view of the concept.

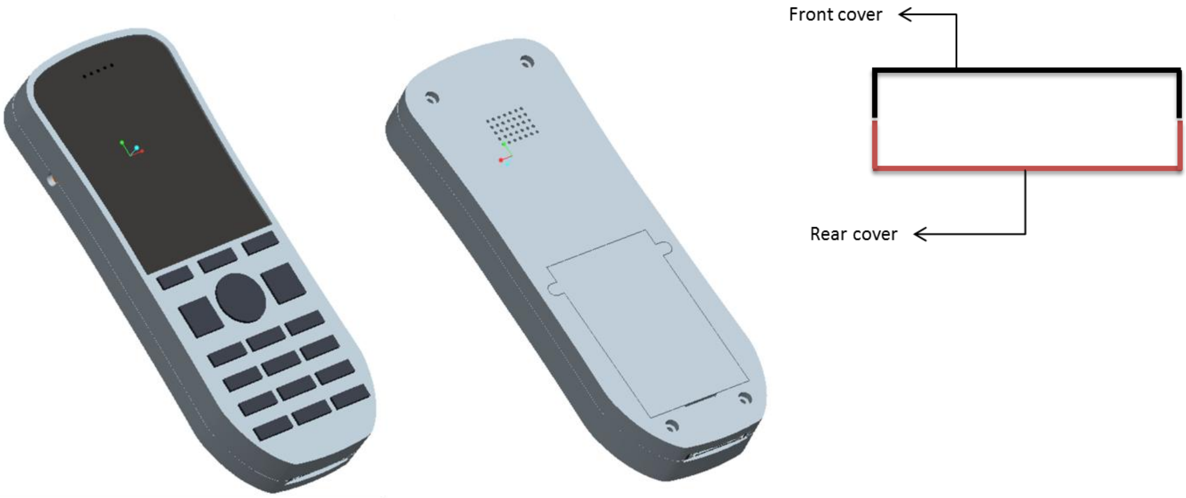


Figure 52 – Concept (2) Foggy+Snowy front and rear view

The fig.53 shows the length wise cross section of Concept Rainy+Foggy with its internal components.

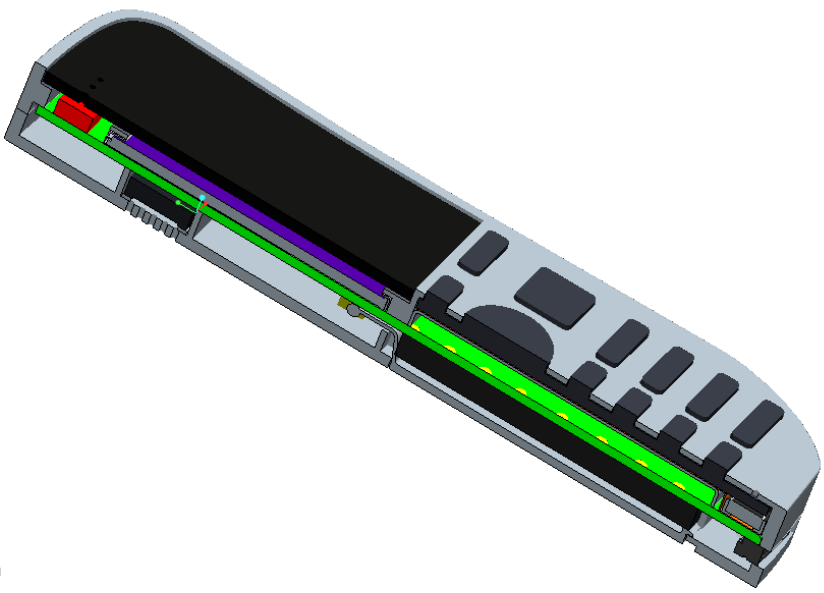


Figure 53 - Concept (2) Foggy+Snowy cross section view

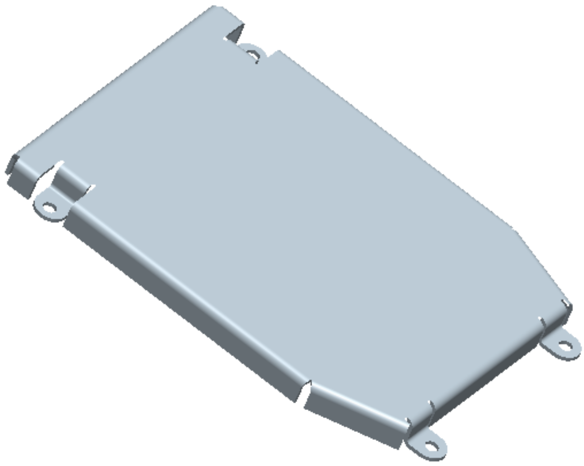


Figure 54 - Concept (2) Foggy+Snowy keypad shield can

The Fig.55 shows the exploded view of the concept in the order of its assembly steps. Possible manufacturing methods are discussed in the information bubble for each component.

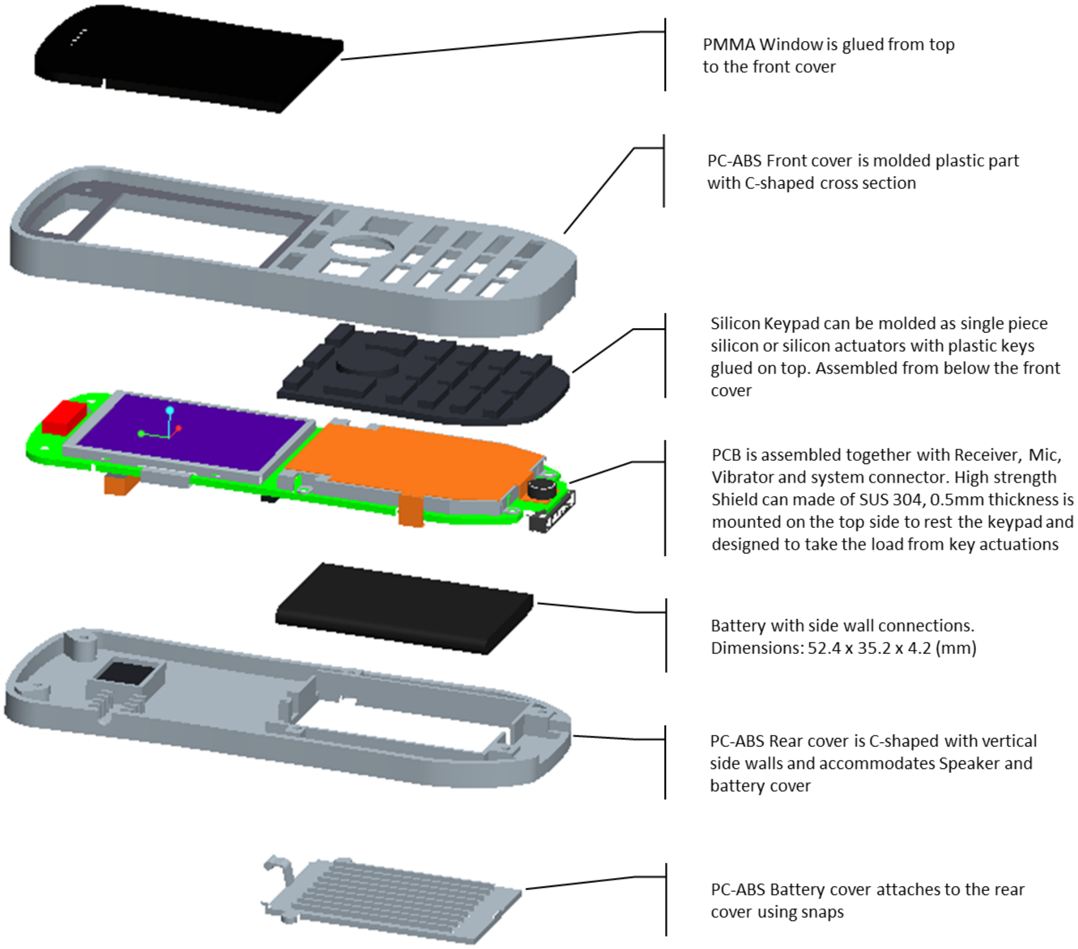


Figure 55 - Concept (2) Foggy+Snowy exploded view with details

A system architecture model was developed for each concept to quickly learn the major component position inside the handset. The fig.56 shows the concept Foggy+Snowy's system architecture.

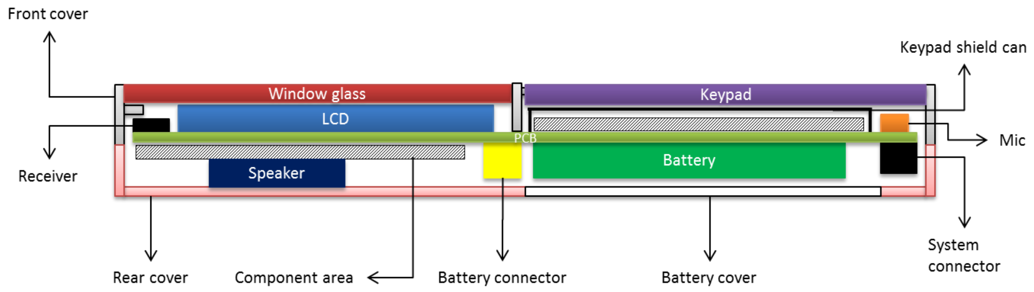


Figure 56 – Concept (2) Foggy+Snowy System architecture

5.3 CONCEPT WINDY + MECHY

Over all dimensions: 133,7 x 52,4 x 14,6 (mm)
The concept was built with a strong metal frame which protects the lower lying components against any load from bending and twisting. The metal frame can be manufactured using metal injection molding technology which makes it very strong compared to the plastic materials. The rear cover is a C-shape section made of plastic which houses all the components. The PCB is reduced in size with half the size of the normal board. This is to reduce the thickness of the handset at the same time to check the different possibility of phone architecture. Components can be placed on either side of the PCB to accommodate the components. The battery is placed on the upper half of the phone for an optimum use of volume space. Fig.57 illustrates the structural cross section. Black line represents the metal frame and red line indicates the plastic rear cover.

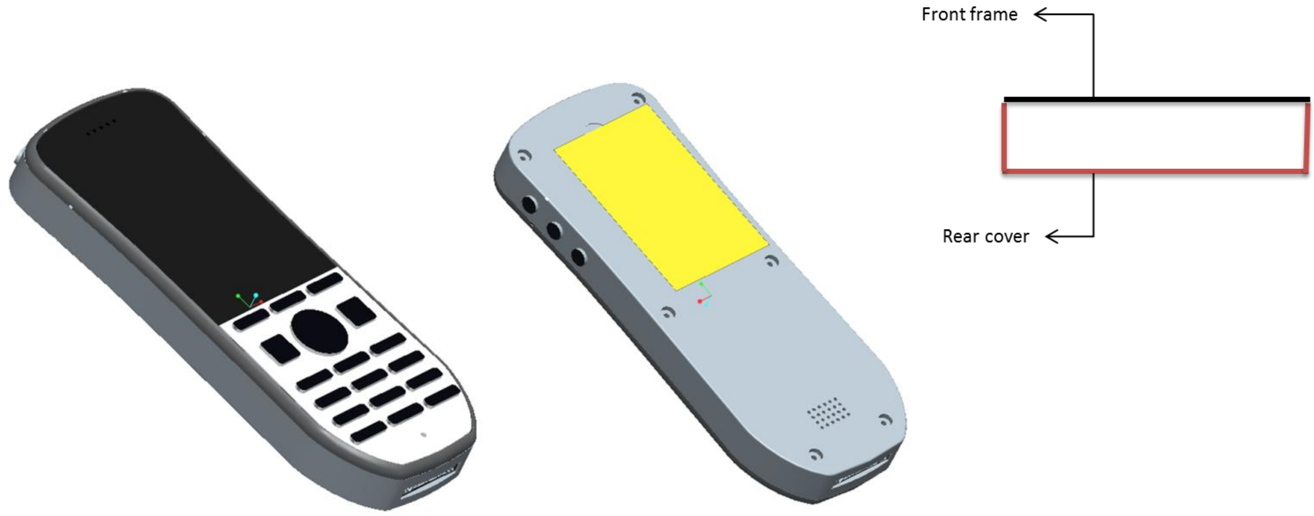


Figure 57 – Concept (3) Windy+Mechy front and rear view

Fig.58 shows the length wise cross section of concept Windy+Mechy along with its internal components.

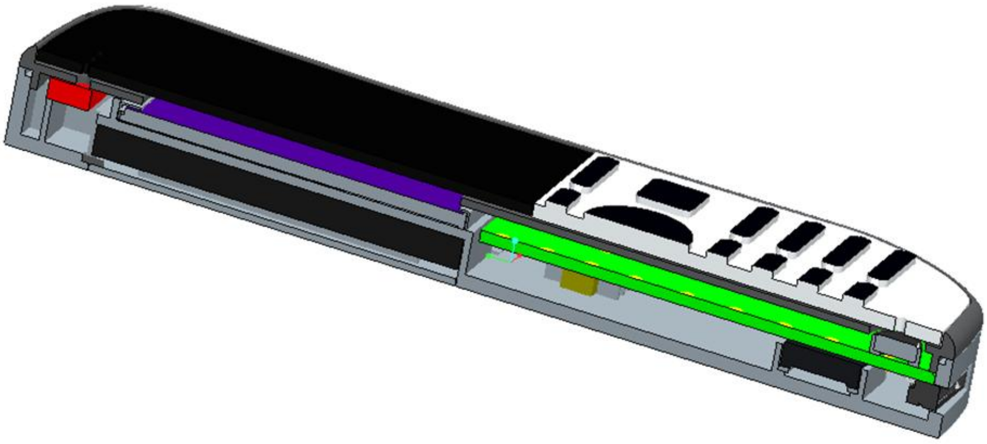


Figure 58 - Concept (3) Windy+Mechy cross section view

The Fig.59 shows the exploded view of the concept in the order of its assembly steps. Possible manufacturing methods are discussed in the information bubble for each component.

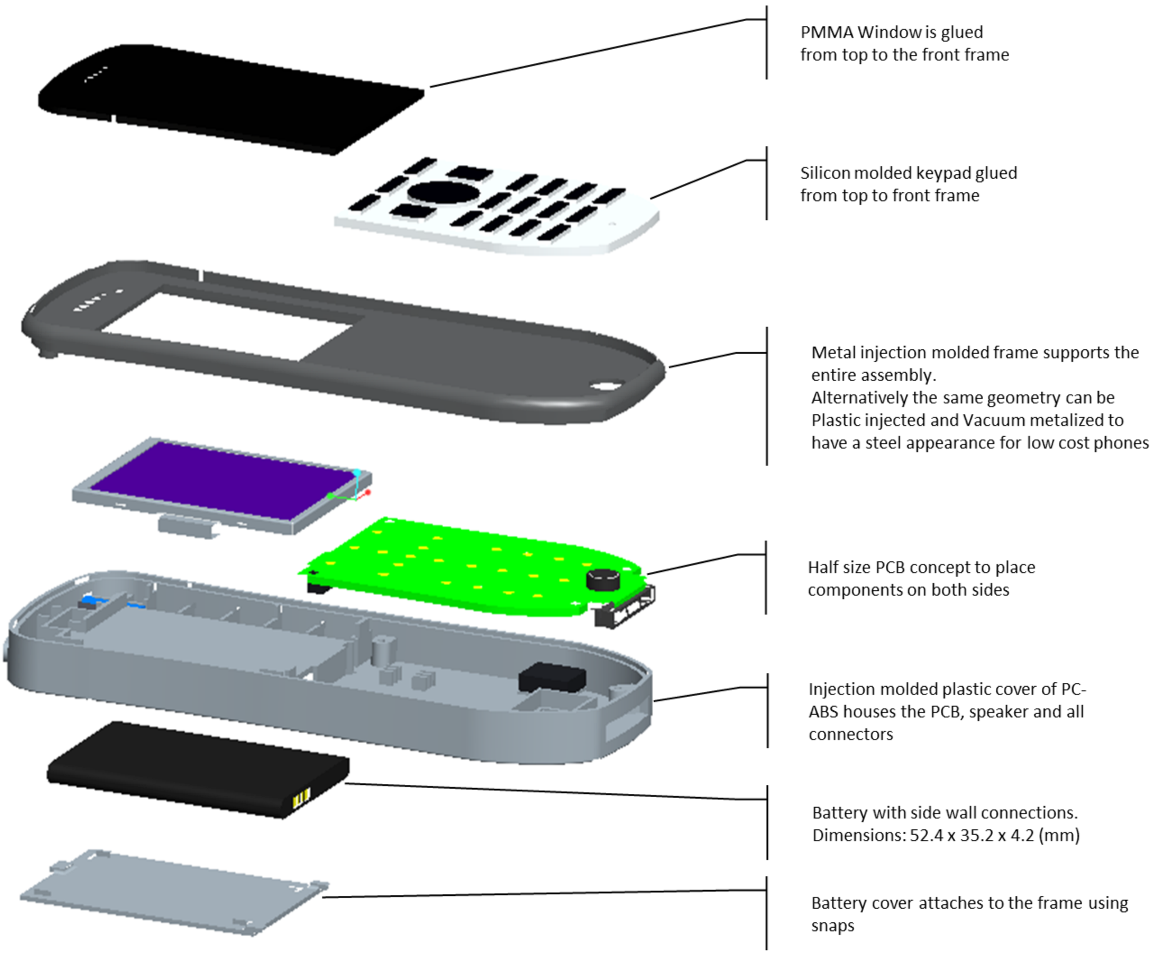


Figure 59 - Concept (3) Windy+Mechy exploded view with details

A system architecture model was developed for each concept to quickly learn the major component position inside the handset. The fig.60 shows the concept Windy+Mechy's system architecture.

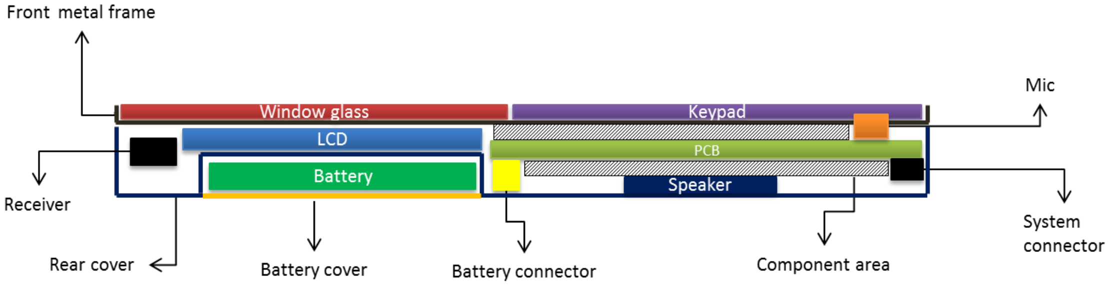


Figure 60 - Concept (3) Windy+Mechy System architecture

6 PROTOTYPE DEVELOPMENT AND TESTING

In order to verify the stiffness and strength of the new concepts, prototypes were manufactured for the three concept design. All the prototypes parts were made by 3D-printing technology using ABS as base material. DH3 prototype was developed and made as reference to compare the results of the new concept. Since prototyping technology has some limitations, the sheet metal part was glued to the ABS prototype and made as a hybrid structure. This structure is considered as equivalent to an over molded sheet metal with plastic part.

The PCB, LCD and battery were reused from the existing phones to simulate actual phone behavior. Screws were also reused from the Existing phones for fastening.

The fig.61 below shows the DH3 prototype with real battery cover and battery reused.

Figure 61 - DH3 handset Prototype

The fig.62 & 63 below shows the Concept 1 (Rainy) prototype parts

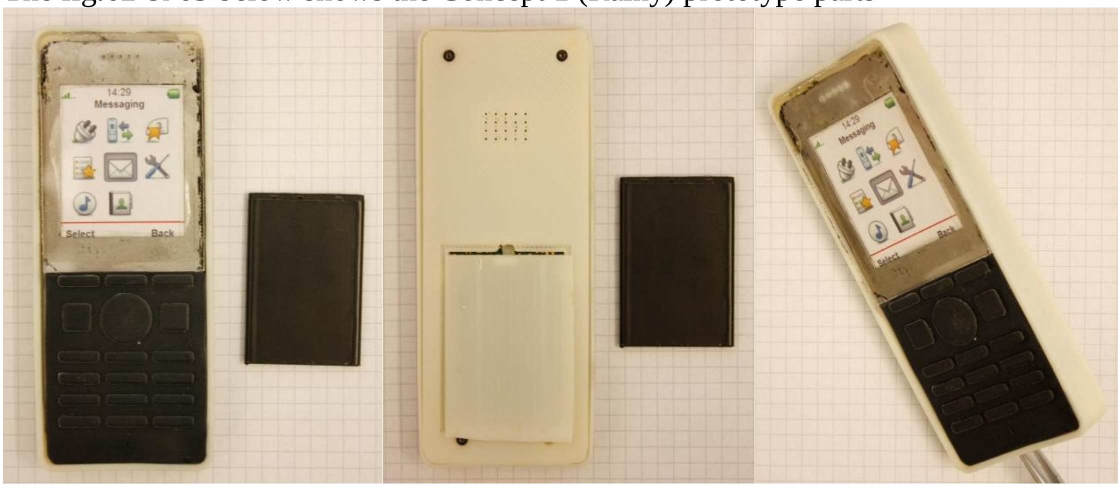


Figure 62 - Concept (1) Rainy prototype

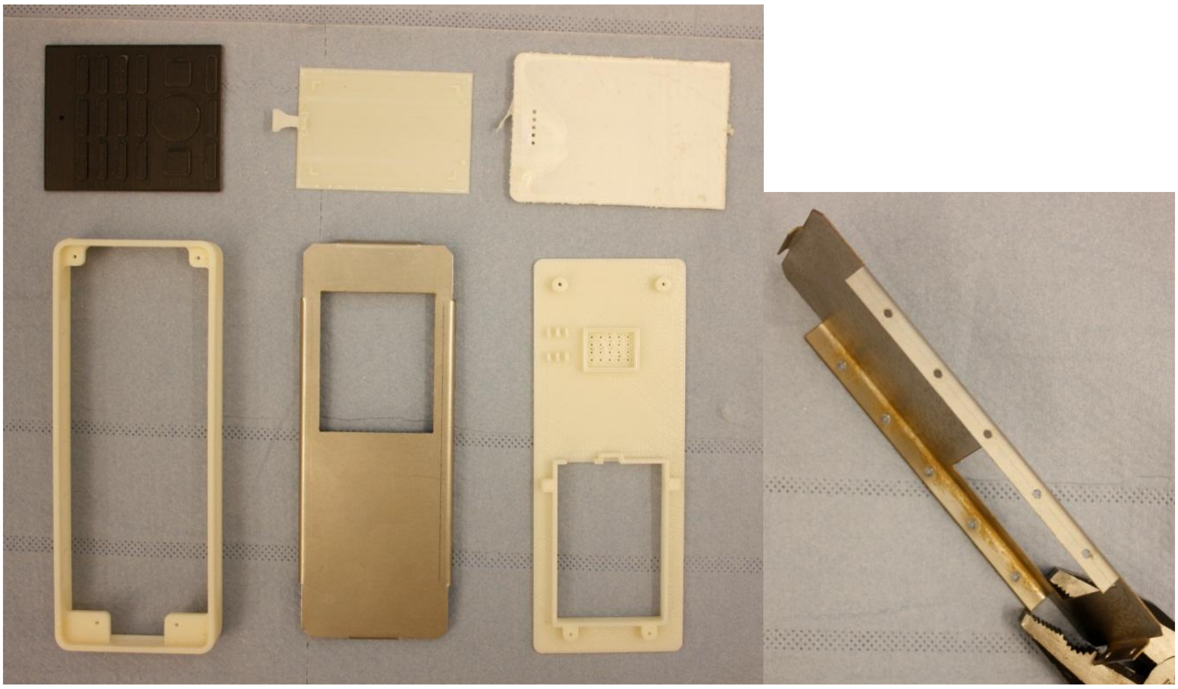


Figure 63 - Concept (1) Rainy prototype parts

The fig.64 & 65 shows the Concept 2 (Foggy+Snowy) prototype

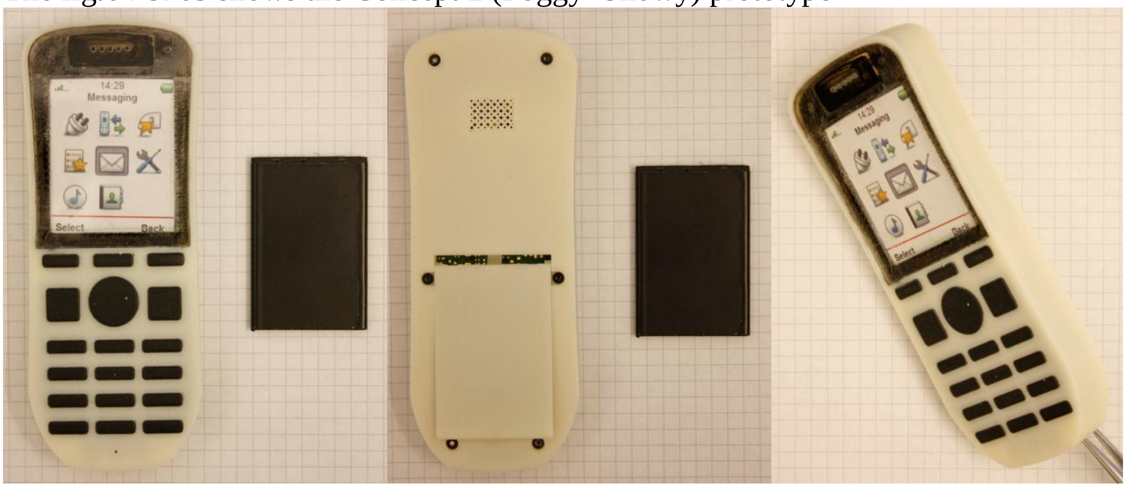


Figure 64 - Concept (2) Foggy+Snowy prototype

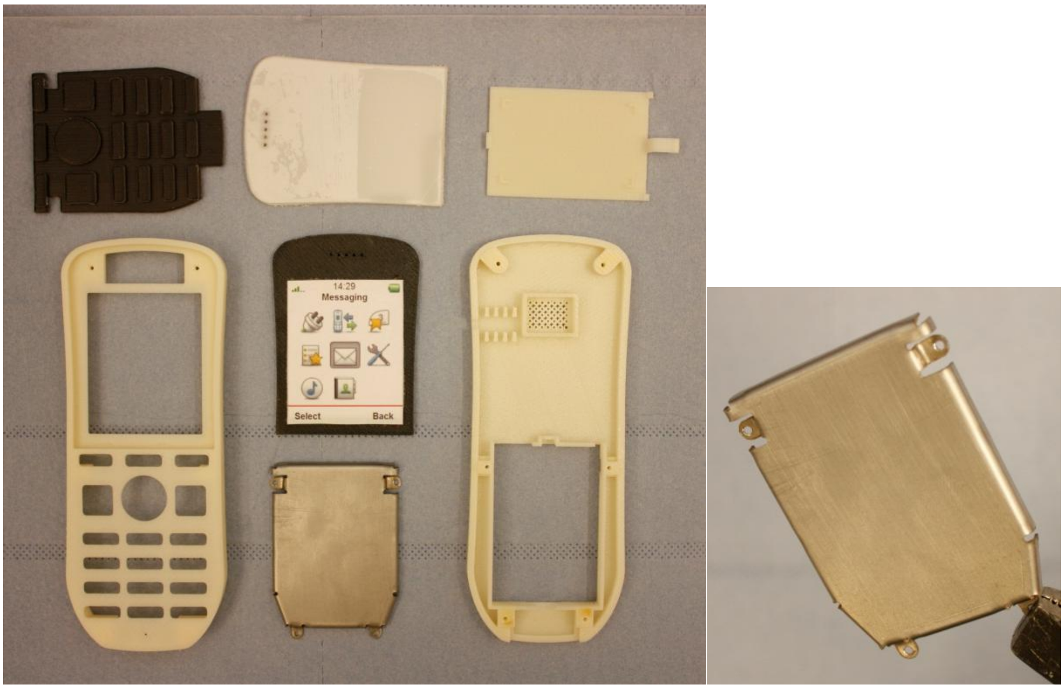


Figure 65 - Concept (2) Foggy+Snowy prototype parts

The fig.66 & 67 below shows the Concept 3 (Windy+Mechy) prototype parts

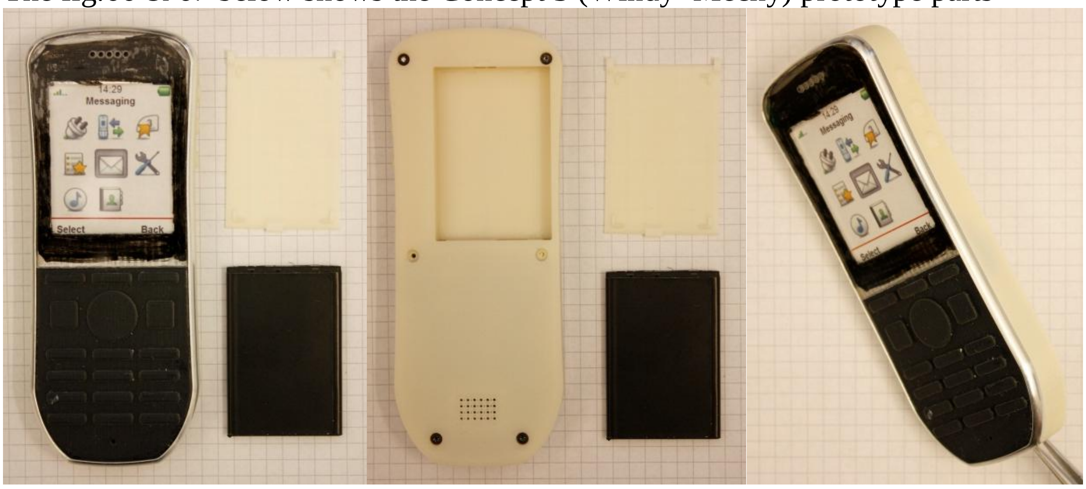


Figure 66 - Concept (3) Windy+Mechy Prototype

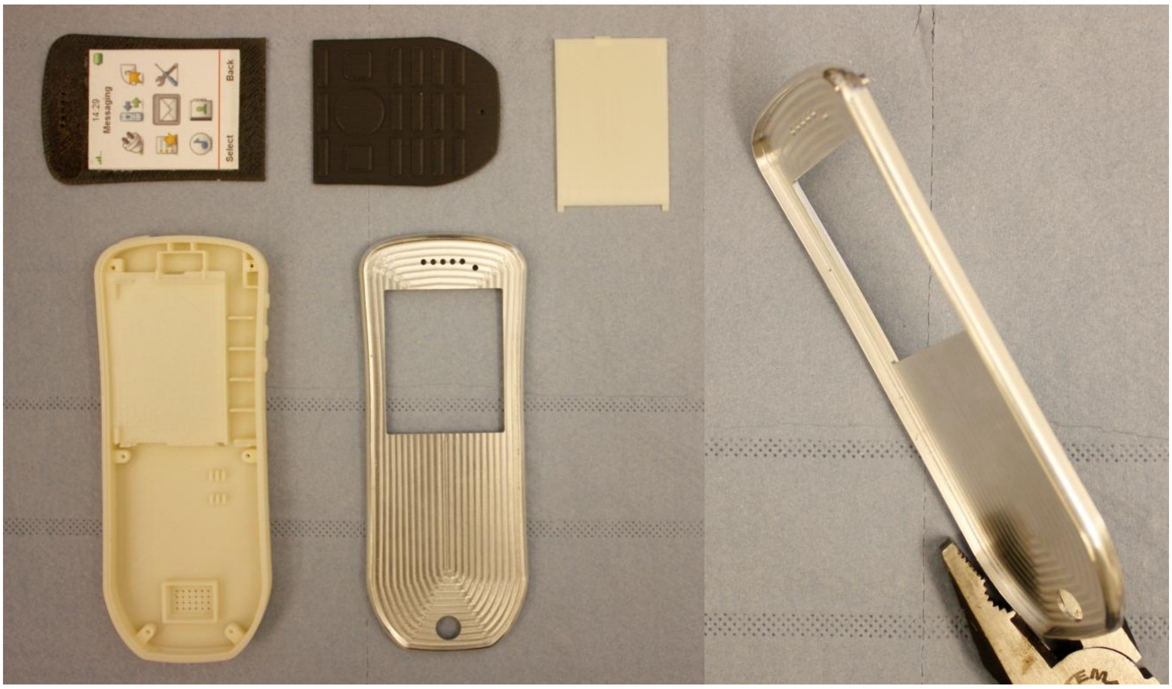


Figure 67 – Concept (3) Windy+Mechy prototype parts

The prototypes were subjected to the 3-point bending test and torsional test methods that were developed early in the project. The DH3 prototype is the reference phone against which the concepts were evaluated. The silicon gasket compresses during the bending and twisting and it is hard to differentiate the effect of silicon from the plastic. Considering this issue, the DH3 is taken as reference due to the absence of any sealing gasket that is made of silicon and so are the concepts.

3-POINT BENDING TEST
The concepts were subjected to a bending stroke length of 2mm since it is a prototype. The maximum force required to bend until 2mm was measured. Load was applied on front side and rear side of the phones. The table.5 shows the results of 3-point bending test.

Prototype			Real DH3 phone		% variation between Proto and real phone	% Increase in stiffness between DH3 proto and concepts	Relative stiffness
Name	Max_Force	Max_Stroke	Max_Force	Max_Stroke			
Unit	N	mm	N	mm			
DH3-F 2MM	137,23	2,04	170	2,06	-19,28		
DH3-B 2MM	127,36	2,04	160	2,03	-20,40		
C1-F 2MM	588,87	2,04				329,11	x 3,2
C1-B 2MM	528,96	2,04				315,34	
C2-F 2MM	348,10	2,04				153,66	x 1,4
C2-B 2MM	306,09	2,04				140,34	
C3-F 2MM	864,01	2,04				529,61	x 4,9
C3-B 2MM	697,36	2,04				447,56	

Table 5 - Bending test results for Prototype

The DH3 prototype test results were compared against the real DH3 handset to identify the difference between the prototype material and real plastic material. The percentage variations of maximum force required to bend until 2mm was calculated and is found to be approximately 20% i.e. the prototype structure is 20% weaker than the actual handset. The increase in stiffness of the concepts against the DH3 prototype was calculated and is listed as above in percent.

From the results it can be concluded that, Concept 1 (Rainy) is 3,2 times stiffer than the DH3 and is the second strongest concept among the three. The use of sheetmetal has provided enough stiffness to withstand a load of 588N maximum. The concept 2 (Foggy+Rainy) is 1,4 times stronger than the DH3 prototype. Due to its simple structure and plastic only design has provided enough stiffness to withstand a load of 348N maximum. The concept 3 (Windy+Mechy) is 4,9 times stronger than the DH3 prototype and is the strongest concept of all. It has proven to withstand extreme load of 864N maximum at 2mm deflection. The use of metal frame has increased the stiffness and it can be used as a decorative part due to its high quality appearance.

TORSIONAL TEST

In terms of torsional load, the prototype structures were considered weak because of the 3D printing architecture. Bearing this in mind, the load conditions were set to 3Nm torque value and the angle of deflection for each torque value was documented. Two deflection values were measured for each torque value by measuring in clockwise and anti-clockwise direction and an average value is calculated. Table.6 shows the twisting test results of the DH3 and concept prototypes.

Prototype												
Torque (Nm)	**Angle of deflection (deg)**											
	DH3			**Concept 1**			**Concept 2**			**Concept 3**		
	I	**II**	**avg**	**I**	**II**	**avg**	**I**	**II**	**avg**	**I**	**II**	**avg**
1	1	1	1	1	1	1	1	1	1	0	0	0
2	3	3	3	3	2	2,5	3	3	3	1	1	1
3	5	5	5	4	4	4	5	6	5,5	2	2	2
Real DH3 phone												
1	0	0	0									
2	3	2	2,5									
3	5	4	4,5									

Table 6 - Twisting test results for Prototype

The test results show the prototype is close to the actual handset. This could be due to the structural similarity of the handset since it the same for DH3 real handset and DH3 prototype handset. It can be considered that both material and structural architecture plays vital role during twisting load conditions.

The concept 3 (Windy+Mechy) due to its metal frame is the stiffest of all due to its metal frame. Concept 1 (Rainy) and Concept 2 (Foggy+Snowy) take second and third position in the stiffness scale.

Both the test results prove the concepts are stiffer than the existing handset. The stiffness of the handset has shown considerable increase and is directly proportional to the amount of metal used in each concept. The more metal, the stiffer are the handsets. At the same time, a balance between cost and metal usage can be sought based on requirements and profits.

7 MATERIALS SELECTION AND MANUFACTURING

Material selection for the handset is one of the important factors that determine the strength and stiffness of the phone. An objective material selection method is much needed and therefore, methods defined by material selection and design (2) were followed by the project. CES selector 2012 program (3) was used to plot the material property graph. Materials for major components of the phone such as frames, battery cover, window, attachment clip, sealing gaskets and sheet metals are involved in material selection.
For each component at the first step the four main factors that determine the material are identified and listed.

1. **Functions** - what is the basic function of the part?
2. **Objective** - what are the design objectives? What are the properties that have to be minimized or maximized?
3. **Constraints** - what are the design constraints? What are the conditions that must be satisfied by the design?
4. **Manufacturing requirements** - possible manufacturing requirements that are standard within the company.

Supporting details such as existing materials, operating loads and environment are identified and documented for reference and comparison. A standard template to capture all the information was developed and the datas are documented for future reference. Fig.68 shows part of the template. The full version is included in the Appendix.G in CD-ROM.

Material selection template

1. Component name:

Insert image of component

2. Existing material
   - 2.1 The materials that are used today ?
   - 2.2 Reason for wanting to change the material ?
   - 2.3 Mass of the component ?
   - 2.4 How it is currently manufactured ?

3. Operating loads and environment
   Provide information about the operating loads:
   - 3.1 Forces, torques, vibration etc:
     (Please be as quantitative as you can "must carry a torque of 0.1 Nm")
   - 3.2 Details of the operating environment: Temperature, pressure, exposure to chemicals/solvents, exposure to radiation,

Figure 68 - Material selection template

All the data are then transferred to CES program for plotting and identifying the right materials. Relevant material properties were set for each component. For example, possible materials for frames were selected by choosing “cost per unit of stiffness” in Y-axis and “mass per unit of stiffness” in X-axis. The material index was selected accordingly in the CES software. If supporting properties were needed such as hardness and impact strength were also listed for more detailed selection.

A four stage of selection process was adopted in the CES program for applying limits. Before applying the four staged approach, a relevant database is selected for each part, which in this case is the so called “Polymer selector”.
Stage 1 - Main properties graph: At first stage, the main properties that determine the material for the part is listed in X and Y axis. Cost and mass are the major factors that are listed for most of the parts.
Stage 2 - Limiting constraints: Properties of material such as transparency, recyclability, RoHS compliance, durability against water were set to limit the number of materials. Complete set of limits are available in the material selection report in Appendix.F.
Stage 3 - Manufacturing process: Manufacturing processes were selected to further limit the number of material for selection.
Stage 4 - Shape: The basic shape of the component is given as reference in this stage.
All the above stages are complimented with additional graphs if required for a more in depth selection.
Material selection process for all the components are described below.

7.1 FRAMES AND BATTERY COVER

Figure 69 - Prototype plastic and sheetmetal frames

The material for frames and battery cover should be stiff enough to withstand the load due to bending and twisting. Currently used material ABS/PC Cycloy 1200 was set as a reference for future comparison against the qualified materials. The stiffness of the material is taken along with the cost and mass of the material. Cost is a mandatory factor that needs to be considered for any product. Since the product is handheld type, the possible material should be low in weight and so the mass of the material is taken in to consideration.

The material index for “mass per unit of stiffness” is given by $\frac{\rho}{\varepsilon_f^{\frac{1}{3}}}$

The material index for “cost per unit of stiffness” is given by $\frac{C_m.\rho}{\varepsilon_f^{\frac{1}{3}}}$

Where, ρ is density of the material expressed in kg/mm^3

$\varepsilon_f^{\frac{1}{3}}$ is flexural modulus expressed in GPa

C_m is the cost of expressed in SEK/Kg

The material index is referred from *M.FAshby (2) and CES program (3)*

The following plot see fig.70 shows the two indices in X and Y axis respectively. Common limits such as RoHS compliance, transparency, resistance against water and recyclability are defined as first limit stage. The material should be compatible for injection molding process or similar and also to secondary process such as painting and surface coating. These processes related limits are set as third stage. The shape of the component is set as the final limiting stage in order to down size the number of material available in the database.

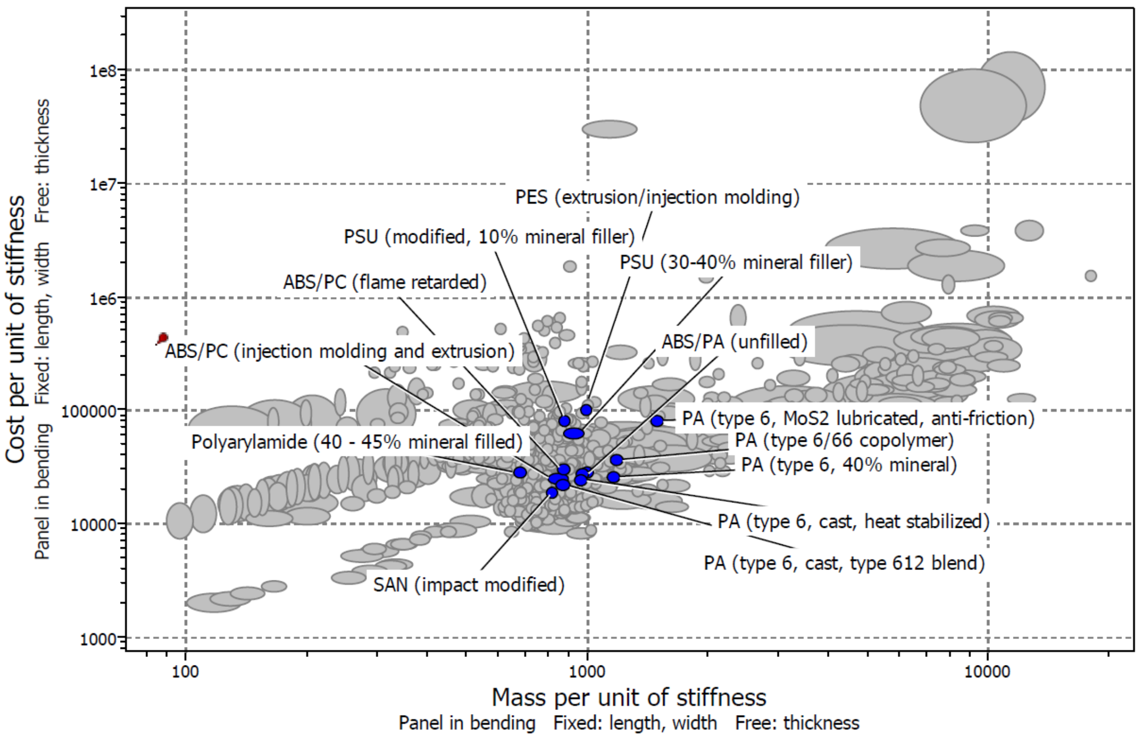


Figure 70 - Cost vs Mass Material selection plot for handset frames and battery cover

Table.7 shows qualified list of materials ranked by their cost. Out of 810 materials from the polymer database, the following are the material that qualifies after the limits were set.

Rank	Material	Cost per unit of stiffness
1	SAN (impact modified)	1.79e4 - 1.98e4
2	PA (type 6, cast, type 612 blend)	2.09e4 - 2.34e4
3	PA (type 6, cast, heat stabilized)	2.32e4 - 2.6e4
4	ABS/PC (injection molding and extrusion)	2.38e4 - 2.75e4
5	PA (type 6, 40% mineral)	2.45e4 - 2.74e4
6	ABS/PA (unfilled)	2.57e4 - 2.88e4
7	Polyarylamide (40 - 45% mineral filled)	2.68e4 - 3.07e4
8	PA (type 6, cast, plasticized)	2.73e4 - 3.07e4
9	ABS/PC (flame retarded)	2.86e4 - 3.21e4
10	PA (type 6/66 copolymer)	3.44e4 - 3.85e4
11	PSU (30-40% mineral filler)	5.83e4 - 6.89e4
12	PSU (modified, 10% mineral filler)	7.54e4 - 8.62e4
13	PA (type 6, MoS2 lubricated, anti-friction)	7.62e4 - 8.53e4
14	PES (20% mineral filled)	9.46e4 - 1.11e5

Table 7 - Qualified materials for Frames and battery cover

The result shows ABS blends in the top three ranks. The flexible nature of ABS material when blended with PA, PC improves stiffness which is perfect for a handheld product. Polyamide (PA) qualifies as the second best material due to its high stiffness as well as molding friendliness. Other non-industry standard materials such as PES, Polyarylamide, PSU and SAN also qualifies giving a wide opportunity to try and test the material beforehand.

Further limits are applied to fine tune and find out the best material possible for the frames. The frames are subjected to severe loading condition during Ascom’s drop tests and thus hardness and impact strength play a major role. These two properties were taken and a graph was plotted with the polymer database along with the above limits. The plot below fig.71 shows the result. Interpreting the graph, materials that lie at the top right corner implying high hardness and impact strength are the best choice for the frames. PA and ABS/PA blends qualifies as the best choice for the frames.

Detailed CES report is included in the appendices for more details.

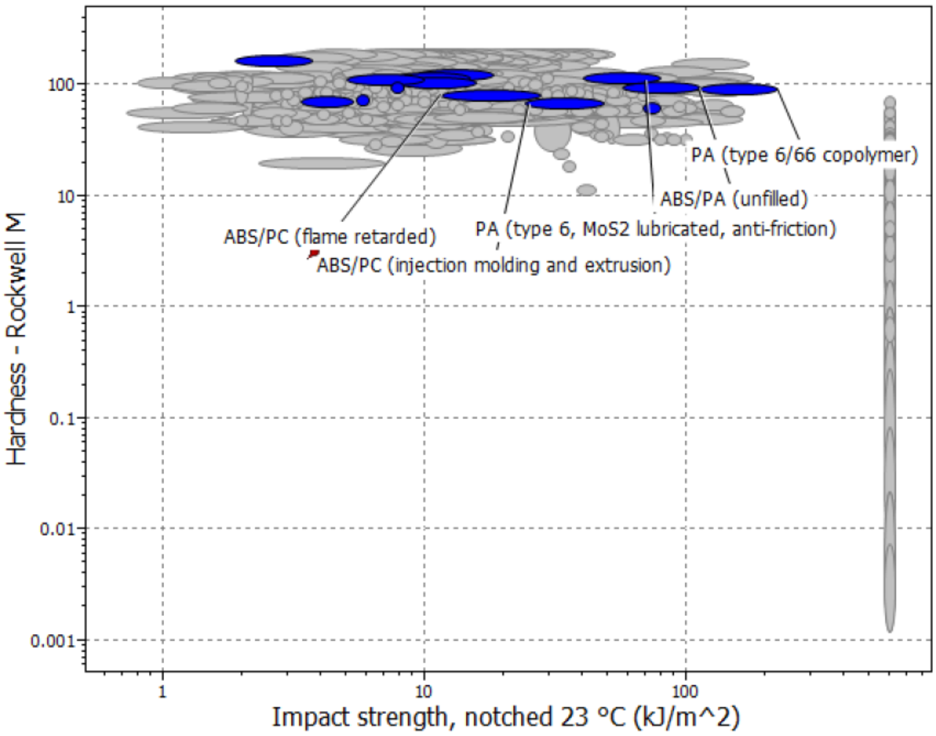


Figure 71 - Hardness vs Impact strength Material selection plot for handset frames and battery cover

7.2 FRAME SHEETMETAL

Figure 72 - Prototype metal components

The sheetmetal integrated in the main frame is an important component which highly contributes to the stiffness of the handset. Common limits such as, compatible with injection molding plastics, resistance against corrosion and water, Toxicity ratings are set. More detailed selection report from CES is included in the appendices.

Mass per unit of stiffness and cost per unit of stiffness are set as X and Y axis respectively as previously discussed in the plastic selection for frames above. The plot fig.73 shows the results of the selection after applying the limits.

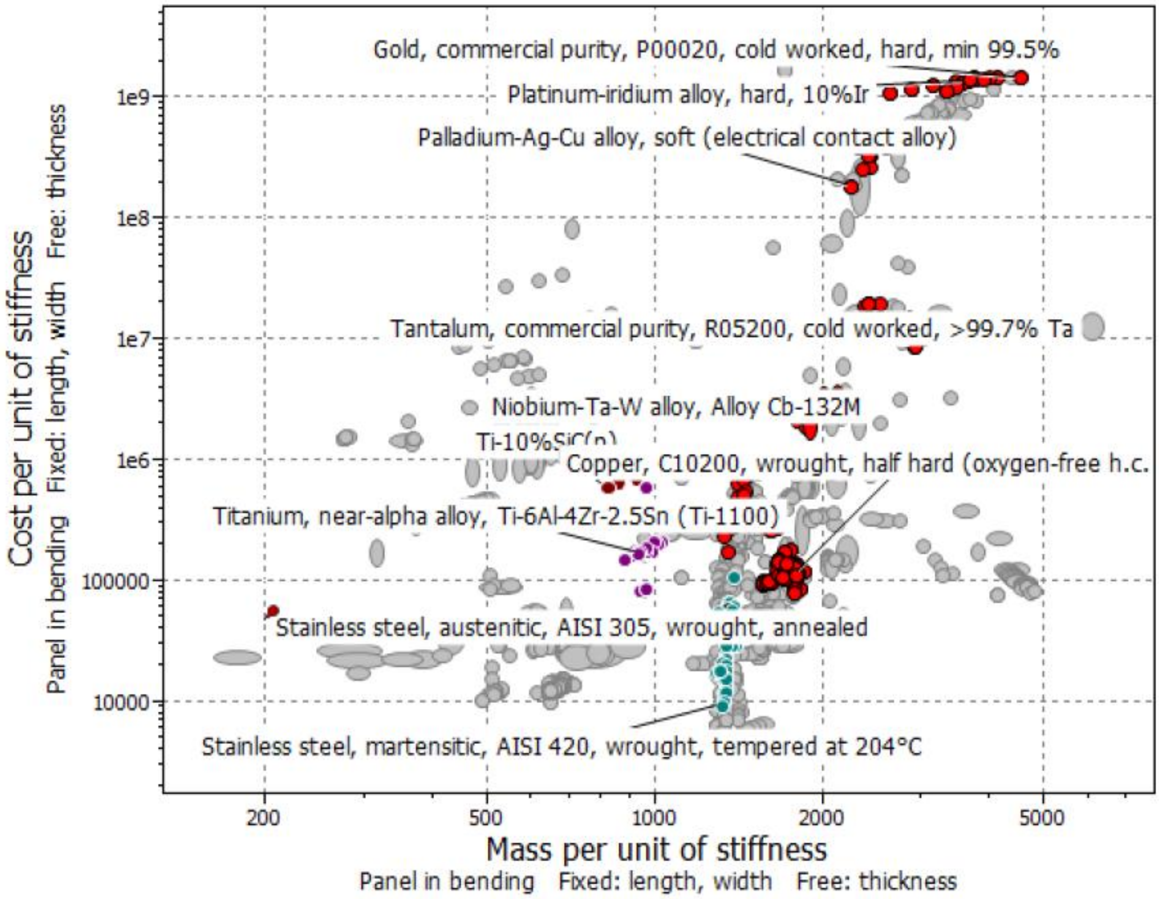


Figure 73 - Cost vs Mass Material selection plot for handset metal components

The results show the possible candidate materials in a wide scale of cost. Although a wise decision can be made based on cost, the qualified few, still need further filtering criteria properties such as hardness and youngs modulus for stiffness. The plot fig.74 shows the above said properties and compliments cost and mass per unit of stiffness for better decision making for materials.

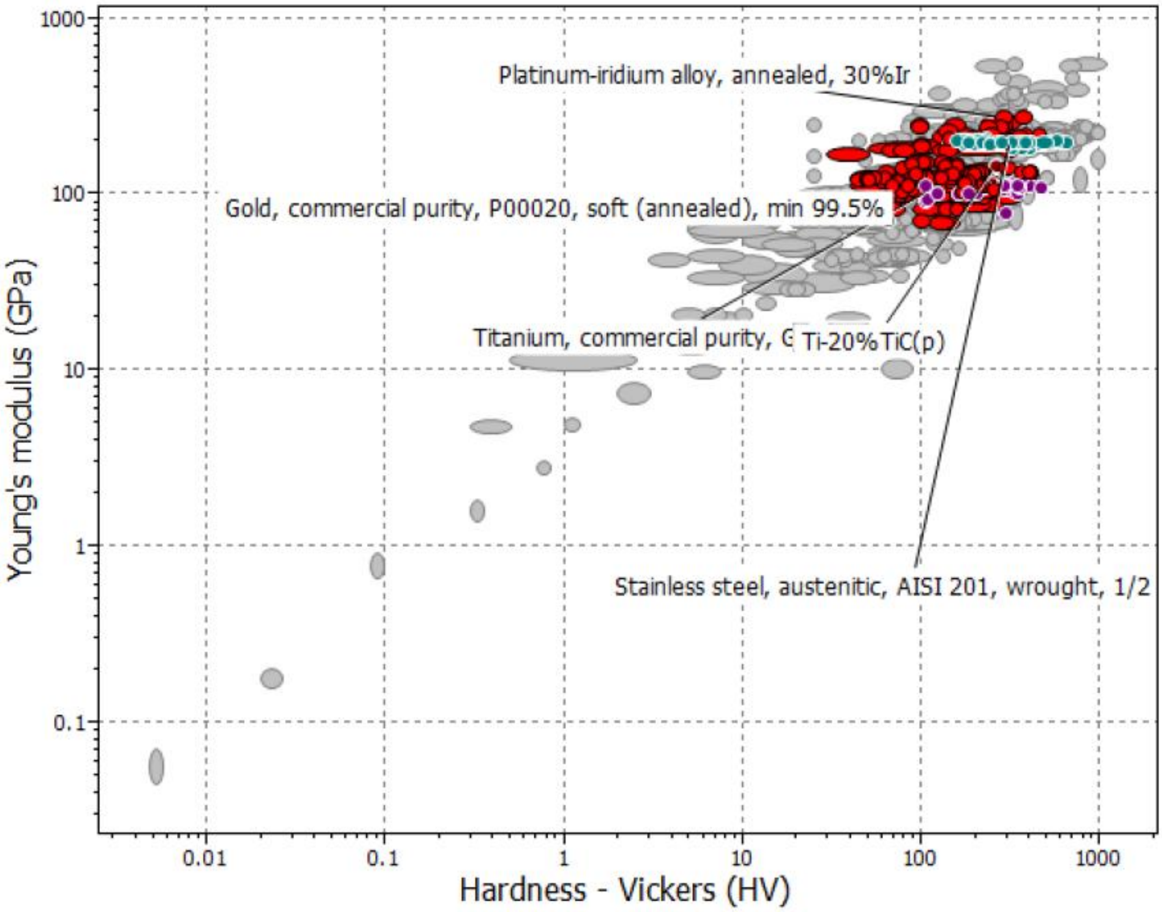


Figure 74 - Stiffness vs Hardness Material selection plot for Handset metal components

The table.8 shows the list of material that are among the qualified list. Gold and platinum can be ignored due to its cost. The stainless steel clearly comes out as the best choice for the sheetmetal frame.

Rank	Material	Cost per unit of stiffness
1	Stainless steel materials	lowest 8.89e3 - 9.84e3
2	Titanium materials	lowest 8.18e4 - 9.02e4

Table 8 - Qualified materials for Frame sheetmetal

7.3 WINDOW

Figure 75 - Prototype Window

Material selection for the window unlike the other components should be considered with different aspect such as impact force. The primary function is to protect the LCD module below it. Similar to other components, cost and mass per unit of stiffness is taken in the X and Y axis. Commons limits were set such as recyclability, manufacturing limits and shape. An important characteristic of window is to be transparent in nature to let the light pass through and it has been included in the limits.

The plot see fig.76 shows the cost vs mass per unit of stiffness.

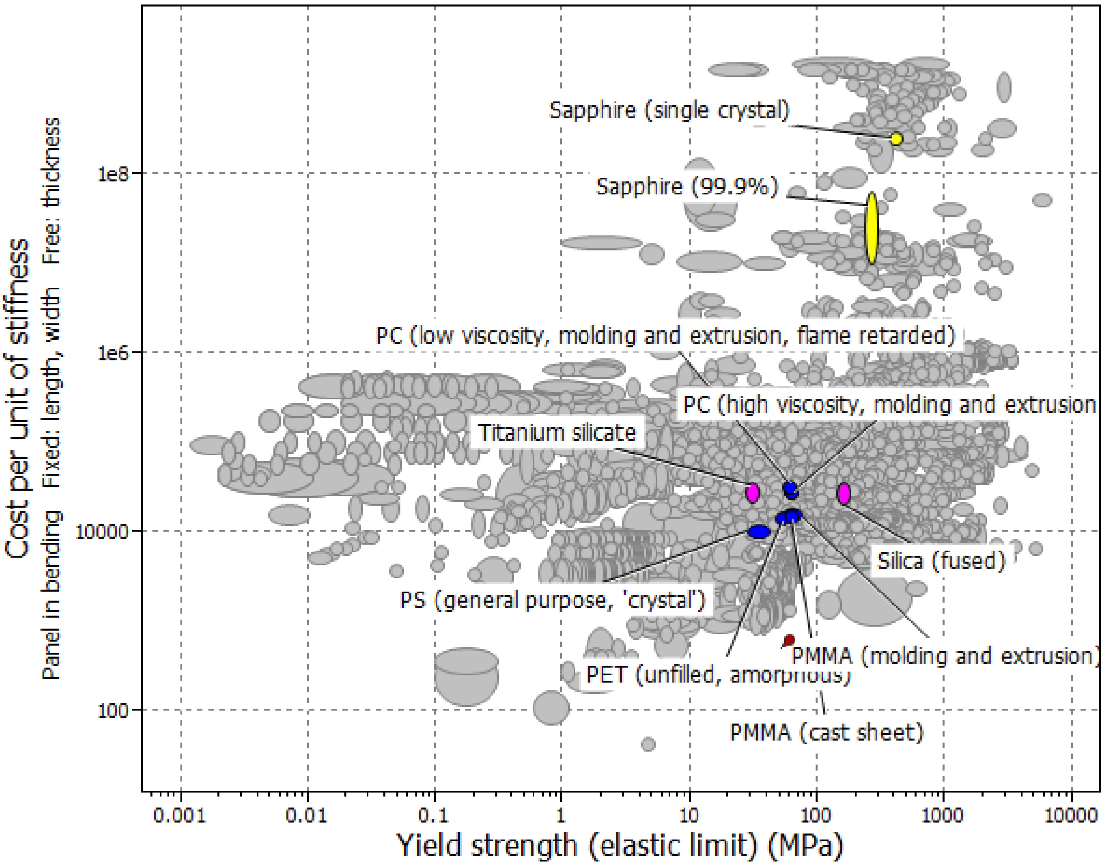


Figure 76 - Cost vs Mass per unit of stiffness plot for Handset window

The sapphire glasses which are non-recyclable are highlighted in the plot although it was not qualified due to its recyclability. This could be interesting to study if the product is aimed with high level of cosmetic appearance. The sapphire glasses are expensive at the same time and are used in watches and other high cost products.
Table.9 shows the list of qualified materials for window and is ranked by their cost.

Rank	Material	Cost per unit of stiffness
1	PS (general purpose, 'crystal')	9.46e3 - 1.07e4
2	PET (unfilled, amorphous)	1.34e4 - 1.55e4
3	PMMA (cast sheet)	1.41e4 - 1.56e4
4	PMMA (molding and extrusion)	1.45e4 - 1.68e4
5	Silica (fused)	2.06e4 - 3.44e4
6	Titanium silicate	2.12e4 - 3.54e4
7	PC (low viscosity, molding and extrusion)	2.6e4 - 2.87e4
8	PC (high viscosity, molding and extrusion)	2.6e4 - 2.87e4
9	PC (low viscosity, molding and extrusion, flame retarded)	2.95e4 - 3.25e4
10	Sapphire (99.9%)	1.03e7 - 6.15e7
11	Sapphire (single crystal)	2.41e8 - 2.58e8

Table 9 - Qualified materials for Window

From the qualified selection process, nine materials had passed the limits. Polycarbonate (PC) tops the rating at rank 1, PET and PMMA has taken the second and third positions. PMMA is a most common material used in most of the handsets today due to its impact strength and flexibility in molding process. A choice can be made between PC and PMMA according to the specific need of the project.

7.4 ATTACHMENT CLIP

The attachment clip secures to the rear side of the phone and makes it possible to wear the handset clipped to pants, belts and pockets etc. The material for this component has to be flexible to certain extent to withstand the sudden impact load that may occur during an accidental release.
Material index for elastic flexibility is plotted on Y axis against the cost of the material to evaluate the best material choice.

Elastic flexibility is given by, $\frac{\sigma_f}{\varepsilon_f}$ (3)

Where, σ_f is flexural strength expressed in MPa

ε_f is Flexural modulus expressed in GPa

Cost is expressed in SEK/kg

The plot fig.77 below shows the result of selection after common limits.

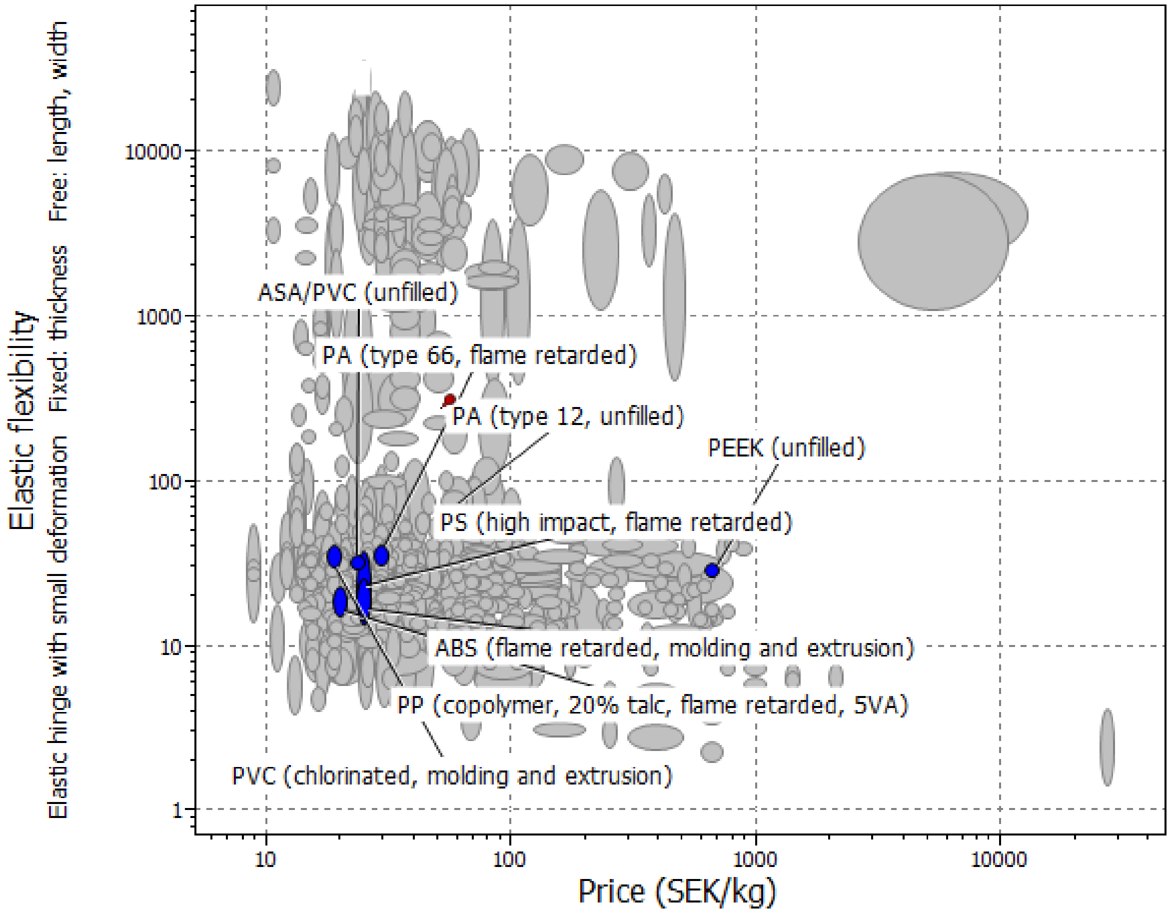


Figure 77 - Elastic flexibility vs cost Material selection plot for Attachment clip

Table.10 shows the qualified material for Attachment clip ranked by their cost.

Rank	Material	Price (SEK/kg)
1	PVC (rigid, molding and extrusion)	8.34 - 9.17
2	PVC-elastomer (Shore A75, flame retarded)	14.2 - 15.6
3	PVC (rigid, high impact, molding and extrusion)	14.8 - 16.2
4	PP (homopolymer, flame retarded V-0)	17.4 - 19.2
5	PVC (chlorinated, molding and extrusion)	17.7 - 19.5
6	PP (copolymer, 20% talc, flame retarded, 5VA)	19 - 20.9
7	ASA/PVC (unfilled)	22.2 - 24.4
8	PS (high impact, flame retarded)	23.5 - 25.9
9	ABS (flame retarded, molding and extrusion)	23.5 - 25.9
10	PA (type 66, flame retarded)	28 - 30.8
11	PC (low viscosity, molding and extrusion, flame retarded)	32.9 - 36.2
12	PEI (unfilled)	111 - 123
13	ETFE (unfilled)	168 - 241
14	PEEK (unfilled)	627 - 689

Table 10 - Qualified material for Attachment clip

ABS is given the top position in the results due to its high youngs modulus. PVC/ASA and PA takes the second and third position. Other interesting materials such as PEEK, Polypropelene and HIPS (High impact polystyrene) are suggested which can be considered based on cost involved for this component.

7.5 SEALING GASKET

Sealing gaskets are used in some of the Ascom phones to seal the gap between top and bottom frames and also to provide grip while holding the phone in hand. The material for this should withstand long service life and should be resistant against chemicals such as weak acids and alkalis. These types of limits were included in the plot. The plot contains tear strength in Y axis against cost of the material listed in X axis.

Maximum conformability index is given by, $\frac{\sigma_f^{\frac{3}{2}}}{\varepsilon}$ (3)

Where, σ_f is flexural strength expressed in MPa

ε is youngs modulus expressed in GPa

Cost of material is expressed in SEK/kg

The result of the plot is shown as below in fig.78

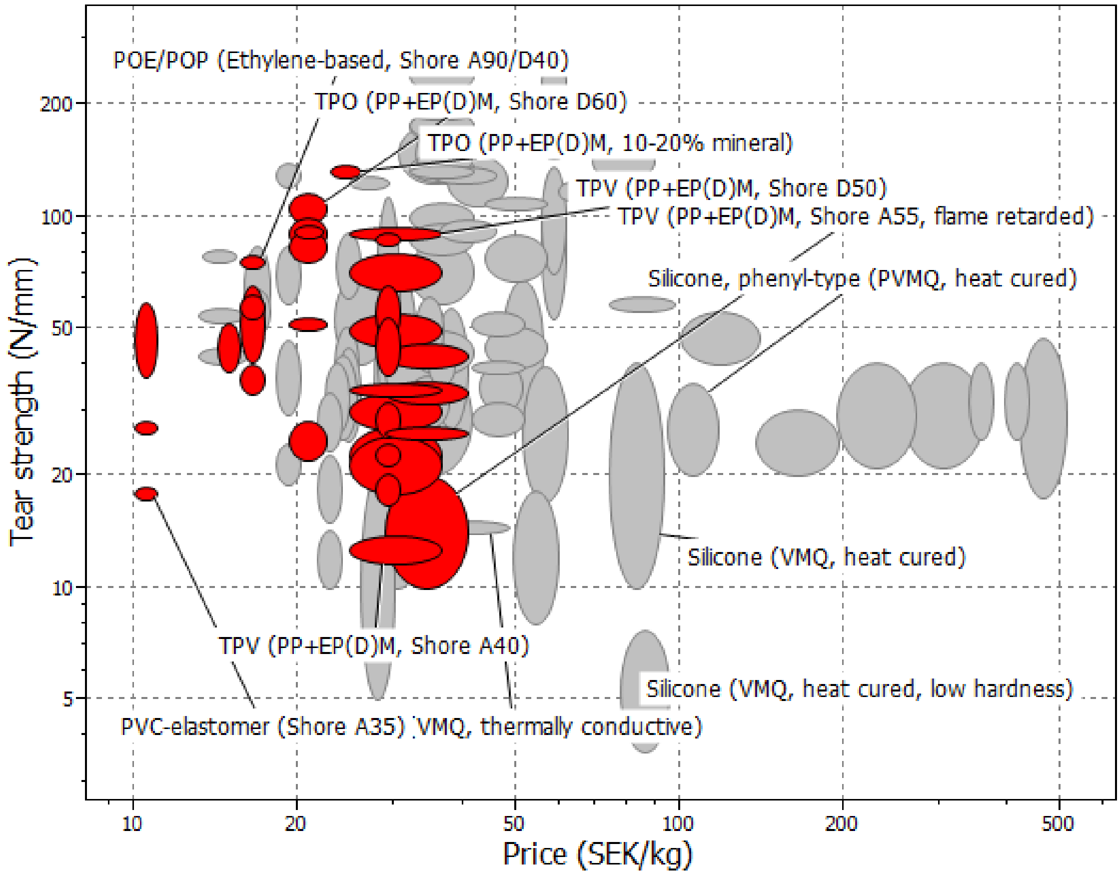


Figure 78 – Tear strength vs Cost material selection plot for sealing gasket

There are a number of materials which pass the criteria and a choice can be made based on cost. The table.11 shows the family of materials that are the best choice for sealing material.

Rank	Material	Price (SEK/kg)
1	PVC-elastomer (Shore A75)	10.1 - 11
2	POE/POP (Propylene-based, Shore A80)	15.7 - 17.3
3	TPO (PP+EP(D)M, Shore D60)	19.3 - 22.4
4	TPV (PP+NBR, Shore A90/D40)	24.9 - 36.5
5	SEBS (Shore A50)	27.7 - 30.5
6	TPV (PP+EP(D)M, Shore A85, flame retarded)	29.1 - 40.7

Table 11 - Qualified materials for sealing gaskets

7.6 SELECTION CHARTS

The selection chart is a custom defined method to objectively verify and compare the new concept cross section against the existing products. The idea is devised by Mr. Robert Holmberg, mechanical design manager at Ascom Wireless Solutions.

THEORY

A handset cross section can be assumed to be a hollow rectangular cross section as shown in fig.79

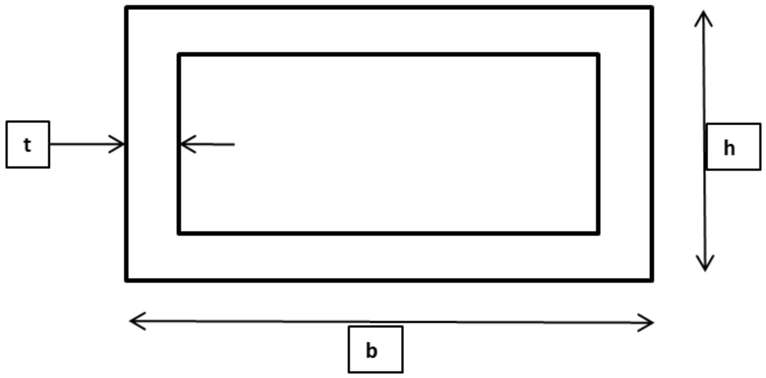


Figure 79 - Hollow rectangular cross section

Second moment of area $Imax$ for a hollow rectangular cross section is given by,

$$\frac{1}{6}h^3t\left(1+3\frac{b}{h}\right) \quad (2)$$

Where, h is the thickness of the cross section expressed in mm
b is the width of the cross section expressed in mm
t is the wall thickness of cross section expressed in mm

Let us assume a handset with a cross section with below values.
b = 50mm; h = 25mm; t = 1mm

With the above equation, the $Imax$ is 18229.17mm^4

If the thickness (h) is reduced to 15mm, $Imax$ becomes 6187.5mm^4

There is approximately 66% difference between the two values for a reduction of 10mm. i.e. the cross section becomes 66% weaker for a 10mm decrease in thickness.
The theory behind this is taken into consideration during the selection chart development.

The background for defining this method is to provide a scale to measure the robustness of the cross section against the existing products very early in the development stage. For this, the cross sectional area, second moment of area and material stiffness were needed to relate against each other.

Bending stiffness given by $E.Imax$ and cross sectional area A were plotted in graph.

Where E is the youngs modulus of the material expressed in N/m^2
$Imax$ is the second moment of area of the cross section expressed in m^4
A is the cross section area of the concepts expressed in m^2

The Ascom DH4 handset is the mid-range phone that addresses the need of low end as well as high end customers and so is taken as reference value to compare the new concept cross sections. The cross section details of the DH4 is obtained from ProEngineer CAD system and plotted in the graph.
The second step is proceeded by plotting various points in the graph with different material properties and same cross section details from the DH4 handset. The materials chosen were,

1. ABS
2. ABS with 40% Glass fiber
3. PA
4. PC
5. PC with 50% Glass fiber
6. PC/ABS
7. PEEK
8. PP with 50% Glass fiber

The above materials were chosen based on the experience of the design team with the materials that are widely used in handset manufacturing industries. The cross section can be assumed as rectangular hollow sections with different breadth and height values. The existing product from Ascom has a width (52mm) to height (25mm) ratio of “2”. The future thinner cross section ratio can be expected to be approximately “3” since the height will be reduced from 25mm to 15 to 18mm with the same width as 50mm.

With the above details the graph was plotted and saved as templates for future use. Five different templates were created with the cross section ratio as shown in the table.12

Width =	**52**	**Ratio**
Different thickness	25	2,1
	22	2,4
	20	2,6
	18	2,9
	16	3,3

Table 12 - Different cross section ratios

The above ratio was assumed with a fixed width of 52mm referred from existing Ascom handsets and varying the height values from 15mm to 20mm.
During the future development project a suitable template can be chosen based on its ratio between breadth and height and can be plotted in this graph with its own cross section and assumed material properties to objectively verify the robustness of the design. The advantage of this graph is, the new concept cross sections can be verified against the existing products very early in the design stage simultaneously i.e. even before developing a prototype. By verifying the cross section against the scale, the designer will be able to modify the cross section and increase the robustness if needed in the design phase itself their by preventing future failures.

The selection charts complements the material selection process and involves cross section details also into the system. Selection chart as of now is a prototype model that could be developed further in future that includes various material properties.
The three concepts that are developed have a cross section ratio of “3”. The fig.80, 81 & 82 shows the concepts plotted in the selection chart template with ratio 3.

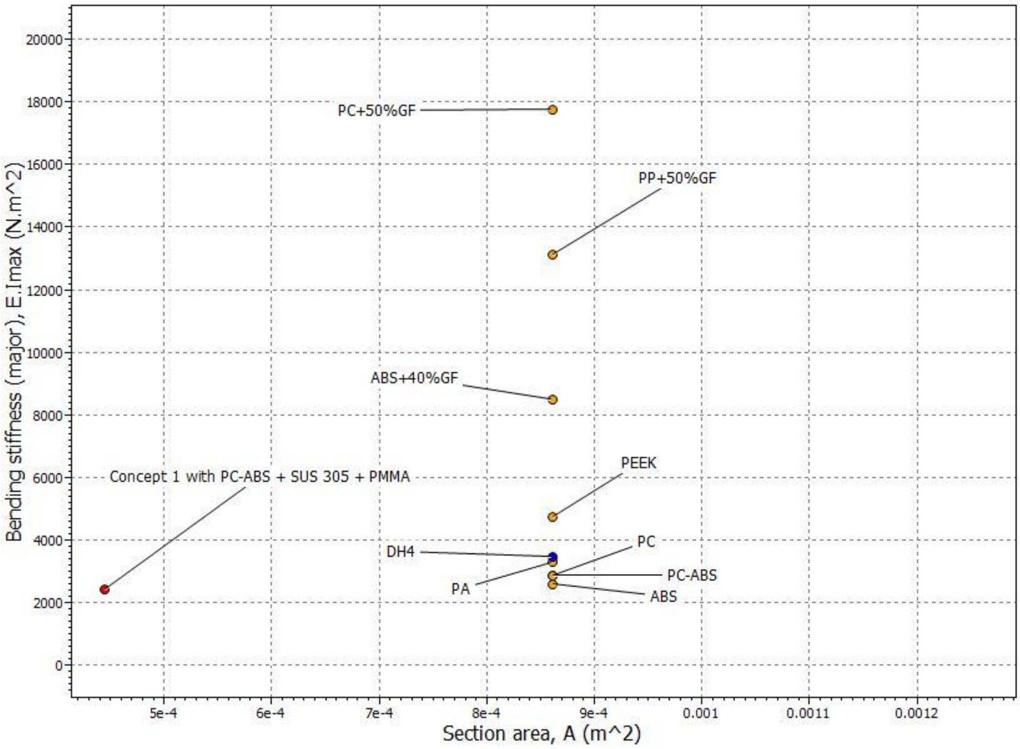


Figure 80 - Concept 1 - Rainy plotted against different materials with DH4 cross section area

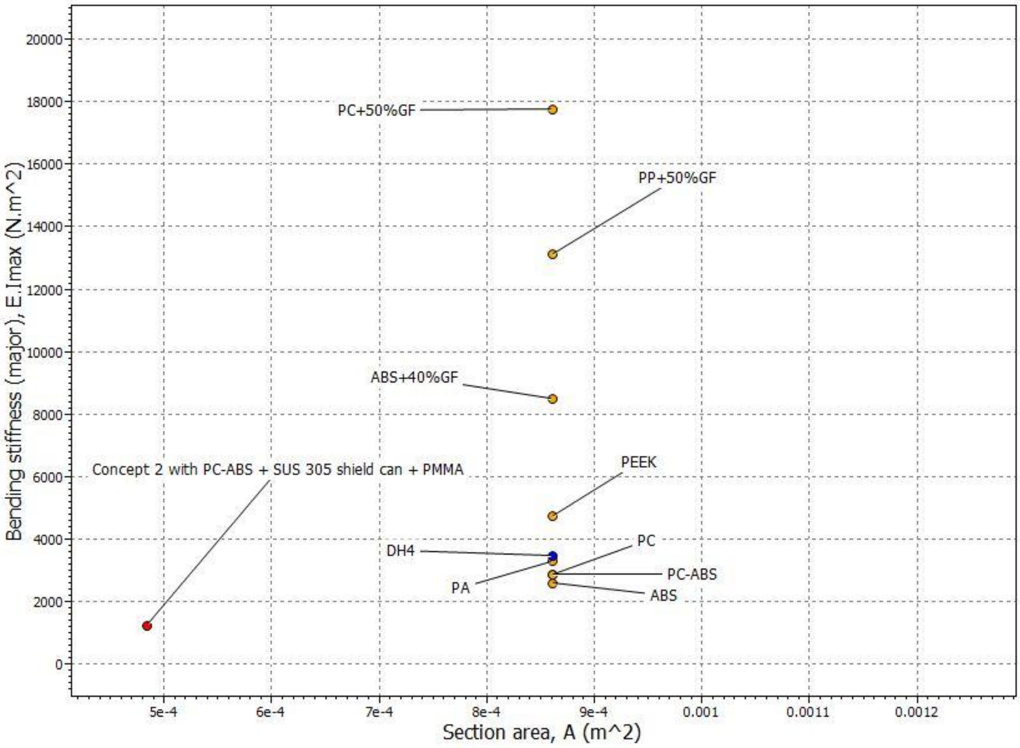


Fig ure 81 - Concept 2 - Foggy+Snowy plotted against different materials with DH4 cross section area

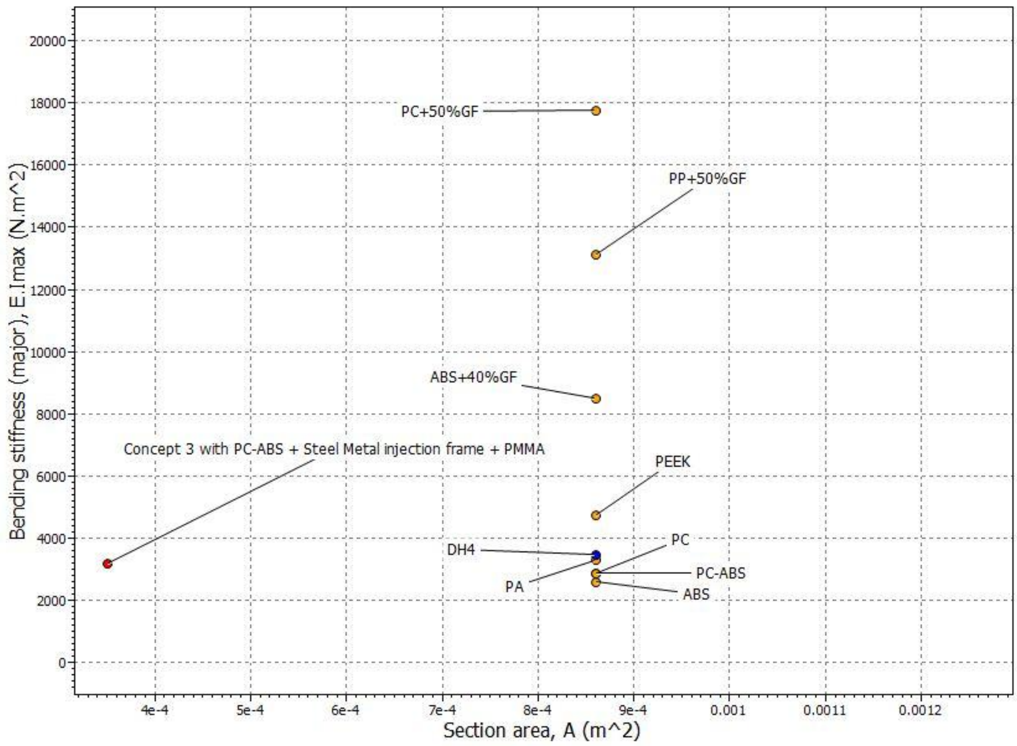


Figure 82 - Concept 3 - Windy+Mechy plotted against different materials with DH4 cross section area

All the three concepts show a considerable stiffness that is almost equal to existing products. Although the concepts have much smaller cross section, it is compensated by its hybrid structure and hybrid materials. This is an additional validation that supports the prototype test results for this project. In future development projects the new concepts can be plotted as shown above and validated for its robustness in design.

Torsional moment of inertia for a hollow rectangular cross section is given by,

$$\frac{2tb^2h^2}{(h+b)}(1-\frac{t}{h})^4 \quad (2)$$

For analyzing the torsional limits on a handset, similar type of graphs were developed with torsional stiffness plotted against cross section area. Due to lack of cross section information from ProEngineer, the plots were not able to be realized with in the time limit. This could be considered as a possible future work for this project.

8 CONCLUSIONS

This project has analyzed the possibilities of the structural design of a handset that is thinner and stronger than the existing handsets. The structured way of working methodology has provided three different mechanical concepts that can be carried forward for further development. The conclusions from the project are:

1. Product development methods used in the project such as, Function tree model, morphological matrix, concept synergy method and material selection process provided precise results. These methods could be considered in the future development projects to save time and cost by increasing the quality of data early in the project.
2. Requirements for the projects are taken from three different sources. By benchmarking the competitors’ products, best practices were captured. Team members experience with the handset was added as new requirements as the project aims to make a thin phone than the existing product. Information from the reliability document was included. The combination of all has resulted in a Function tree model that captures all the main functions and sub function along with the detailed requirements.
3. The 3-point bending test and torsional test were new test methods that are defined to check the stiffness of the thinner handsets. Although the torsional test method is a prototype, it could be further developed with more accurate machines to have precise results. Both these tests can be added in the testing process for future thin handsets.
4. The material selection process has highlighted the need for switching the existing materials to stiffer materials such as hybrids. ABS/PC, ABS/PA etc, are some of the possible material that meets the needs of a thinner handset.
5. In theory smaller cross sections are comparatively weaker than the thicker handsets due to differences in cross section size. This can be compensated with better materials as discussed above at the same time with better architecture that can with stand loads. Clever distribution of given volume of material plays vital role here. I-shape and C-shape cross sections are better in with standing severe bending and twisting loads. Hybrid structures such as sheetmetal-plastic (overmolding) and metal frame fastened with plastic covers provide a more rigid structure compared to plastic only frames.
6. The concept Windy and Mechy has analyzed the possibilities of using a smaller PCB to make the handset more compact. FPC gives flexibility to the design and could be implemented to take advantage of volume space in a more effective way.
7. The developed prototypes from the concepts have provided valuable test results that show improvement in the stiffness and strength thus setting up a path for future handset architecture. Although the concepts were not up to manufacturing standards and were intended be simple, it has given a clear understanding of different structural architectures, cross sections and materials.

9 DISCUSSION

All the major handset manufacturers face the need for an upgrade and redesign of their existing handsets at certain time intervals and this project has evaluated the preliminary work for mechanical design of the handset.

The new proposed testing methods, 3-point bending and torsional test are developed as a concept prototype and could be further developed to match the needs of the new handsets. More accurate machines for the torsional test process are need for accurate results but the method could be carried forward from the concept test methods. The load levels of the test are set high on this project and thus needs consideration for future implementation.

New hybrid materials are required to meet the demands of the future thinner handsets. The material selection procedure followed in the project can be further enhanced by setting more precise limits according to the needs of specific projects. The use of CES program and the methods developed by MF Ashby are highly recommended for an objective material selection. Although the materials that are proposed in this project are higher in cost in some cases, a balance between the stiffness level and cost has to be decided by the project team during future development. Also the use of hybrid materials is recommended in order to achieve higher stiffness levels.

The concepts and prototype test results have provided valuable insights about different architectural designs and highlight the need for switching to a hybrid structure for future design. Although the cost of manufacturing hybrid structures are comparatively higher when compared to the existing manufacturing process followed now, it could provide with a better handset stiffness and strength that meets the demand in future. Further cost model could be developed with more accurate cost details to investigate the profit in return to the investment.

Hardware PCB design proposed by one of the concept shows the possibilities of building a compact handset by using half size PCB although it might be lot more work for hardware designers. This design can be considered and further investigated from a hardware perspective for the pros and cons.

10 FURTHER WORK

Some of the recommendations are listed below that might be considered as future work for this project.

1. The project as dealt with mechanical design and its associated structural strength. The hardware design is considered in a much broader level such as placement of components and PCB size and shape. Thus, a more detailed hardware design investigation should be conducted that includes, half size PCB design, PCB routing, antenna placement and audio tuning.
2. The mechanical concepts proposed by the project are intended to be simple and thus excludes detailed mechanical design which is compatible with the manufacturing processes. In case of implementation of the one the concepts in the future, a more detailed mechanical design of each component has to be carried out for actual production. The concepts could be taken as a foundation for different structural built up.
3. Within the limited time frame of the project, three different concepts and suitable materials were proposed. There could be more possible materials and hybrid structures that could be investigated according to the requirements of specific projects in future.
4. The function tree model is developed to capture the requirements of the mechanical design for a handset. The scope of the model can be further expanded to include hardware (electronics) and software requirements. The function tree model thus has the potential to evolve as functional product model capturing all the requirements of the handset.
5. Selection charts are defined to analyze the bending stiffness values against the cross sections. Torsional stiffness which analyzes the torsional load that act on the handset could not be realized. This is due to lack of data for DH4 torsional moment of inertia from ProEngineer CAD system. This could be considered as a future work for this project.
6. A customer survey could be conducted to understand their perspective on the handsets to better define how much stiffness should be set apart from reliability requirements.

11 REFERENCES

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2. Michael F.Ashby (2011): Material selection in Mechanical design, fourth edition, Elsevier, Oxford, UK

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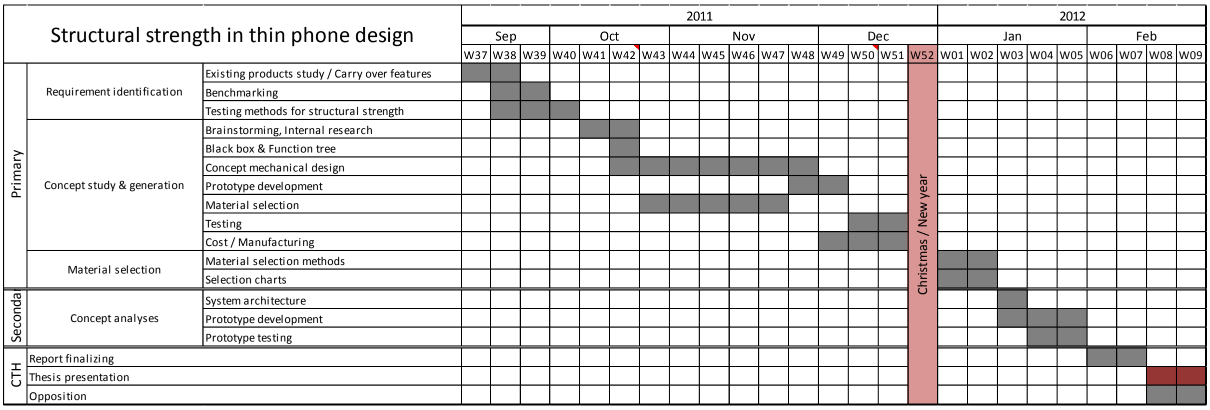
12 APPENDICES

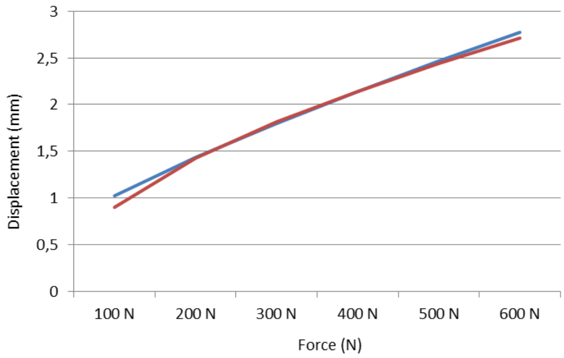
12.1 APPENDIX A - TIME PLAN

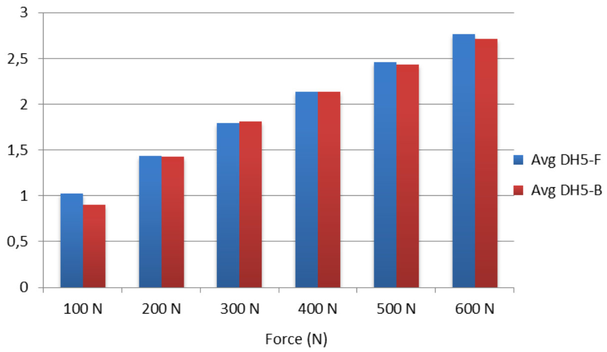
A time plan for the project is set in order to work effectively as possible.

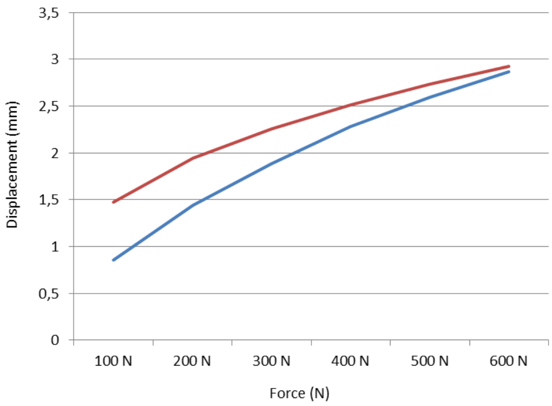


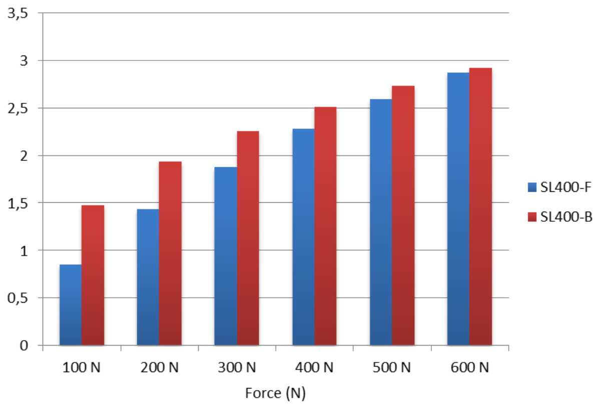
12.2 APPENDIX.B – TEST RESULTS

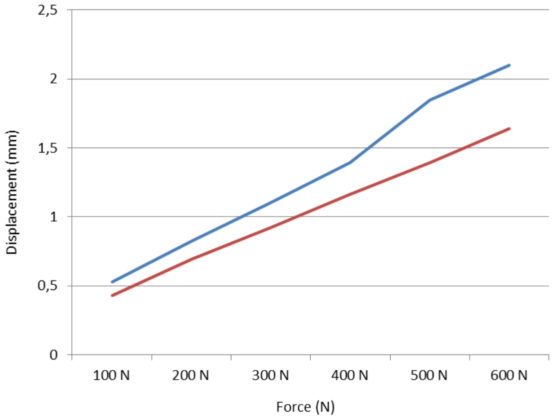
3-Point bending test result plots for Ascom DH5, Siemens SL400, Siemens SL78H

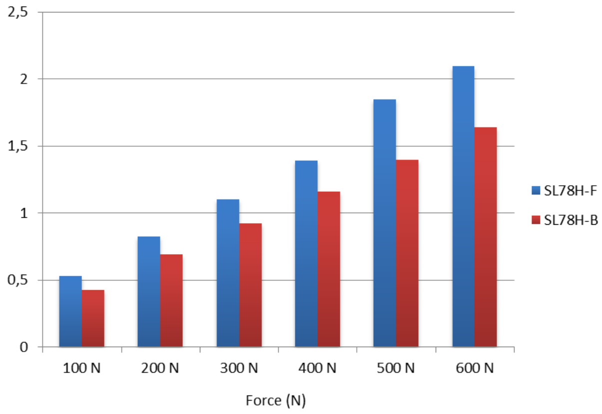












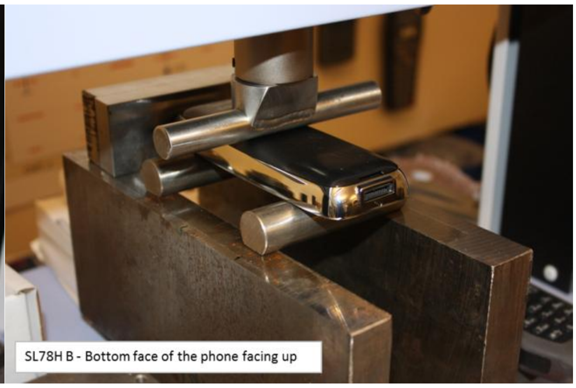

DH4 TOP F - Front face of the phone facing up


DH4 TOP B - Front face of the phone facing down

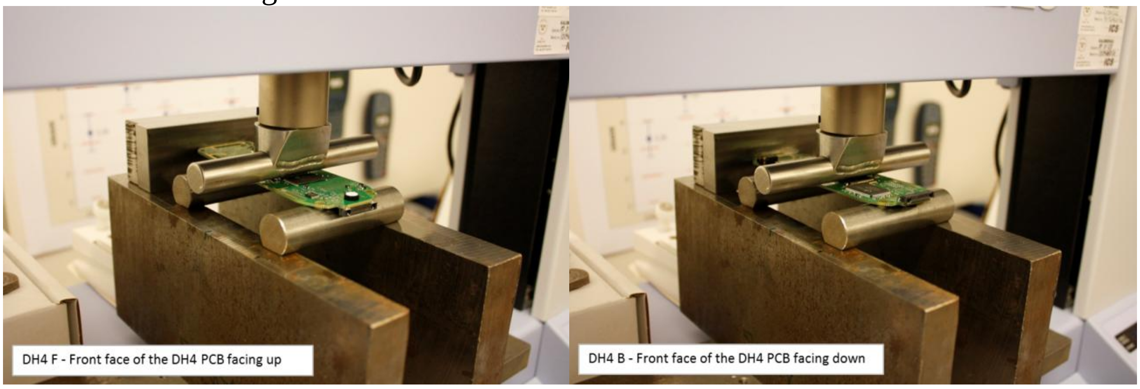

SL400 F - Front face of the phone facing up


SL400 B - Bottom face of the phone facing up


SL78H F - Front face of the phone facing up

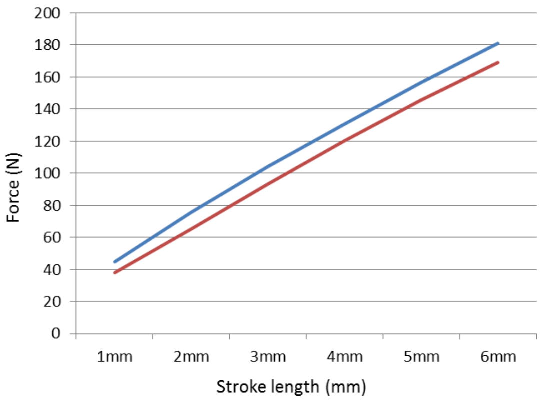

SL78H B - Bottom face of the phone facing up

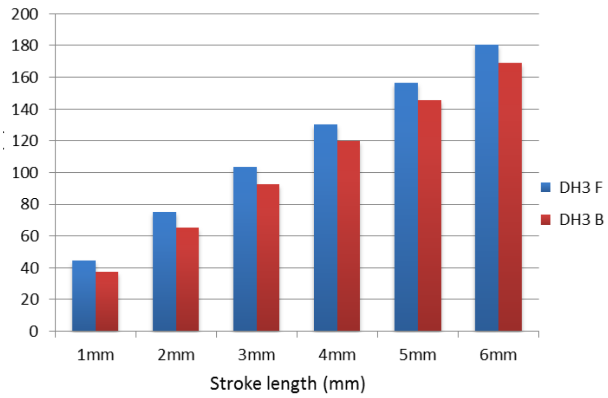
PCB 3-Point bending test

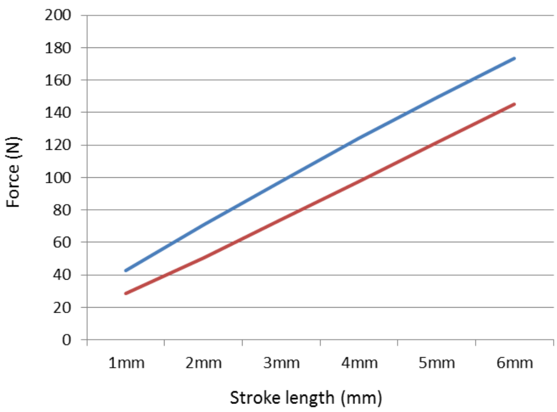


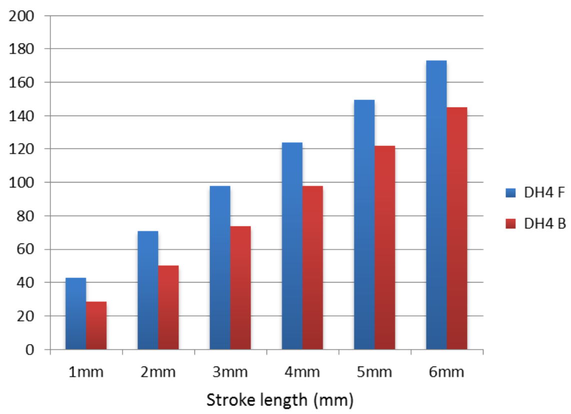
Name	Max_Force	Max_Stroke	Force at 1mm	Force at 2mm	Force at 3mm	Force at 4mm	Force at 5mm	Force at 6mm
Unit	N	mm	N	N	N	N	N	N
DH3 F	182,04	6,03	44,50	75,16	103,74	130,51	156,62	180,72
DH3 B	170,34	6,04	37,78	65,19	92,94	120,20	145,65	169,06
DH4 F	174,54	6,04	42,93	71,10	97,90	124,18	149,52	173,26
DH4 B	146,49	6,04	28,79	50,39	73,91	97,83	121,82	145,26
DH5 F	201,00	6,04	57,43	94,90	126,37	153,88	179,03	199,67
DH5 B	158,49	6,04	31,19	55,33	79,29	102,97	126,09	156,35

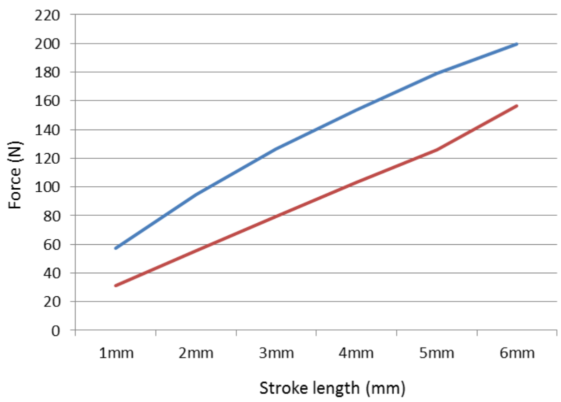
PCB 3-point bending results

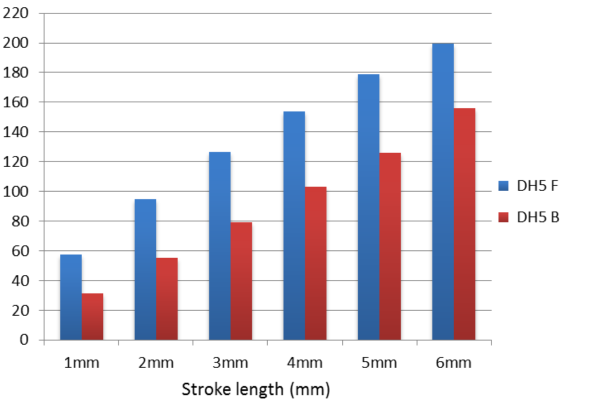










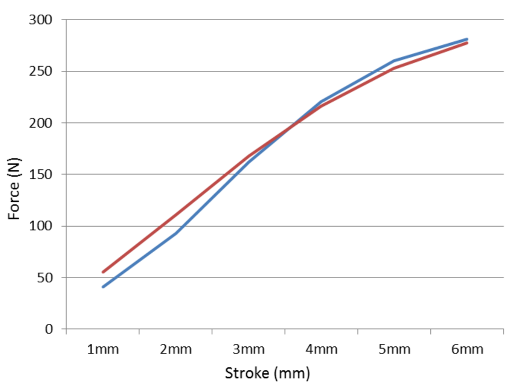


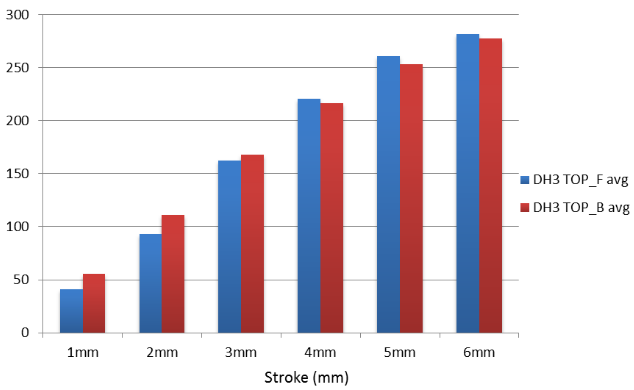
DH3 Parts 3-point bending results

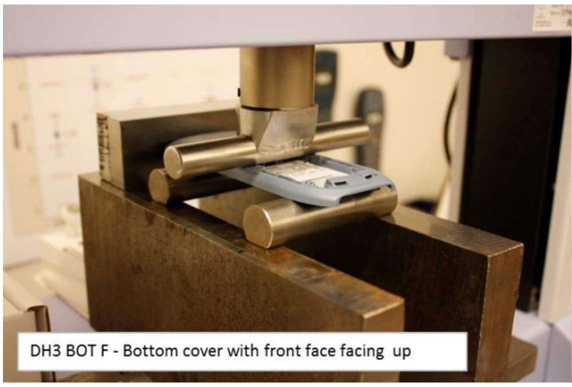
Name	Max_Force (N)	Max_Stroke (mm)	Force at 1mm	Force at 2mm	Force at 3mm	Force at 4mm	Force at 5mm	Force at 6mm
DH3 TOP1_F	283,11	6,04	40,99	93,38	162,36	221,26	261,43	282,58
DH3 TOP2_F	280,91	6,04	41,26	93,06	161,58	220,00	259,59	279,87
DH3 TOP_F avg	282,01	6,04	41,12	93,22	161,97	220,63	260,51	281,23
DH3 BOT1_F	166,34	6,04	43,15	74,32	102,86	127,90	149,04	165,58
DH3 BOT2_F	161,96	6,04	41,93	72,50	100,57	125,07	145,54	161,22
DH3 BOT_F avg	164,15	6,04	42,54	73,41	101,72	126,48	147,29	163,40
DH3 TOP1_B	278,26	6,04	55,00	110,70	167,67	216,43	253,11	277,30
DH3 TOP2_B	278,06	6,04	55,85	111,19	167,40	215,89	252,68	277,10
DH3 TOP_B avg	278,16	6,04	55,43	110,95	167,54	216,16	252,89	277,20
DH3 BOT1_B	171,14	6,04	38,66	66,07	95,35	123,33	149,49	170,25
DH3 BOT2_B	173,14	6,04	42,54	75,42	104,57	131,26	153,41	171,82
DH3 BOT_B avg	172,14	6,04	40,60	70,75	99,96	127,29	151,45	171,03

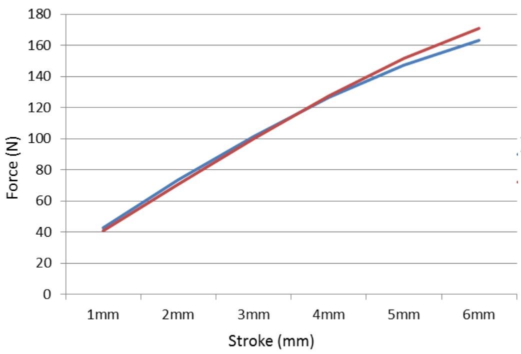

DH3 TOP F - Top cover with front face facing up

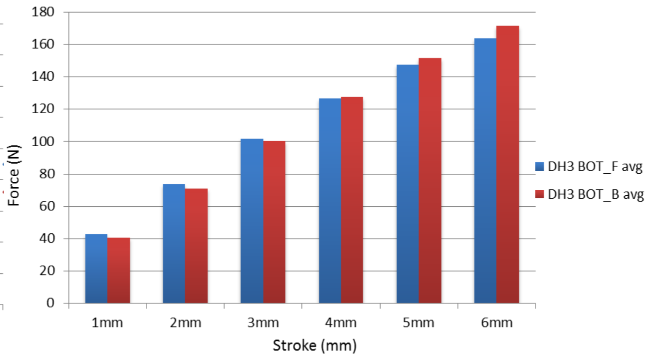

DH3 TOP B - Top cover with front face facing down







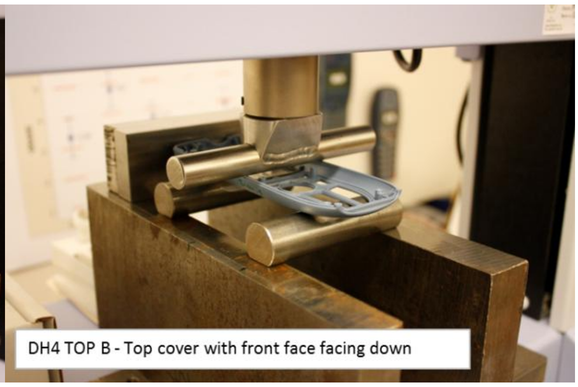


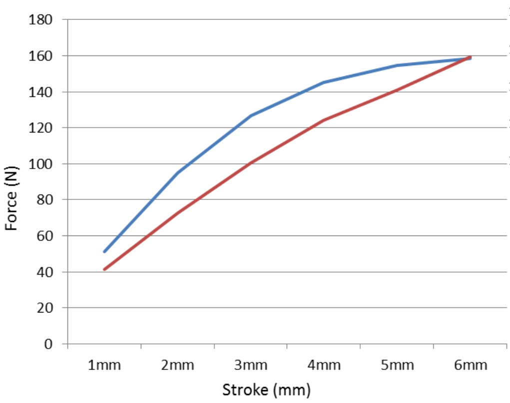


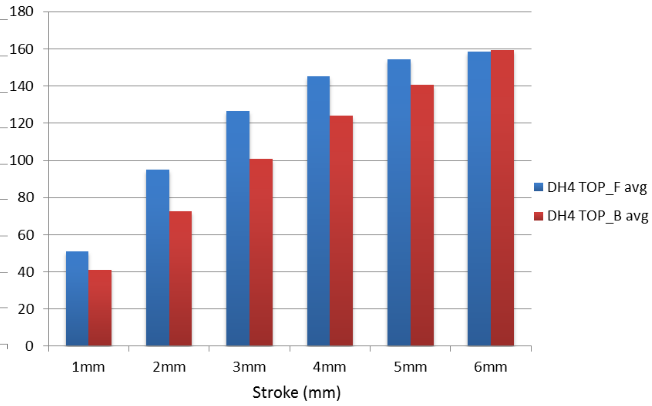
DH4 3-point bending test results

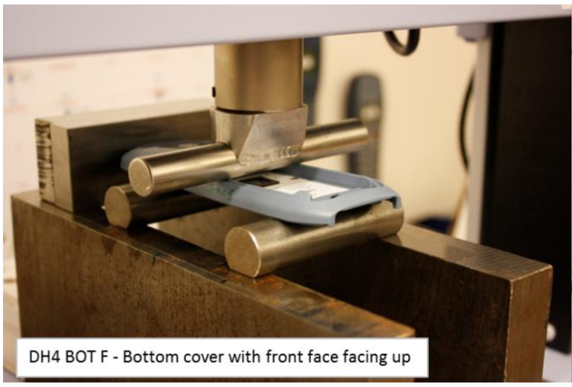
Name	Max_Force (N)	Max_Stroke (mm)	Force at 1mm	Force at 2mm	Force at 3mm	Force at 4mm	Force at 5mm	Force at 6mm
DH4 TOP1_F	159,54	6,04	51,02	95,54	127,44	146,26	155,57	159,43
DH4 TOP2_F	157,58	6,04	51,36	94,61	125,76	144,18	153,50	157,38
DH4 TOP_F avg	158,56	6,04	51,19	95,07	126,60	145,22	154,53	158,40
DH4 BOT1_F	263,49	6,04	43,82	99,15	150,85	196,62	233,31	262,06
DH4 BOT2_F	269,94	6,04	49,09	104,35	155,53	201,64	238,19	268,48
DH4 BOT_F avg	266,71	6,04	46,46	101,75	153,19	199,13	235,75	265,27
DH4 TOP1_B	160,79	6,04	41,68	73,03	101,22	124,63	139,93	159,46
DH4 TOP2_B	161,07	6,04	40,71	72,42	100,13	123,63	141,51	159,53
DH4 TOP_B avg	160,93	6,04	41,19	72,73	100,68	124,13	140,72	159,49
DH4 BOT1_B	258,98	6,04	57,82	102,96	149,12	192,63	229,01	257,61
DH4 BOT2_B	263,74	6,04	55,75	105,89	153,30	195,70	232,24	262,28
DH4 BOT_B avg	261,36	6,04	56,79	104,42	151,21	194,16	230,62	259,95
DH4 MID1_F	30,75	6,03	13,75	16,69	20,60	24,28	27,75	30,67
DH4 MID2_F	30,00	6,07	13,99	17,30	21,56	24,38	27,67	29,86
DH4 MID_F avg	30,38	6,05	13,87	16,99	21,08	24,33	27,71	30,27
DH4 MID1_B	28,34	6,04	14,14	18,11	21,69	24,80	26,97	28,31
DH4 MID2_B	28,37	6,03	13,92	17,79	21,40	24,40	26,91	28,35
DH4 MID_B avg	28,35	6,04	14,03	17,95	21,54	24,60	26,94	28,33


DH4 TOP F - Top cover with front face facing up

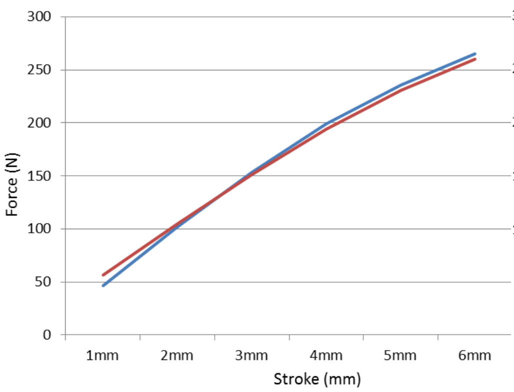

DH4 TOP B - Top cover with front face facing down

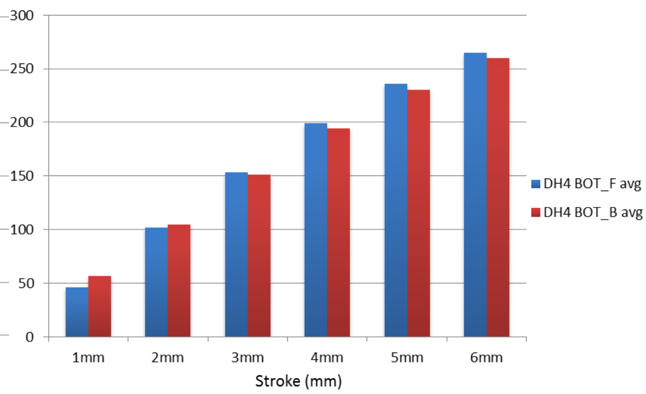

180
160
140
120
100
80
60
40
20
0
Force (N)
1mm
2mm
3mm
4mm
5mm
6mm
Stroke (mm)

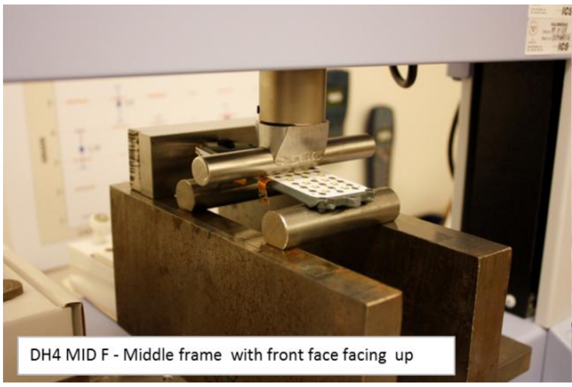

180
160
140
120
100
80
60
40
20
0
1mm
2mm
3mm
4mm
5mm
6mm
Stroke (mm)
DH4 TOP_F avg
DH4 TOP_B avg


DH4 BOT F - Bottom cover with front face facing up

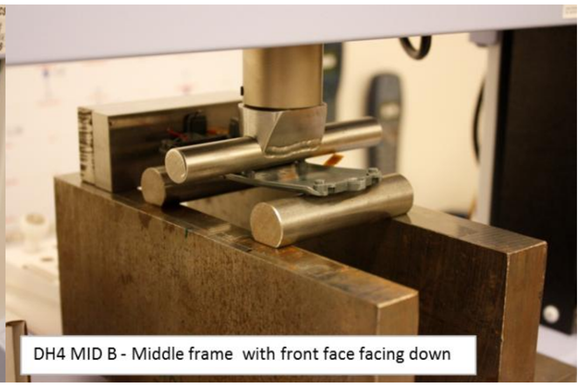

DH4 BOT B - Bottom cover with front face facing down


300
250
200
150
100
50
0
Force (N)
1mm
2mm
3mm
4mm
5mm
6mm
Stroke (mm)

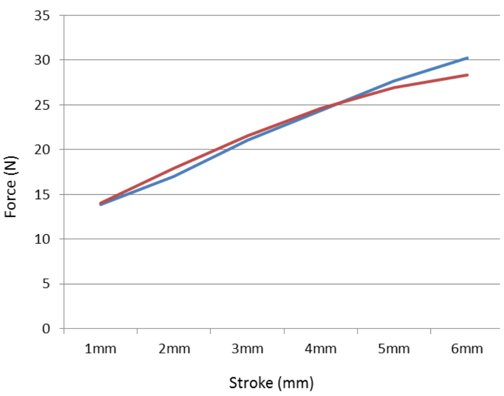

300
250
200
150
100
50
0
1mm
2mm
3mm
4mm
5mm
6mm
Stroke (mm)
DH4 BOT_F avg
DH4 BOT_B avg

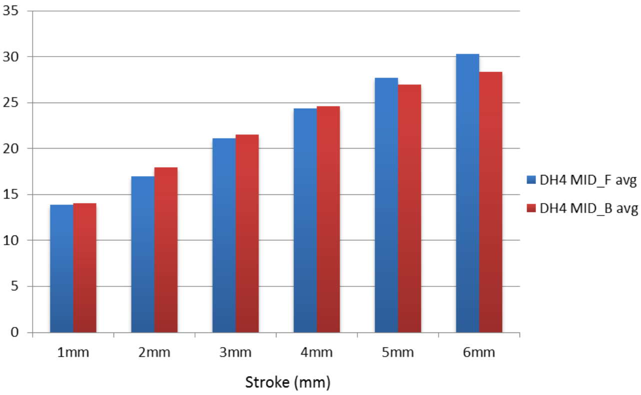


DH4 MID F - Middle frame with front face facing up



DH4 MID B - Middle frame with front face facing down

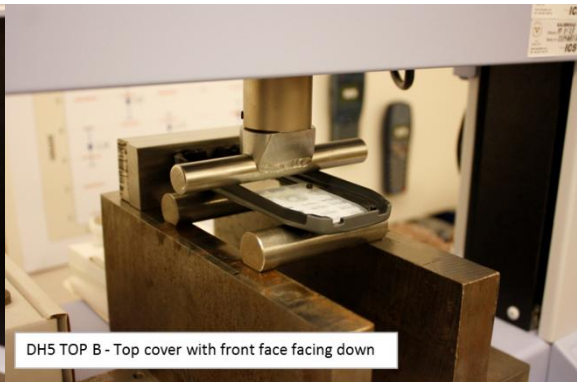




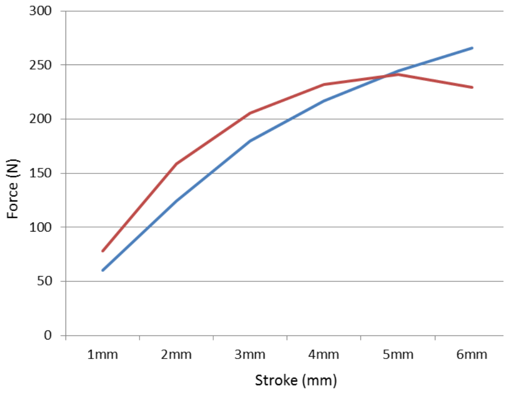
DH5 3-Point bending test results

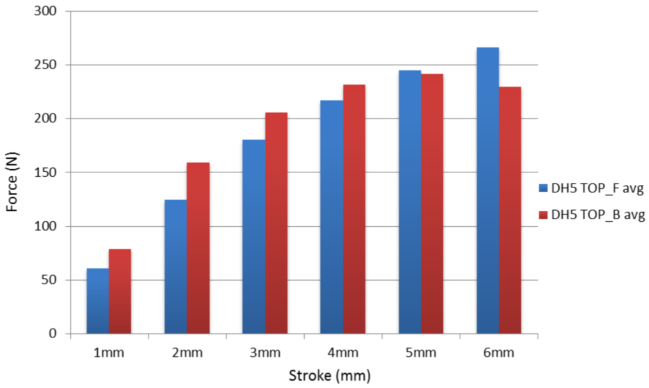
Name	Max_Force (N)	Max_Stroke (mm)	Force at 1mm	Force at 2mm	Force at 3mm	Force at 4mm	Force at 5mm	Force at 6mm
DH5 TOP1_F	267,08	6,04	59,82	123,82	179,92	217,48	245,18	265,65
DH5 TOP2_F	267,45	6,04	61,15	125,56	180,41	216,56	244,37	265,90
DH5 TOP_F avg	267,27	6,04	60,48	124,69	180,16	217,02	244,78	265,77
DH5 BOT1_F	368,92	6,04	44,24	110,41	182,61	252,16	314,24	366,22
DH5 BOT2_F	374,72	6,04	44,38	109,89	181,58	251,23	318,97	372,22
DH5 BOT_F avg	371,82	6,04	44,31	110,15	182,10	251,70	316,60	369,22
DH5 TOP1_B	236,10	5,01	78,27	162,90	207,07	229,24	236,00	228,08
DH5 TOP2_B	246,82	5,11	78,61	154,40	203,56	234,29	246,43	230,82
DH5 TOP_B avg	241,46	5,06	78,44	158,65	205,32	231,77	241,21	229,45
DH5 BOT1_B	331,94	6,04	68,90	132,06	190,97	240,67	283,92	329,69
DH5 BOT2_B	332,63	6,04	67,60	131,41	191,08	240,43	282,97	330,25
DH5 BOT_B avg	332,28	6,04	68,25	131,73	191,02	240,55	283,44	329,97
DH5 MID1_F	421,16	6,03	118,85	245,95	341,74	394,27	415,62	421,11
DH5 MID2_F	423,15	6,03	115,12	243,21	341,44	394,99	416,93	423,00
DH5 MID_F avg	422,15	6,03	116,98	244,58	341,59	394,63	416,27	422,05
DH5 MID1_B	295,92	6,04	75,70	136,84	202,56	248,48	280,44	295,85
DH5 MID2_B	296,40	6,03	75,40	138,19	203,80	249,77	281,95	296,36
DH5 MID_B avg	296,16	6,04	75,55	137,52	203,18	249,12	281,19	296,11

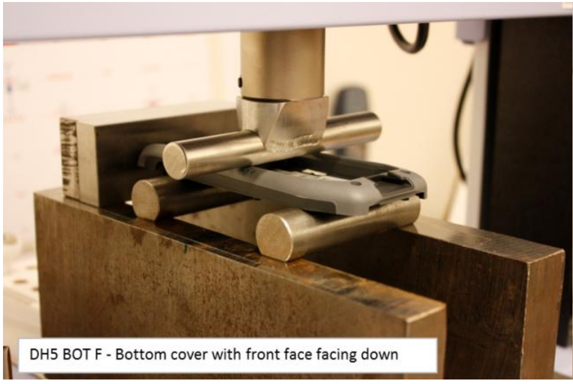
DH5 TOP F - Top cover with front face facing up



DH5 TOP B - Top cover with front face facing down

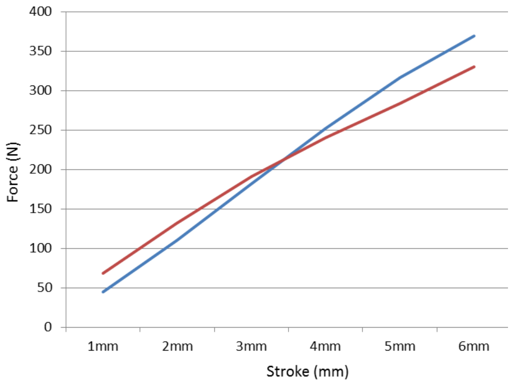


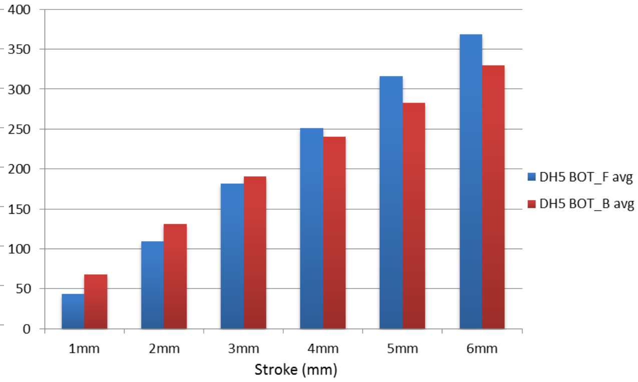


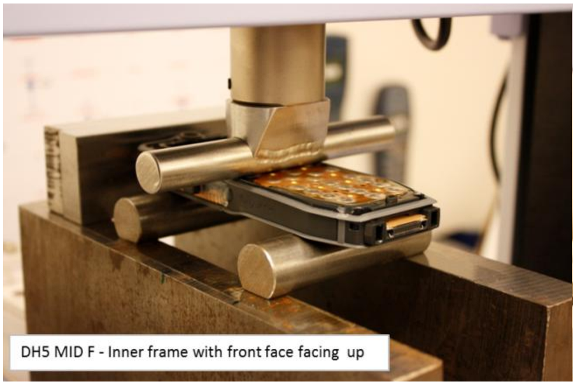


DH5 BOT F - Bottom cover with front face facing down

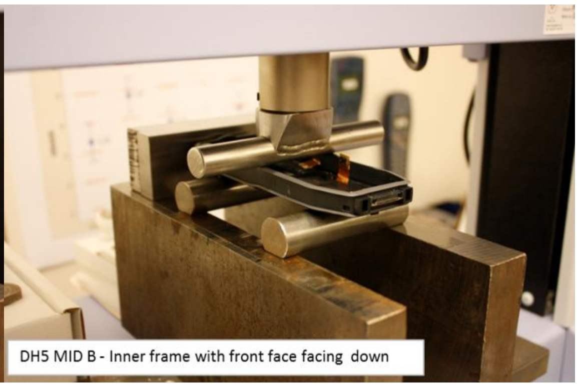
DH5 BOT B - Bottom cover with front face facing down



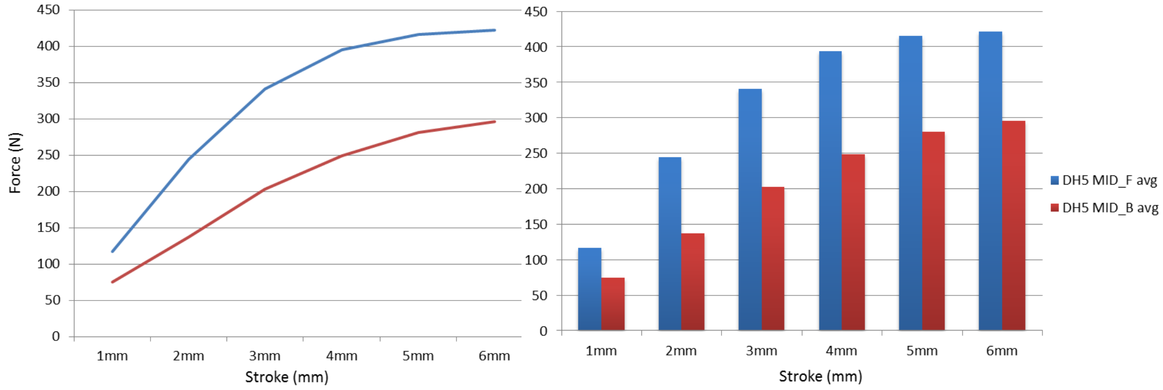




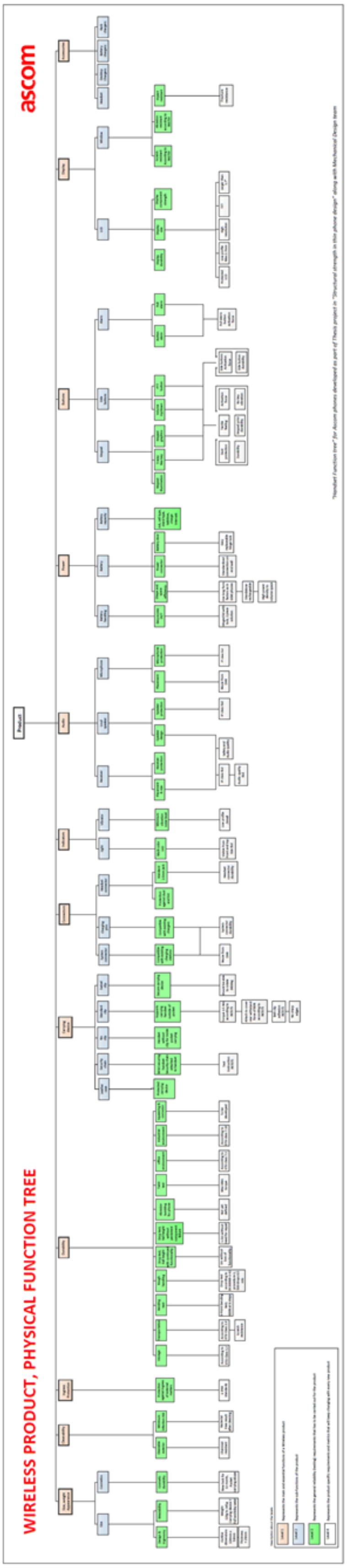
DH5 MID F - Inner frame with front face facing up

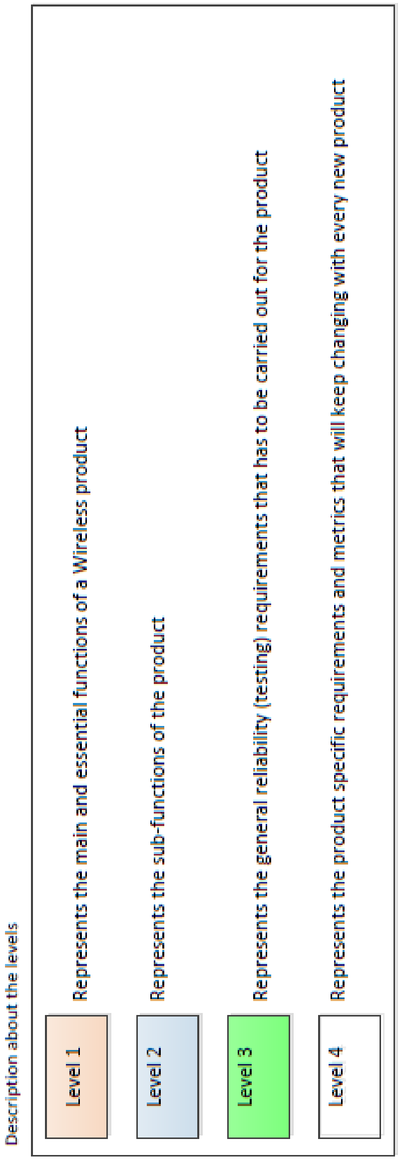


DH5 MID B - Inner frame with front face facing down

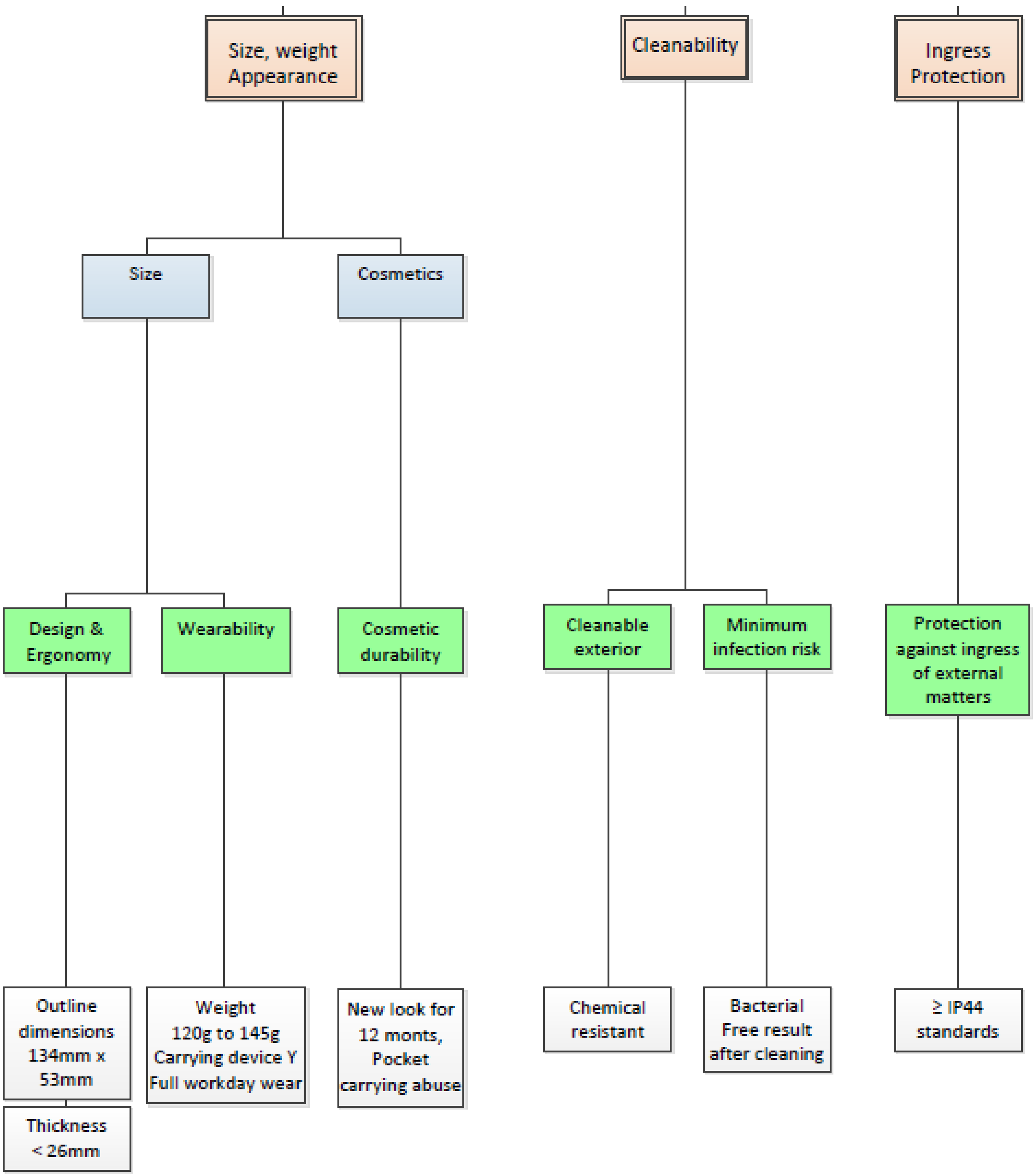

Force (N)
450
400
350
300
250
200
150
100
50
0
1mm
2mm
3mm
4mm
5mm
6mm
Stroke (mm)
DH5 MID_F avg
DH5 MID_B avg

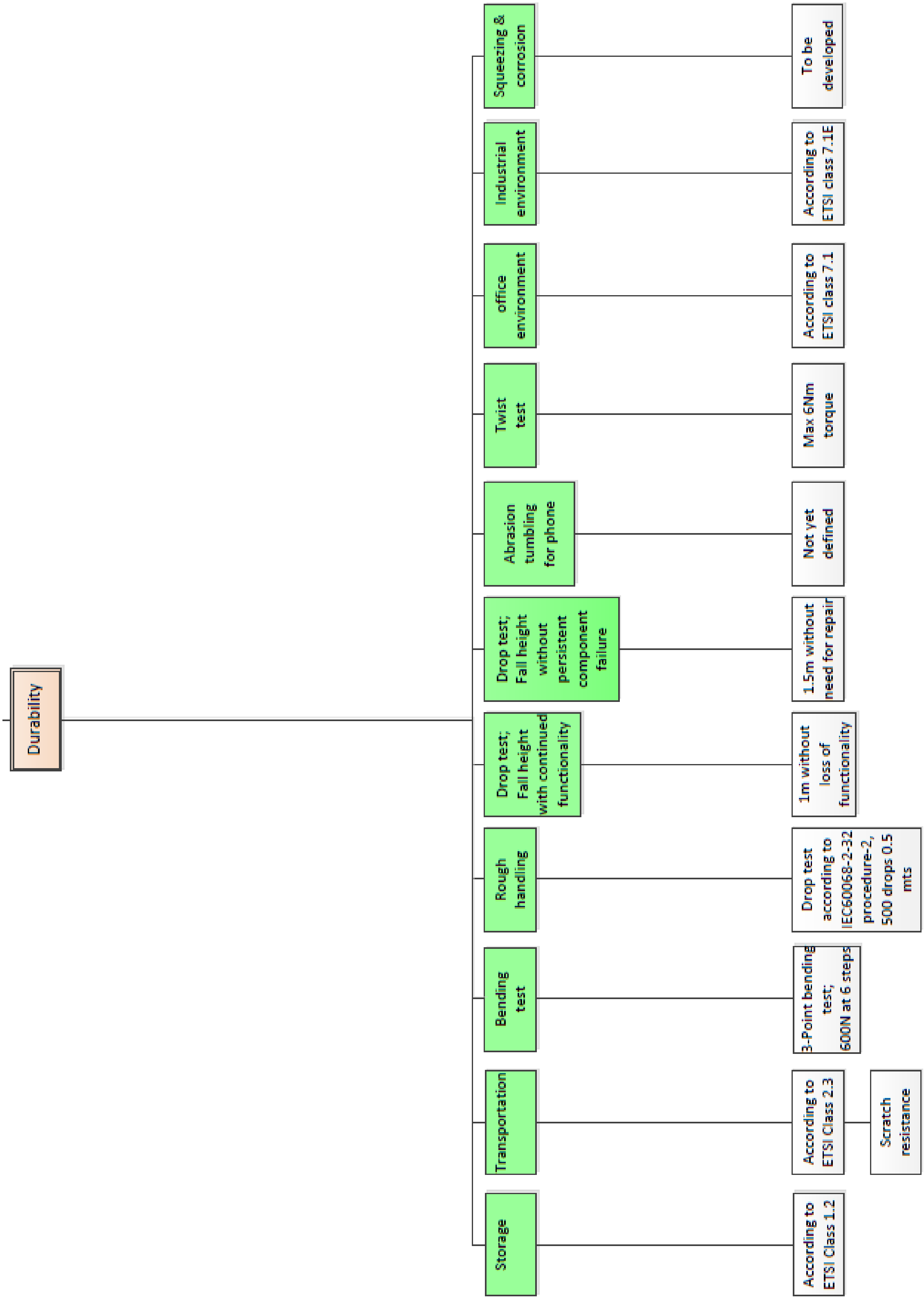
12.3 APPENDIX.C - FUNCTION TREE



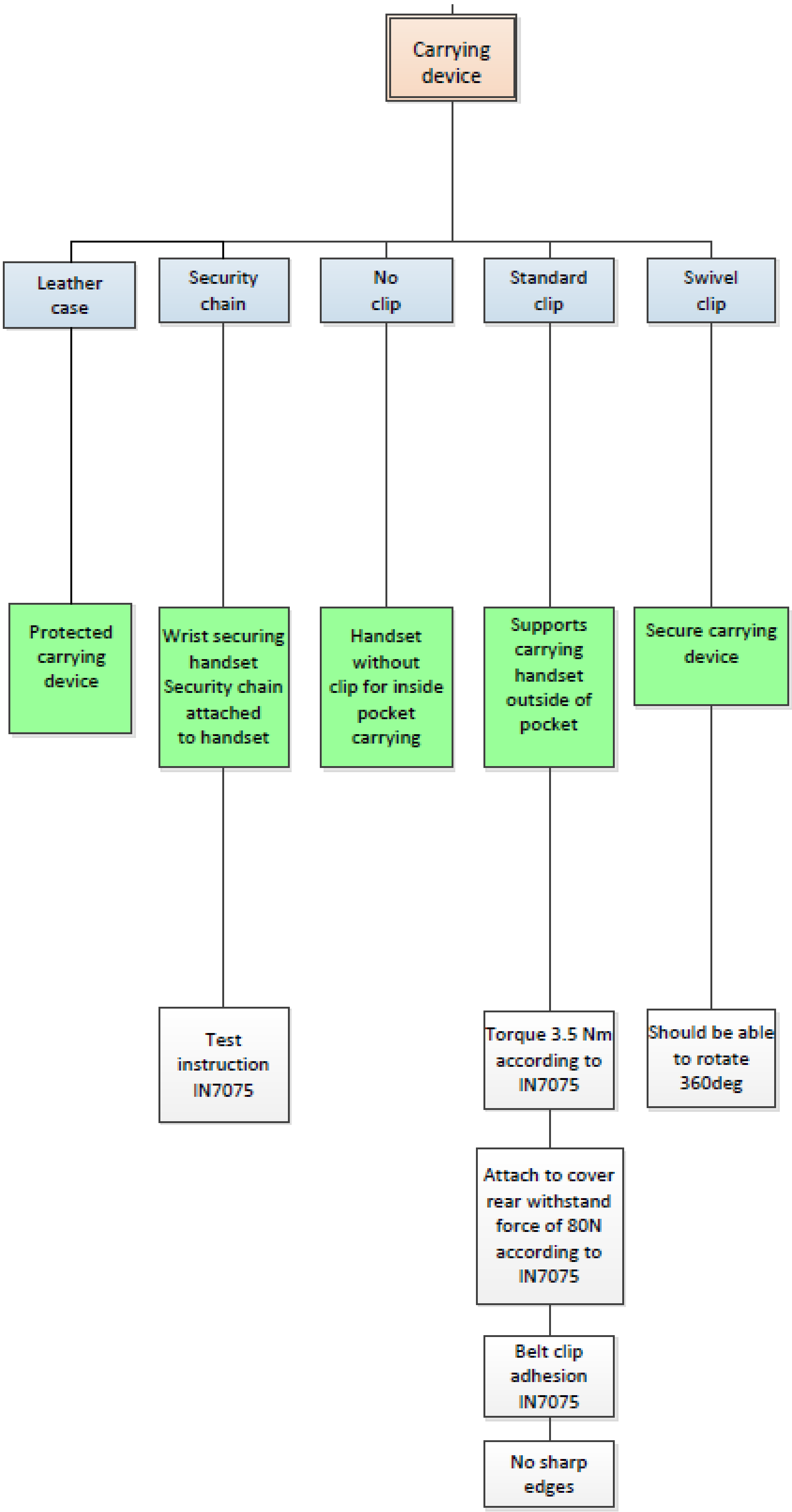


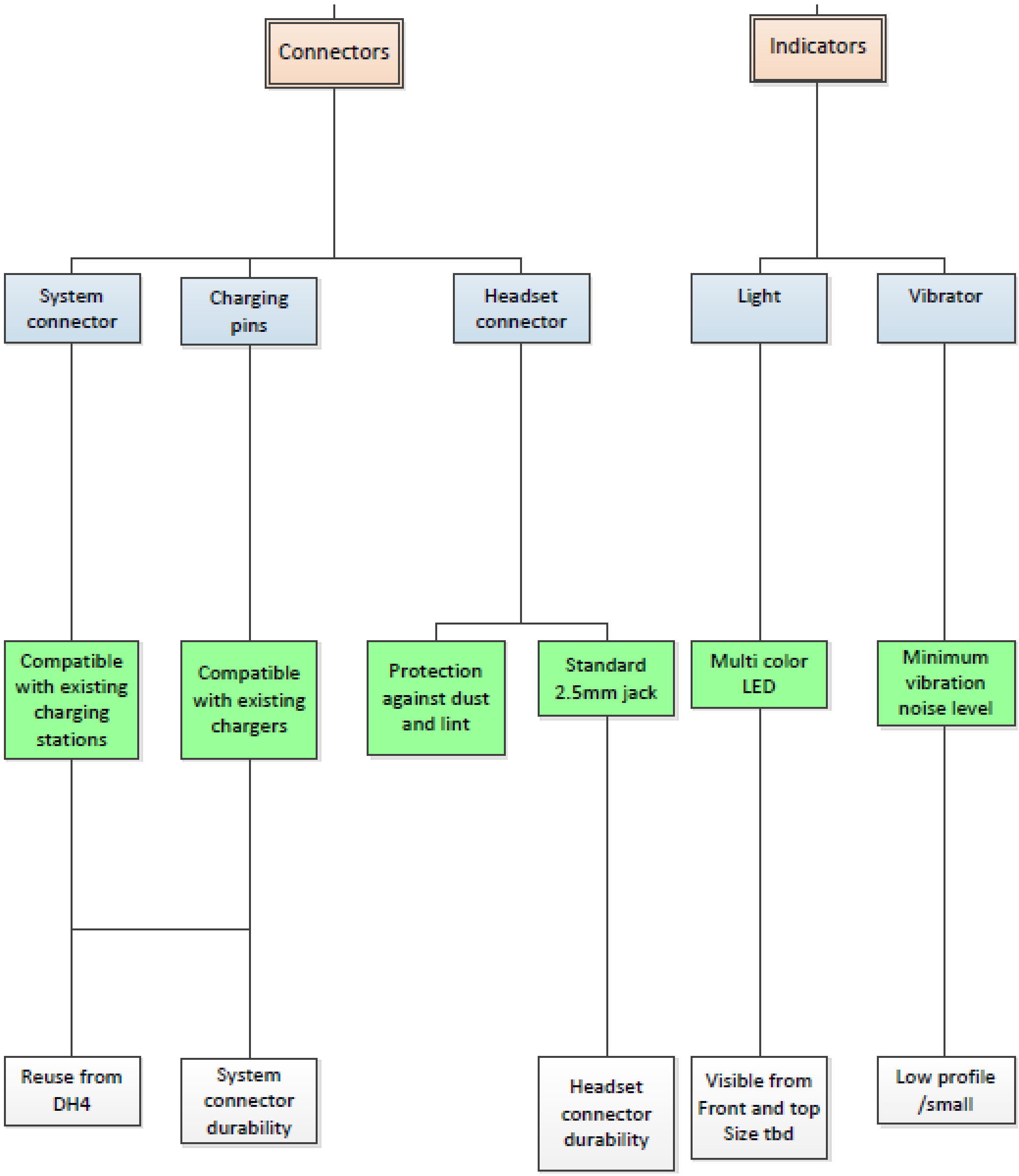
FUNCTION TREE SPLIT

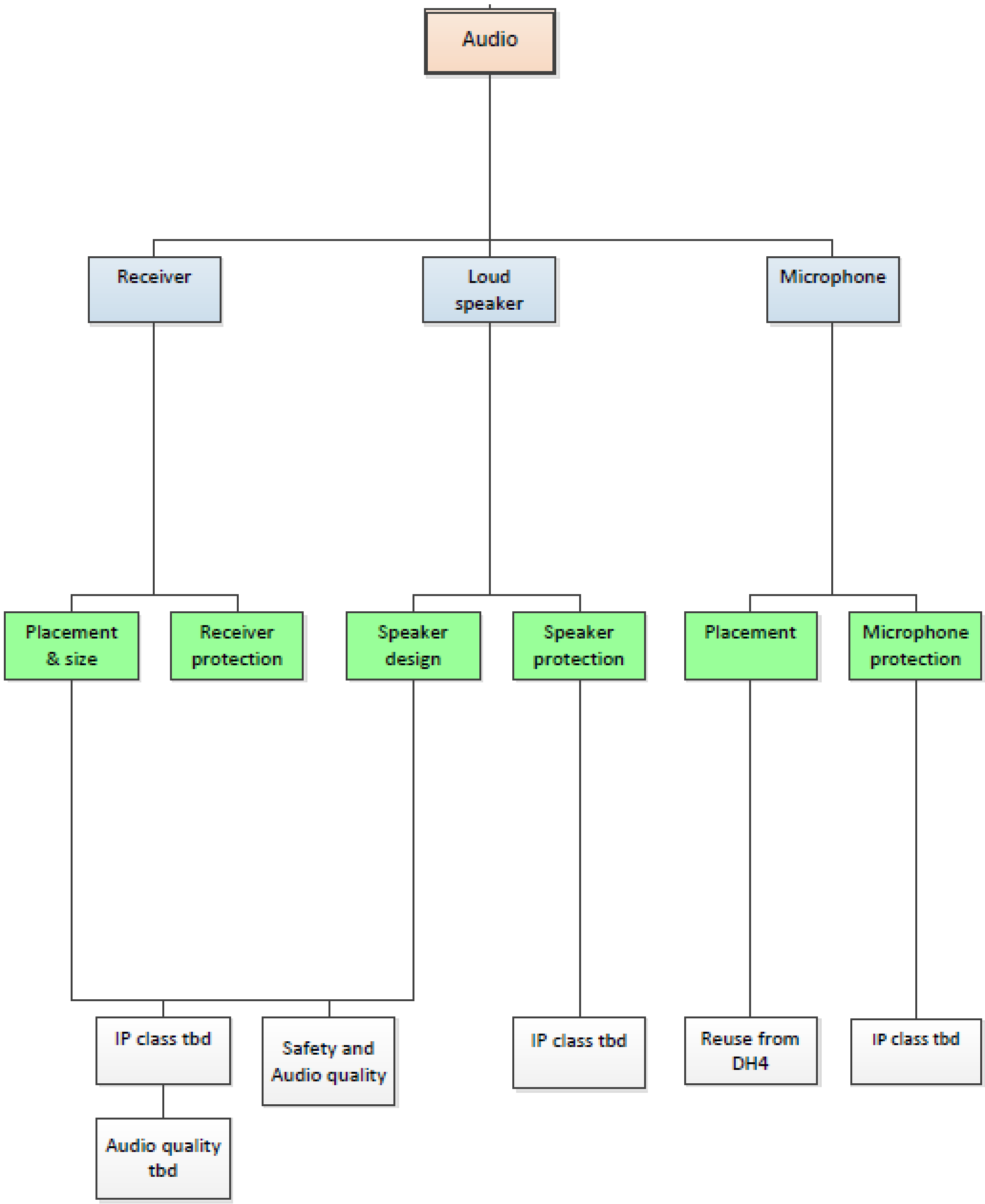


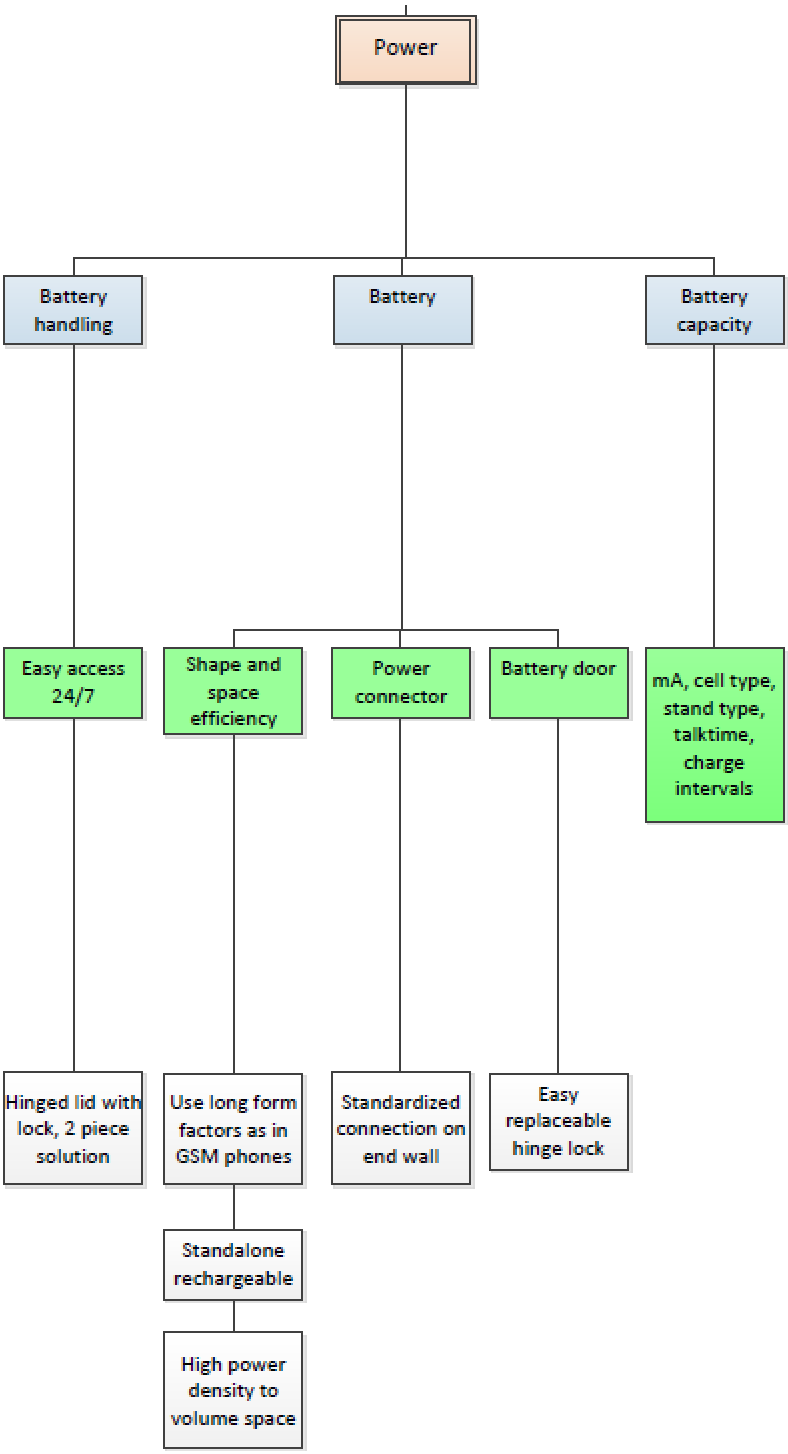


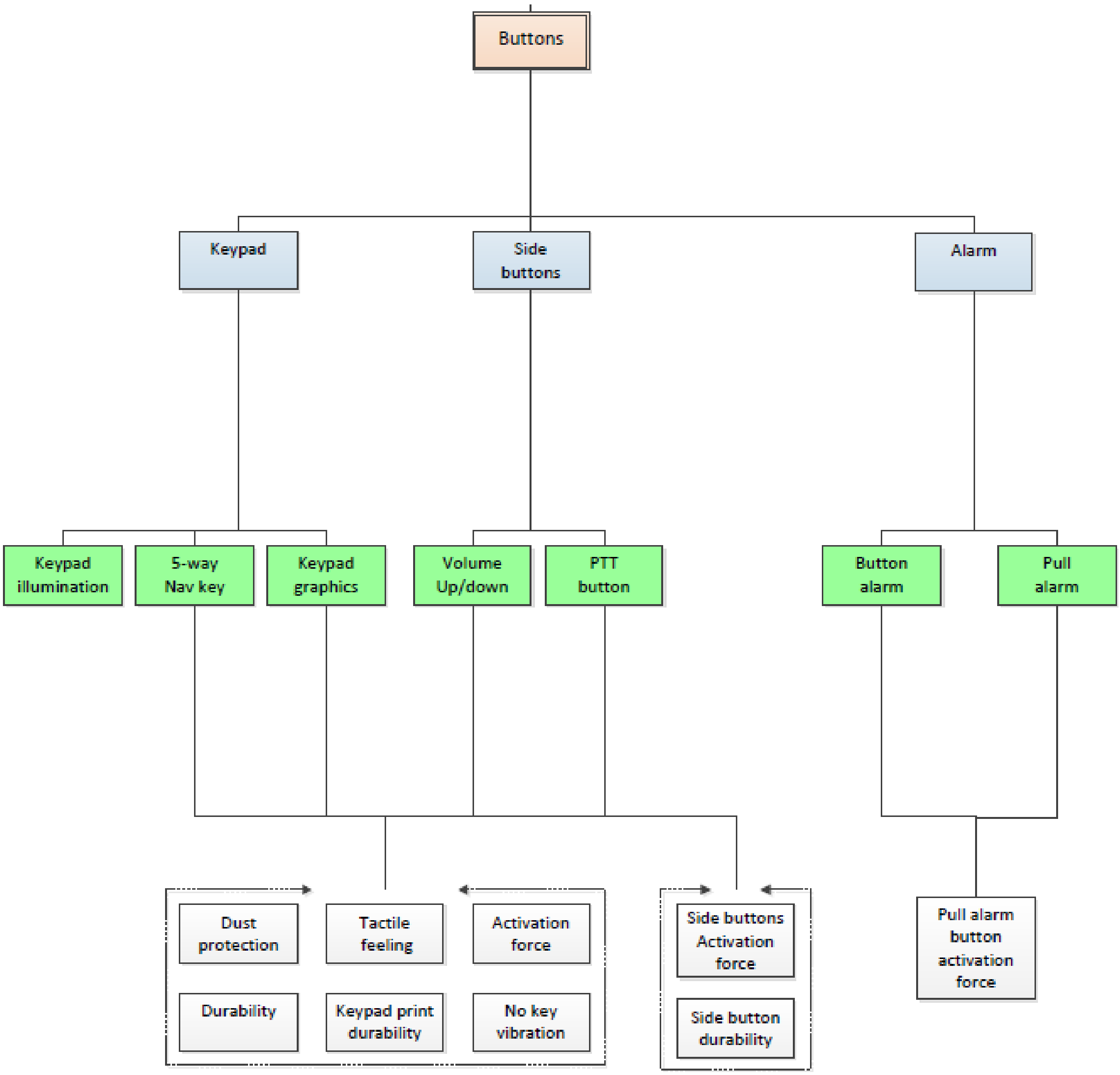
Durability
Storage
According to ETSI Class 1.2
Transportation
According to ETSI Class 2.3
Scratch resistance
Bending test
3-Point bending test; 600N at 6 steps
Rough handling
Drop test according to IEC60068-2-32 procedure-2, 500 drops 0.5 mts
Drop test; Fall height with continued functionality
1m without loss of functionality
Drop test; Fall height without persistent component failure
1.5m without need for repair
Abrasion tumbling for phone
Not yet defined
Twist test
Max 6Nm torque
office environment
According to ETSI class 7.1
Industrial environment
According to ETSI class 7.1E
Squeezing & corrosion
To be developed

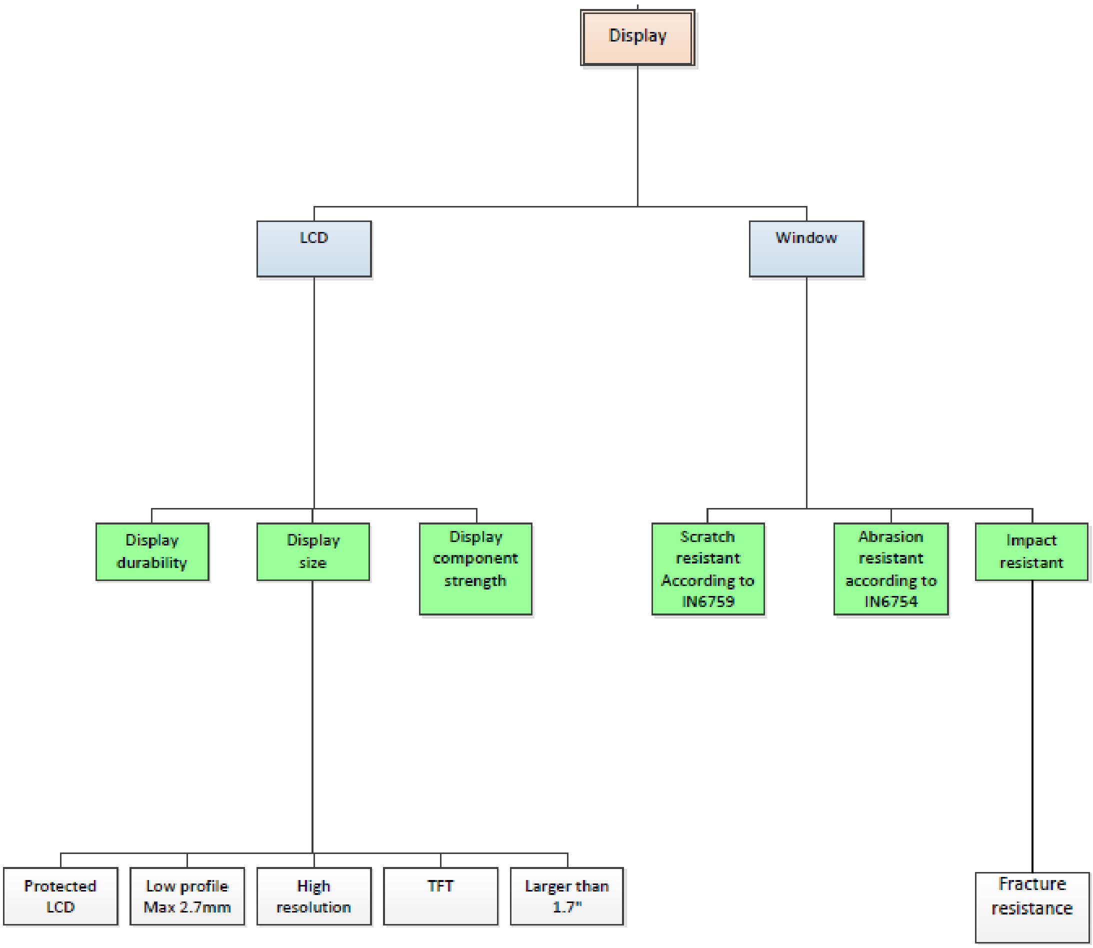

Carrying device
Leather case
Security chain
No clip
Standard clip
Swivel clip
Protected carrying device
Wrist securing handset Security chain attached to handset
Handset without clip for inside pocket carrying
Supports carrying handset outside of pocket
Secure carrying device
Test instruction IN7075
Torque 3.5 Nm according to IN7075
Should be able to rotate 360deg
Attach to cover rear withstand force of 80N according to IN7075
Belt clip adhesion IN7075
No sharp edges

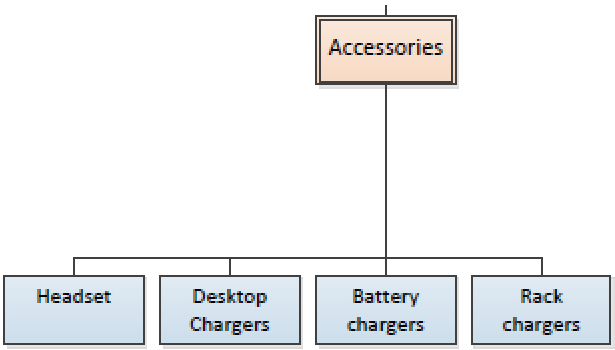

Connectors
Indicators
System connector
Charging pins
Headset connector
Light
Vibrator
Compatible with existing charging stations
Compatible with existing chargers
Protection against dust and lint
Standard 2.5mm jack
Multi color LED
Minimum vibration noise level
Reuse from DH4
System connector durability
Headset connector durability
Visible from Front and top Size tbd
Low profile /small


Audio
Receiver
Loud speaker
Microphone
Placement & size
Receiver protection
Speaker design
Speaker protection
Placement
Microphone protection
IP class tbd
Safety and Audio quality
IP class tbd
Reuse from DH4
IP class tbd
Audio quality tbd

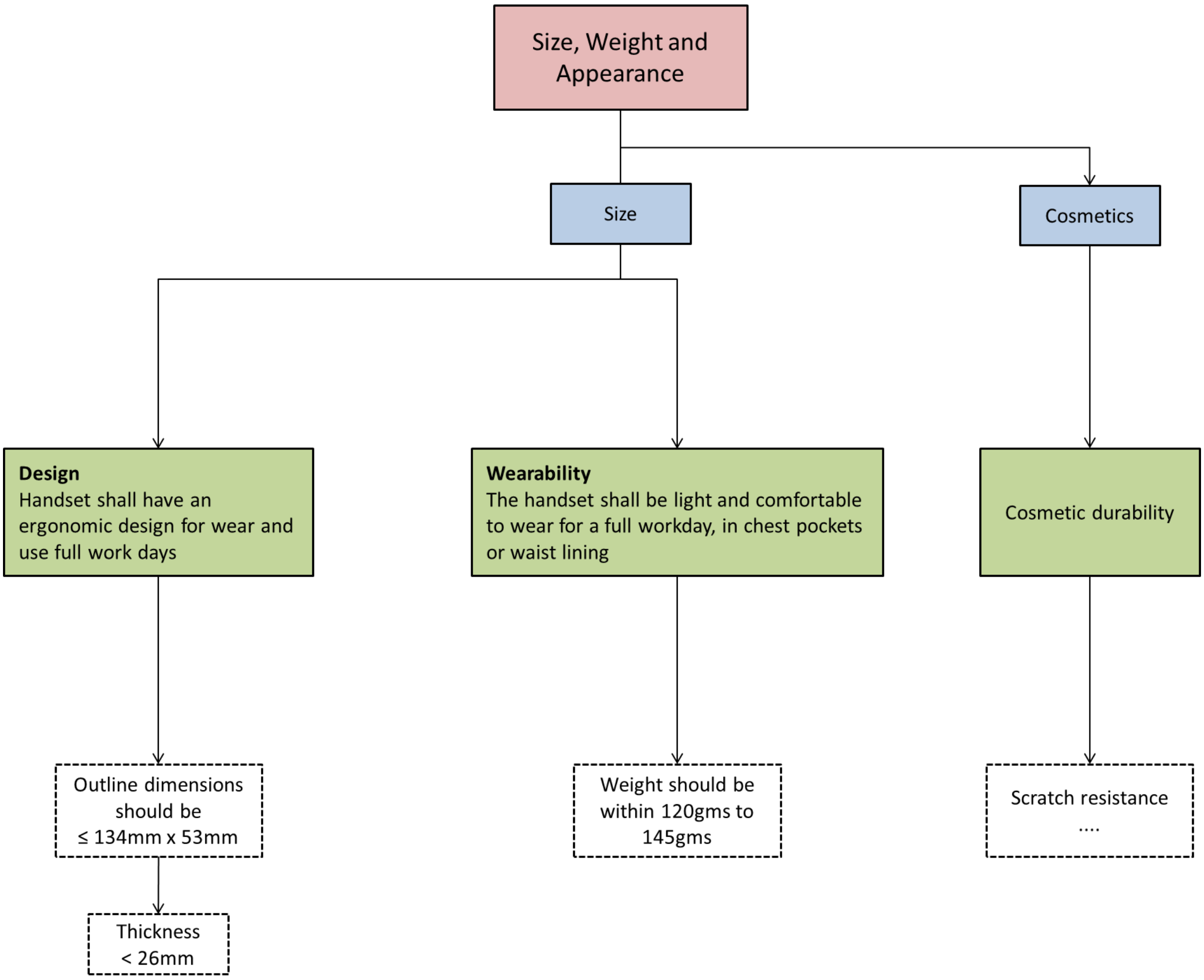

Power
Battery handling
Battery
Battery capacity
Easy access 24/7
Shape and space efficiency
Power connector
Battery door
mA, cell type, stand type, talktime, charge intervals
Hinged lid with lock, 2 piece solution
Use long form factors as in GSM phones
Standardized connection on end wall
Easy replaceable hinge lock
Standalone rechargeable
High power density to volume space

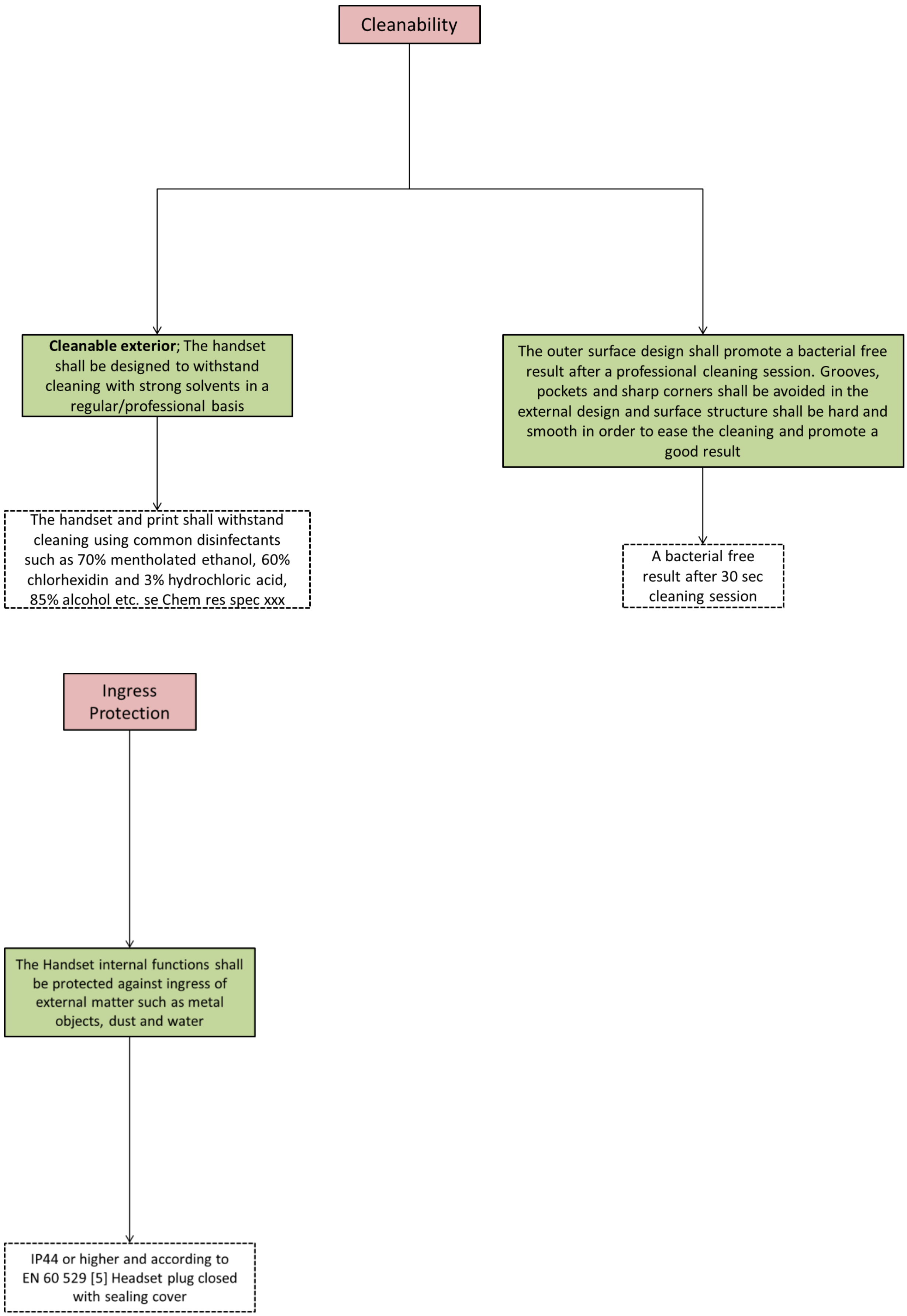

Buttons
Keypad
Side buttons
Alarm
Keypad illumination
5-way Nav key
Keypad graphics
Volume Up/down
PTT button
Button alarm
Pull alarm
Dust protection
Tactile feeling
Activation force
Durability
Keypad print durability
No key vibration
Side buttons Activation force
Side button durability
Pull alarm button activation force

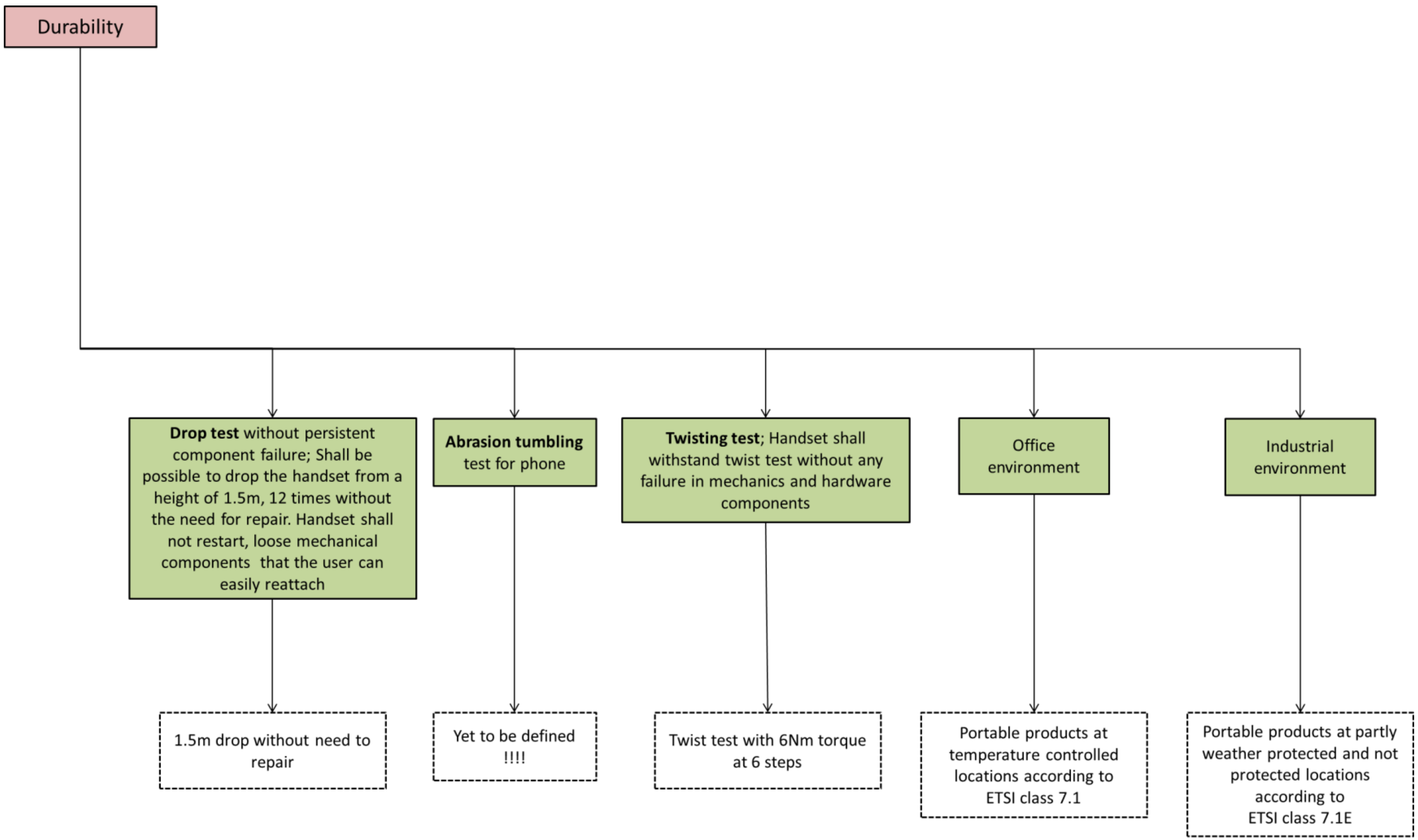

Display
LCD
Window
Display durability
Display size
Display component strength
Scratch resistant According to IN6759
Abrasion resistant according to IN6754
Impact resistant
Protected LCD
Low profile Max 2.7mm
High resolution
TFT
Larger than 1.7"
Fracture resistance

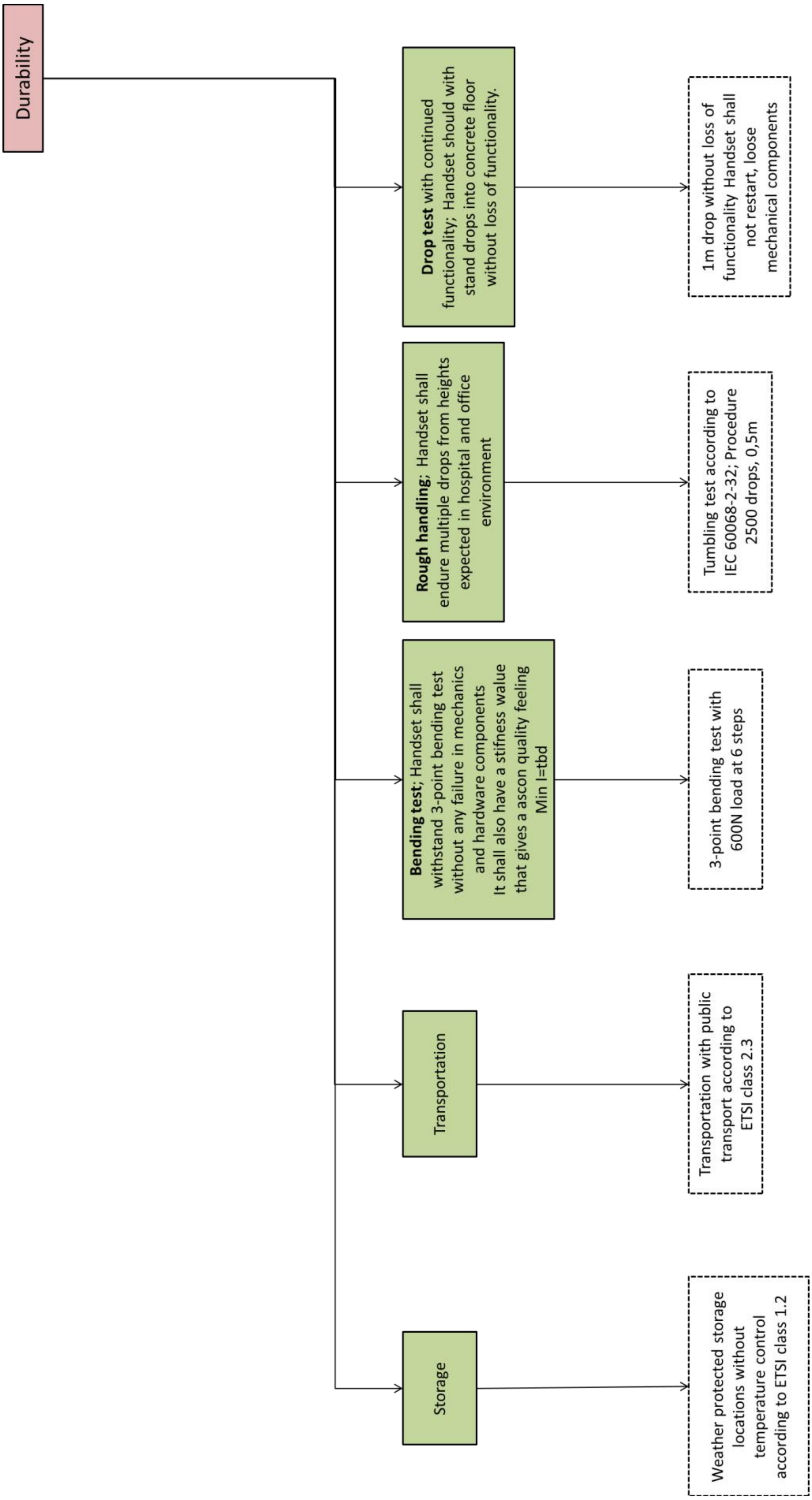

Accessories
Headset
Desktop Chargers
Battery chargers
Rack chargers

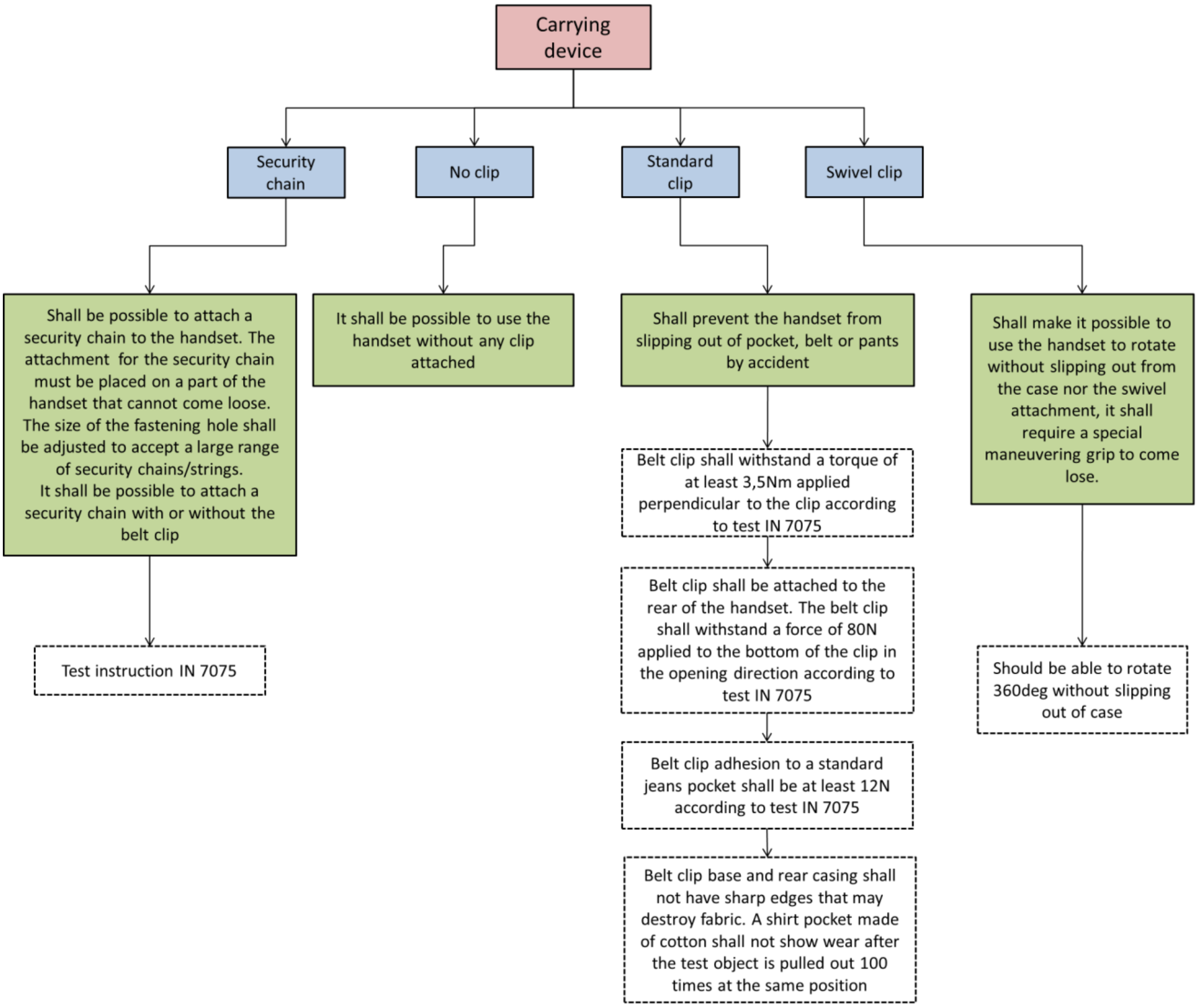
FUNCTION TREE SPLIT UP WITH DETAILS

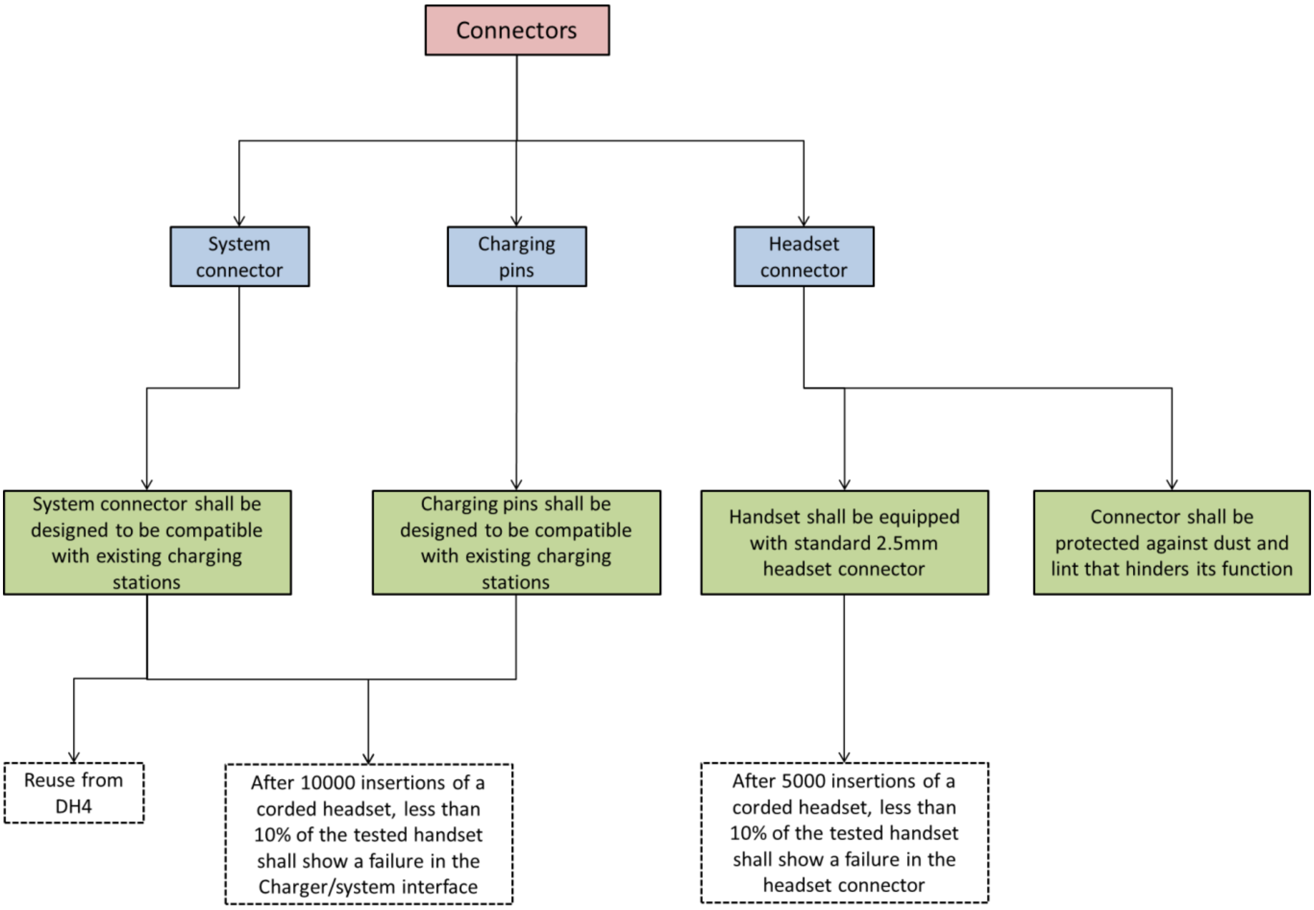


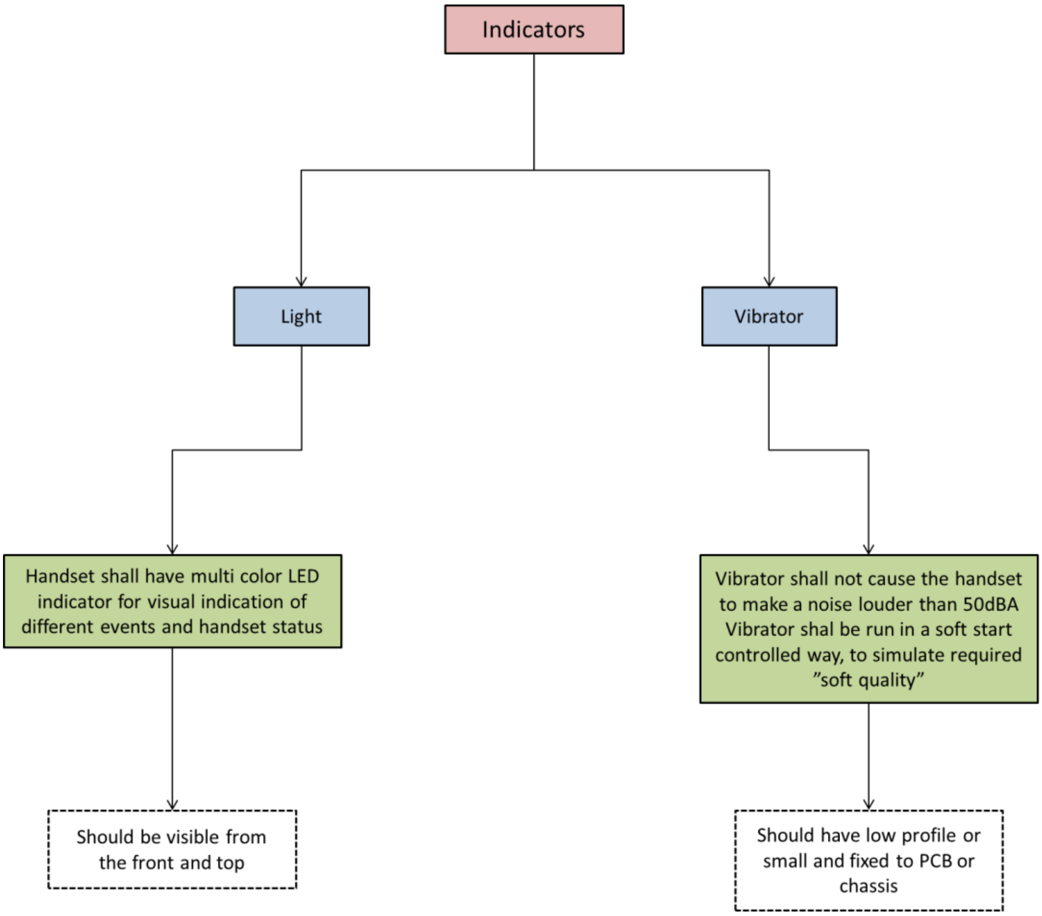

Cleanability
Cleanable exterior; The handset shall be designed to withstand cleaning with strong solvents in a regular/professional basis
The handset and print shall withstand cleaning using common disinfectants such as 70% mentholated ethanol, 60% chlorhexidin and 3% hydrochloric acid, 85% alcohol etc. se Chem res spec xxx
The outer surface design shall promote a bacterial free result after a professional cleaning session. Grooves, pockets and sharp corners shall be avoided in the external design and surface structure shall be hard and smooth in order to ease the cleaning and promote a good result
A bacterial free result after 30 sec cleaning session
Ingress Protection
The Handset internal functions shall be protected against ingress of external matter such as metal objects, dust and water
IP44 or higher and according to EN 60 529 [5] Headset plug closed with sealing cover

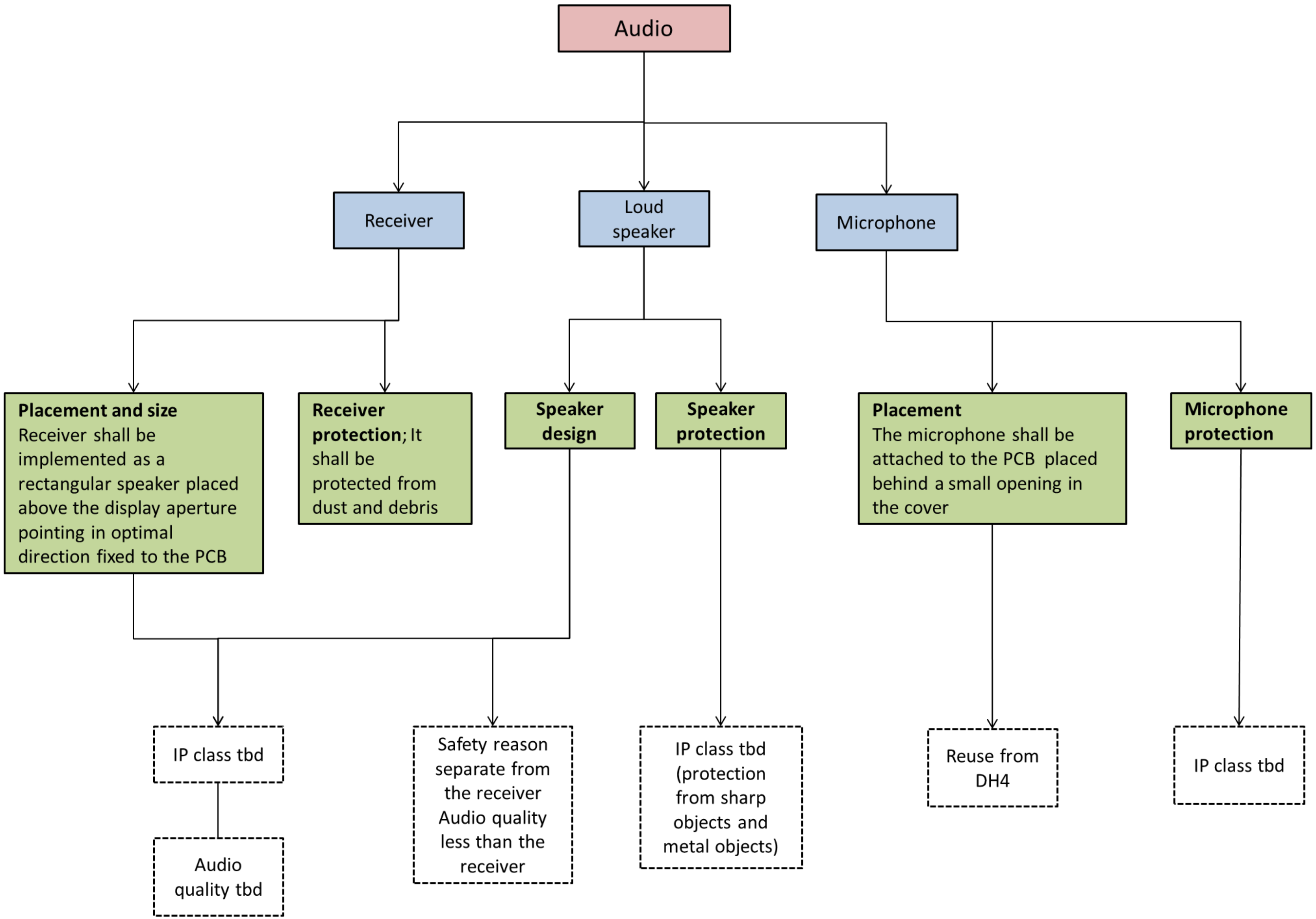

Durability
Drop test without persistent component failure; Shall be possible to drop the handset from a height of 1.5m, 12 times without the need for repair. Handset shall not restart, loose mechanical components that the user can easily reattach
Abrasion tumbling test for phone
Twisting test; Handset shall withstand twist test without any failure in mechanics and hardware components
Office environment
Industrial environment
1.5m drop without need to repair
Yet to be defined !!!!
Twist test with 6Nm torque at 6 steps
Portable products at temperature controlled locations according to ETSI class 7.1
Portable products at partly weather protected and not protected locations according to ETSI class 7.1E

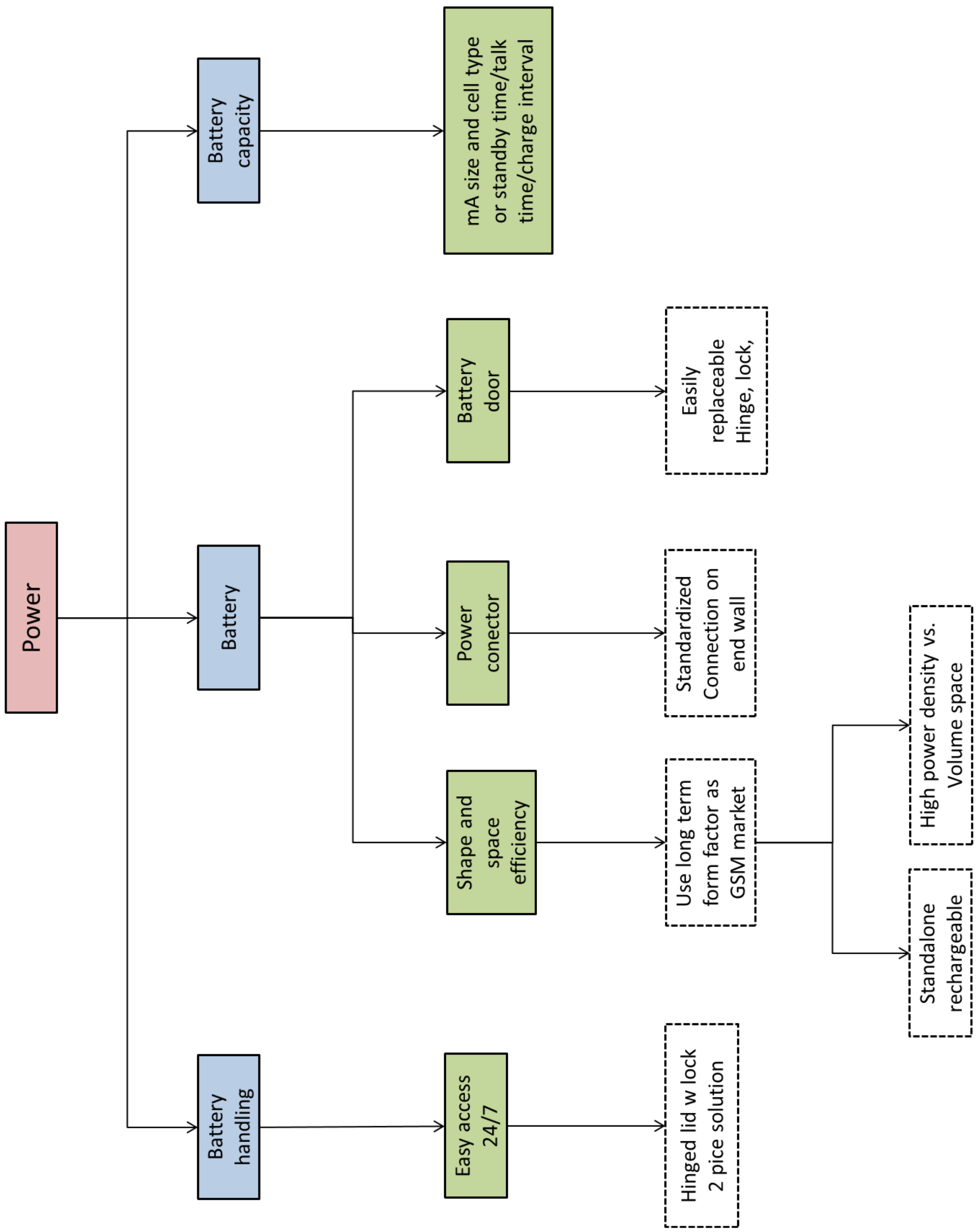

Durability
Drop test with continued functionality; Handset should with stand drops into concrete floor without loss of functionality.
1m drop without loss of functionality Handset shall not restart, loose mechanical components
Rough handling; Handset shall endure multiple drops from heights expected in hospital and office environment
Tumbling test according to IEC 60068-2-32; Procedure 2500 drops, 0,5m
Bending test; Handset shall withstand 3-point bending test without any failure in mechanics and hardware components
It shall also have a stifness walue that gives a ascon quality feeling
Min I=tbd
3-point bending test with 600N load at 6 steps
Transportation
Transportation with public transport according to ETSI class 2.3
Storage
Weather protected storage locations without temperature control according to ETSI class 1.2

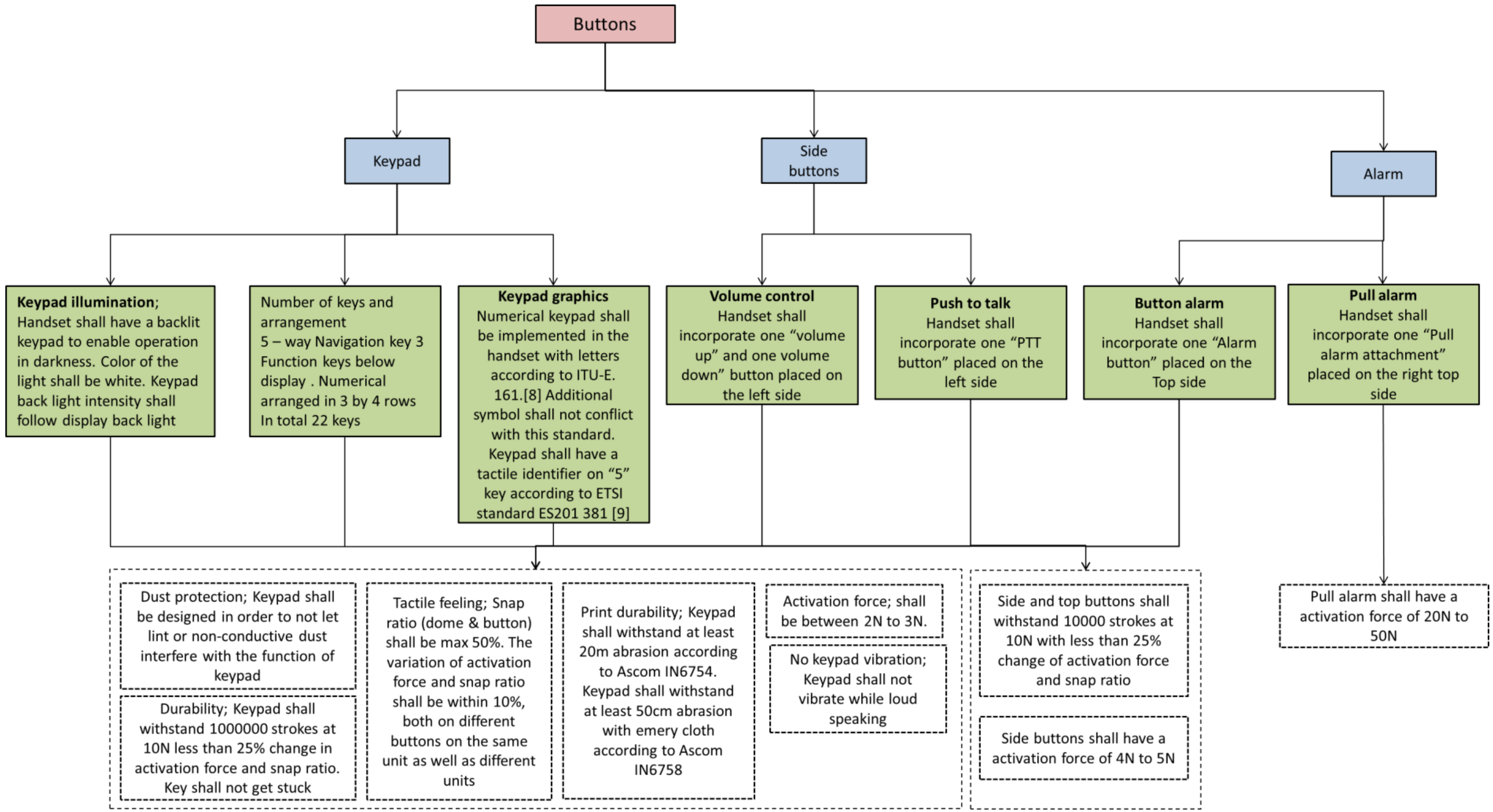

Carrying device
Security chain
No clip
Standard clip
Swivel clip
Shall be possible to attach a security chain to the handset. The attachment for the security chain must be placed on a part of the handset that cannot come loose. The size of the fastening hole shall be adjusted to accept a large range of security chains/strings. It shall be possible to attach a security chain with or without the belt clip
It shall be possible to use the handset without any clip attached
Shall prevent the handset from slipping out of pocket, belt or pants by accident
Shall make it possible to use the handset to rotate without slipping out from the case nor the swivel attachment, it shall require a special maneuvering grip to come lose.
Belt clip shall withstand a torque of at least 3,5Nm applied perpendicular to the clip according to test IN 7075
Test instruction IN 7075
Belt clip shall be attached to the rear of the handset. The belt clip shall withstand a force of 80N applied to the bottom of the clip in the opening direction according to test IN 7075
Should be able to rotate 360deg without slipping out of case
Belt clip adhesion to a standard jeans pocket shall be at least 12N according to test IN 7075
Belt clip base and rear casing shall not have sharp edges that may destroy fabric. A shirt pocket made of cotton shall not show wear after the test object is pulled out 100 times at the same position


Connectors
System connector
Charging pins
Headset connector
System connector shall be designed to be compatible with existing charging stations
Charging pins shall be designed to be compatible with existing charging stations
Handset shall be equipped with standard 2.5mm headset connector
Connector shall be protected against dust and lint that hinders its function
Reuse from DH4
After 10000 insertions of a corded headset, less than 10% of the tested handset shall show a failure in the Charger/system interface
After 5000 insertions of a corded headset, less than 10% of the tested handset shall show a failure in the headset connector

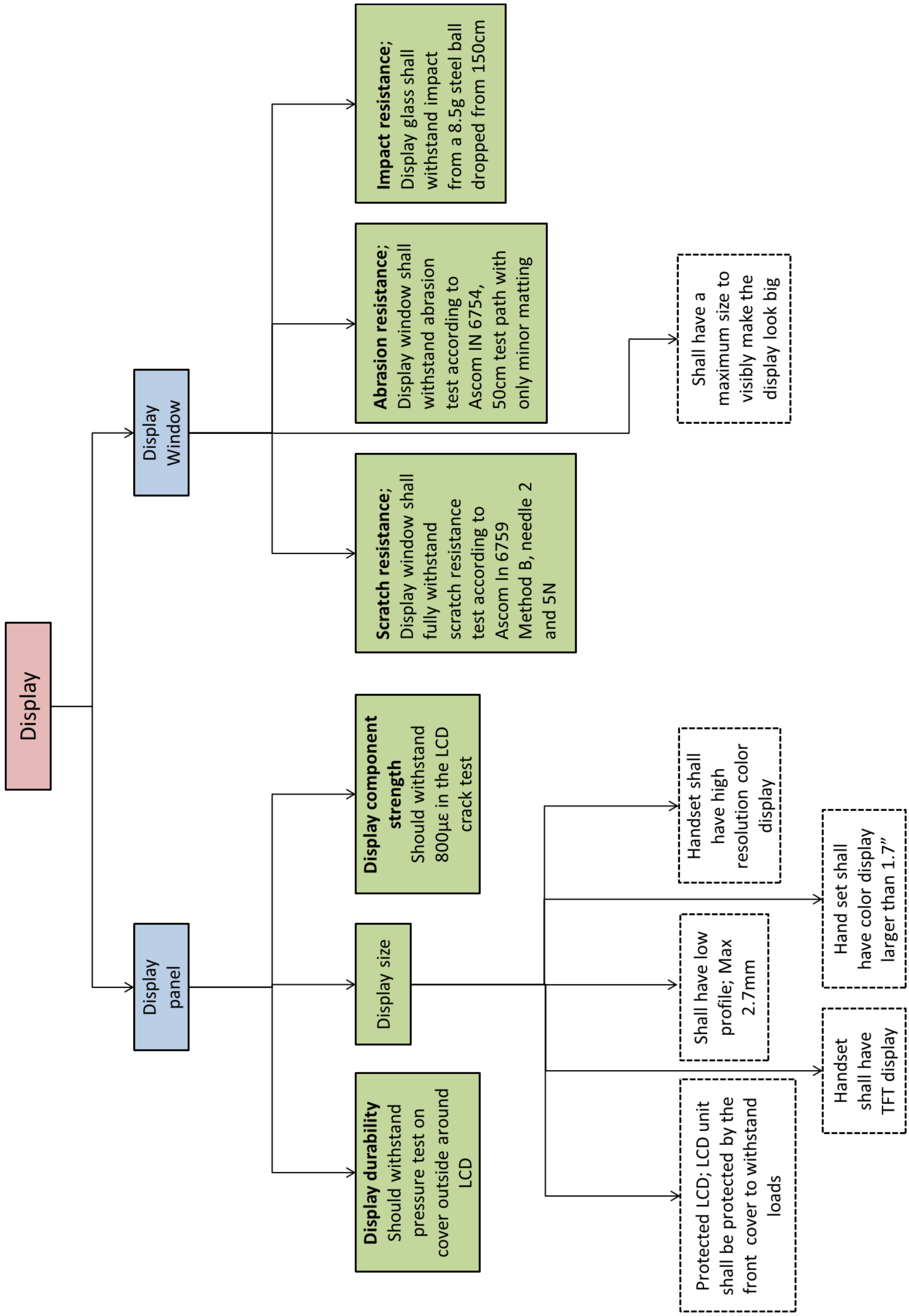

Indicators
Light
Vibrator
Handset shall have multi color LED indicator for visual indication of different events and handset status
Vibrator shall not cause the handset to make a noise louder than 50dBA Vibrator shal be run in a soft start controlled way, to simulate required "soft quality"
Should be visible from the front and top
Should have low profile or small and fixed to PCB or chassis


Audio
Receiver
Loud speaker
Microphone
Placement and size Receiver shall be implemented as a rectangular speaker placed above the display aperture pointing in optimal direction fixed to the PCB
Receiver protection; It shall be protected from dust and debris
Speaker design
Speaker protection
Placement The microphone shall be attached to the PCB placed behind a small opening in the cover
Microphone protection
IP class tbd
Audio quality tbd
Safety reason separate from the receiver Audio quality less than the receiver
IP class tbd (protection from sharp objects and metal objects)
Reuse from DH4
IP class tbd

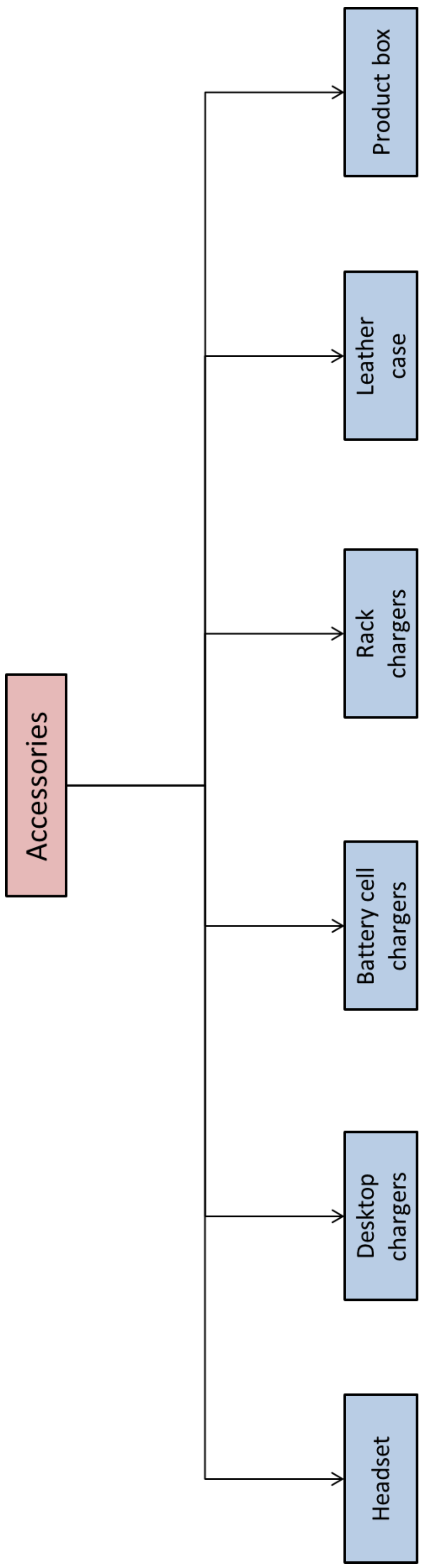

Power
Battery capacity
Battery
Battery handling
mA size and cell type or standby time/talk time/charge interval
Battery door
Power conector
Shape and space efficiency
Easy access 24/7
Easily replaceable Hinge, lock,
Standardized Connection on end wall
Use long term form factor as GSM market
Hinged lid w lock 2 pice solution
High power density vs. Volume space
Standalone rechargeable



Buttons
Keypad
Side buttons
Alarm
Keypad illumination; Handset shall have a backlit keypad to enable operation in darkness. Color of the light shall be white. Keypad back light intensity shall follow display back light
Number of keys and arrangement
5 – way Navigation key 3 Function keys below display . Numerical arranged in 3 by 4 rows
In total 22 keys
Keypad graphics
Numerical keypad shall be implemented in the handset with letters according to ITU-E. 161.[8] Additional symbol shall not conflict with this standard. Keypad shall have a tactile identifier on "5" key according to ETSI standard ES201 381 [9]
Volume control
Handset shall incorporate one "volume up" and one volume down" button placed on the left side
Push to talk
Handset shall incorporate one "PTT button" placed on the left side
Button alarm
Handset shall incorporate one "Alarm button" placed on the Top side
Pull alarm
Handset shall incorporate one "Pull alarm attachment" placed on the right top side
Dust protection; Keypad shall be designed in order to not let lint or non-conductive dust interfere with the function of keypad
Durability; Keypad shall withstand 1000000 strokes at 10N less than 25% change in activation force and snap ratio. Key shall not get stuck
Tactile feeling; Snap ratio (dome & button) shall be max 50%. The variation of activation force and snap ratio shall be within 10%, both on different buttons on the same unit as well as different units
Print durability; Keypad shall withstand at least 20m abrasion according to Ascom IN6754. Keypad shall withstand at least 50cm abrasion with emery cloth according to Ascom IN6758
Activation force; shall be between 2N to 3N.
No keypad vibration; Keypad shall not vibrate while loud speaking
Side and top buttons shall withstand 10000 strokes at 10N with less than 25% change of activation force and snap ratio
Side buttons shall have a activation force of 4N to 5N
Pull alarm shall have a activation force of 20N to 50N



Display
Display Window
Display panel
Impact resistance; Display glass shall withstand impact from a 8.5g steel ball dropped from 150cm
Abrasion resistance; Display window shall withstand abrasion test according to Ascom IN 6754, 50cm test path with only minor matting
Scratch resistance; Display window shall fully withstand scratch resistance test according to Ascom In 6759 Method B, needle 2 and 5N
Shall have a maximum size to visibly make the display look big
Display component strength Should withstand 800με in the LCD crack test
Display size
Display durability Should withstand pressure test on cover outside around LCD
Handset shall have high resolution color display
Hand set shall have color display larger than 1.7”
Shall have low profile; Max 2.7mm
Handset shall have TFT display
Protected LCD; LCD unit shall be protected by the front cover to withstand loads

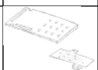
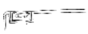
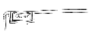
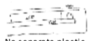
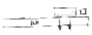
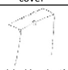

Accessories
Product box
Leather case
Rack chargers
Battery cell chargers
Desktop chargers
Headset

12.4 APPENDIX.D - MORPHOLOGICAL MATRIX

Solutions / Functions	1	2	3	4	5	6	7	8	9	10
1. Geometry build up	Type1	Type2	Type3							
2. Covers / Frames	Plastic molding	Over mold plastic with metal	Magnesium thixotrophic molding	Deep drawn sheet metal	Plastic to Plastic overmolding					
3. PCB	Half size PCB	Full size PCB	Flexible printed circuit (FPC)	2-Split PCB	PCB - FPC					
4. Antenna	Heat stacked to plastic frame	PCB antenna	FPC antenna	External antenna	Sticker type antenna	Laser etched antenna				
5. System connector	Soldered to PCB	Mounted on Plastic cover and connected through FPC	Plug in type	No system connector, powered by Wireless induction charging	Charging pins only	System connector and charging pins	System connector mounted on speaker box with Antenna	Mounted of plastic frame connected thru springs	System connector molded into plastic frame	Bluetooth system connetor
6. Headset connector	Soldered to PCB	Mounted on Plastic cover and connected through FPC	Connected to PCB through wires	Bluetooth with no Headset connector	System connector is also Headset connector	Mounted of plastic frame connected thru springs	Molded into plastic frame	Magnetic interface		
7. Receiver	Soldered to PCB	Connected to PCB through wires	Connected to PCB by Pogopins/spring pads *(Slide in like Siemens)*	Glued to Front cover/Frame	Slide on to frame / PCB	Mounted on FPC				
8. Loud speaker	Soldered to PCB	Connected to PCB through wires	Connected to PCB by Pogopins/spring pads *(Slide in like Siemens)*	Glued to cover rear	Small/Thin speaker with Speaker box to increase decibel *(Antenna mounted like sticker)*	Slide on to frame / PCB	Mounted on FPC			
9. Micro phone	Soldered to PCB	Connected to PCB through wires	Connected to PCB by Pogopins/spring pads *(Slide in like Siemens)*	Glued to frame/cover front	Slide on to frame / PCB	Mounted on FPC				
10.LED light guide	Plastic guide from LED	Plastic guide over molded in cover front	Integrated with window	No separate plastic guide; LED directly lights up	Silicon light guide like in Maddox	LED mounted on plastic frame				
11. Vibrator	Soldered to PCB	Connected to PCB through wires and mounted on cover/Frame	Connected to PCB by Pogopins/spring pads	Mounted on Speaker box along with Speaker	Cylindrical vibrator soldered to PCB	Loud speaker tuned as Vibrator (in concept)				
12. Battery connector	Soldered to PCB	Connection on side wall	Connector with plugs	No connector; Battery directly soldered to PCB through wires	Connector with metal strips *(Motorola)*	Slide into plastic frame				
13. Battery	Battery with hard cover	Battery without hard cover *(Can be packed effectively in volume space)*	Battery connectors on side wall	Battery integrated with battery door	Battery with wire connectors	Connector with metal strips *(Motorola)*				
14. Battery door	Slide in door with snaps	Door with locks	No door; battery charged using connectors/charging pins	Cover rear is designed to be battery door	Battery door design like in cameras *(Canon in lab)*	Battery integrated with battery door				
15. Keypad	Silicon molded keypad with numbers printed	Keypad with separate plastic keytops	Thin sheet keypad (Siemens)	Keypad mounted on Front cover	Keypad molded with front cover	Keypad attached to PCB along with dome sheet and light guide	Keypad attached to inner frame	Touch sensitive keys	Thin silicon keypad	
16. Side buttons	Molded to frame	Mounted on frame	Mounted on side wall of frame on FPC (like DH5)							
17. LCD	Mounted on PCB	Mounted on front cover	Mounted on Inner frame	Integrated; window glass and LCD	LCD with Sheet metal protection cover					
18. Window	Glued to front cover	Over molded with Front cover	Snap on to Front cover	Ultrasonic welded with Front cover	Integrated; window glass and LCD	Entire cover front molded with window material and painted				
19. Security chain	Molded in plastic	Metal insert in plastic	Locks with battery door							
20. No clip	No Clip									
21. Standard clip	Clip on to cover rear	Molded in cover rear	Attach with screws	Clip over molded in to rear cover						
22. Swivel clip	Clip on to cover rear	Molded in cover rear	Attach with screws	Clip over molded in to rear cover						

12.5 APPENDIX.E - CONCEPT SYNERGY

Criteria for Synergy		Grade	
A	Design/Technology/Strategy	●	Adds high value
B	Manufacturing of parts	◑	Fits well
C	Assembly	○	Does not add value
D	Repair	⊗	Conflict
E	Cost		

Functions	Solution	Criteria	Grade	Description of synergy
1. Geometry build up	Type2			Rainy
		A	◑	
		B	◑	
2. Covers / Frames	Over mold plastic with metal	C	●	
		D	◑	
		E	⊗	
		A	◑	
		B	◑	
3. PCB	 Full size PCB + FPC	C	○	
		D	◑	
		E	⊗	
		A	◑	
		B	●	
4. Antenna	 PCB antenna	C	●	
		D	●	
		E	●	
		A	◑	
		B	◑	
5. System connector	 Soldered to PCB	C	○	
		D	○	
		E	◑	
		A	●	
		B	◑	
6. Headset connector	 Mounted of plastic frame connected thru springs	C	●	
		D	●	
		E	⊗	
		A	◑	
		B	◑	
7. Receiver	 Glued to Front cover/Frame	C	◑	
		D	◑	
		E	◑	
		A	◑	
		B	◑	
8. Loud speaker	 Glued to cover rear	C	◑	
		D	◑	
		E	●	
		A	◑	
		B	◑	
9. Micro phone	 Glued to frame/cover front	C	◑	
		D	◑	
		E	◑	
		A	◑	
		B	●	
10.LED light guide	 No separate plastic guide; LED directly lights up	C	●	
		D	●	
		E	●	
		A	●	
		B	●	
11. Vibrator	 Soldered to PCB	C	●	
		D	○	
		E	●	
		A	●	
		B	●	
12. Battery connector	 Soldered to PCB	C	●	
		D	○	
		E	●	
		A	●	
		B	●	
13. Battery	 Battery connectors on side wall	C	●	
		D	●	
		E	●	
		A	○	
		B	○	
14. Battery door	 Door with locks	C	○	
		D	○	
		E	○	
		A	●	
		B	◑	
15. Keypad	 Thin sheet keypad (Siemens)	C	●	
		D	●	
		E	○	
		A	●	
		B	○	
16. Side buttons	 Mounted on frame	C	◑	
		D	◑	
		E	○	
		A	◑	
		B	◑	
17. LCD	 Mounted on PCB	C	◑	
		D	◑	
		E	○	
		A	◑	
		B	◑	
18. Window	 Glued to front cover	C	◑	
		D	○	
		E	○	
		A	●	
		B	●	
19. Security chain	 Molded in plastic	C	●	
		D	○	
		E	●	
		A		
		B		
20. No clip	*(N/A)*	C		
		D		
		E		
		A	●	
		B	○	
21. Standard clip	 Attach with screws	C	◑	
		D	●	
		E	○	
		A	●	
		B	○	
22. Swivel clip	 Attach with screws	C	◑	
		D	●	
		E	○	

12.6 APPENDIX.F – MATERIAL SELECTION CES REPORTS

Summary – Frames and battery cover	Stage Details

1. Selection data

Database	Polymer Selector
Table	MaterialUniverse
Subset	Polymers - All
Reference	ABS/PC (injection molding and extrusion)

2. Selection criteria (summary)

Stage	Attribute	Constraints	Pass
1	Cost per unit of stiffness		809
	Mass per unit of stiffness		
2	RoHS (EU) compliant grades?	✓	15
	Transparency	Opaque	
	Water (fresh)	Excellent	
	Water (salt)	Acceptable	
	Recycle	✓	
	Landfill	✓	
3	Hardness - Rockwell M		590
	Impact strength, notched 23 °C (kJ/m^2)		
4	ProcessUniverse	Shaping\Molding\Injection	777
		Surface treatment\Painting and printing	
		Surface treatment\Surface coatings	
5	Shape	3-D\Solid	731

3. Selection results

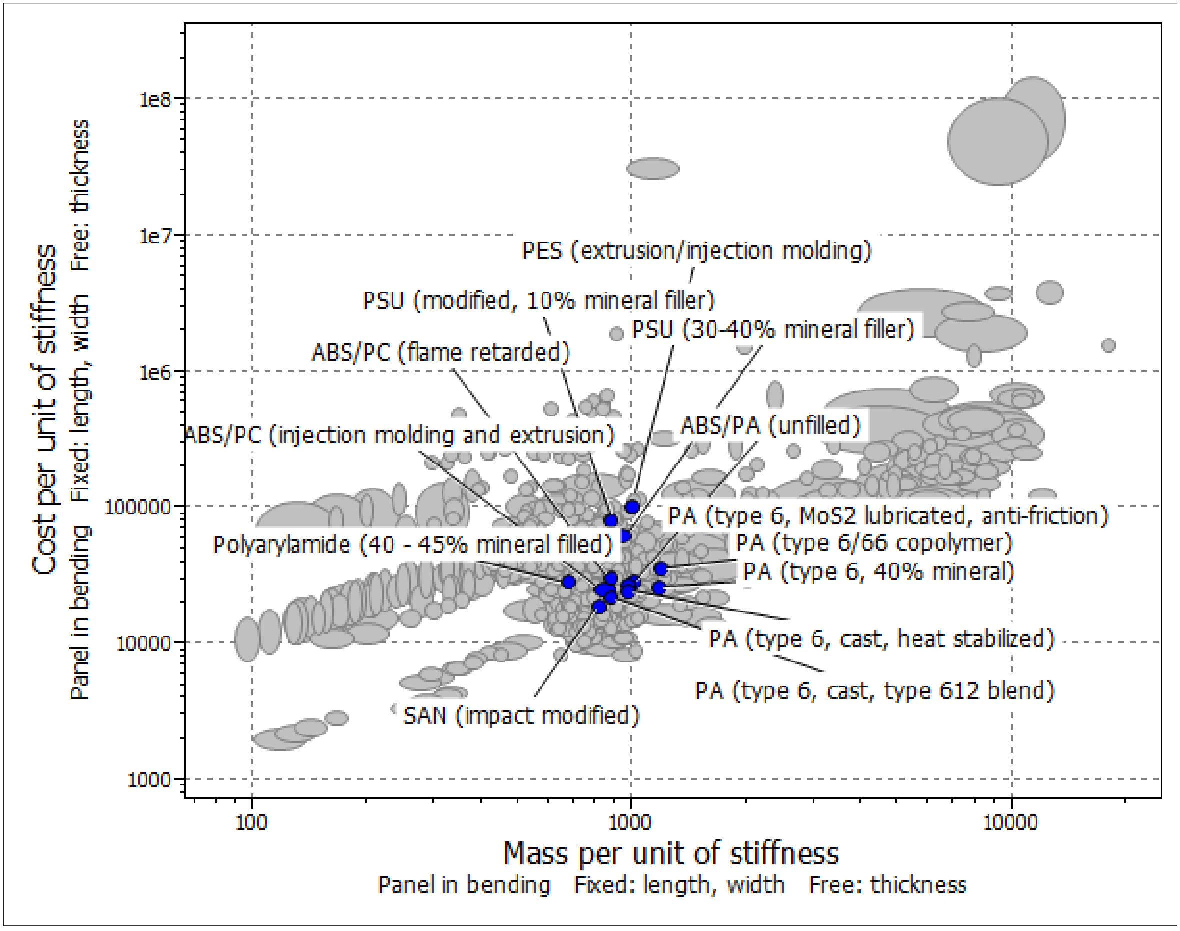
Records passing: All Stages	14 of 810
Ranked by:	Cost per unit of stiffness
Ranked order:	Low to high

Rank	Material	Cost per unit of stiffness
1	SAN (impact modified)	1.79e4 - 1.98e4
2	PA (type 6, cast, type 612 blend)	2.09e4 - 2.34e4
3	PA (type 6, cast, heat stabilized)	2.32e4 - 2.6e4
4	ABS/PC (injection molding and extrusion)	2.38e4 - 2.75e4
5	PA (type 6, 40% mineral)	2.45e4 - 2.74e4
6	ABS/PA (unfilled)	2.57e4 - 2.88e4
7	Polyarylamide (40 - 45% mineral filled)	2.68e4 - 3.07e4
8	PA (type 6, cast, plasticized)	2.73e4 - 3.07e4
9	ABS/PC (flame retarded)	2.86e4 - 3.21e4
10	PA (type 6/66 copolymer)	3.44e4 - 3.85e4
11	PSU (30-40% mineral filler)	5.83e4 - 6.89e4
12	PSU (modified, 10% mineral filler)	7.54e4 - 8.62e4
13	PA (type 6, MoS2 lubricated, anti-friction)	7.62e4 - 8.53e4
14	PES (20% mineral filled)	9.46e4 - 1.11e5

Change number of records to display...

Stage Details

Stage 1:	Mass per unit of stiffness, Cost per unit of stiffness	[Summary]



Axis attributes or formula

Cost per unit of stiffness	[Price]*[Density]/([Flexural modulus]^(1/3))
Mass per unit of stiffness	[Density]/([Flexural modulus]^(1/3))

Display & selection settings:	
Results intersection:	On
Fail estimated records:	Off
Pass when:	Any part of record within selection

Records passing:	809 of 810

Stage 2:	Limiting constraints	Summary

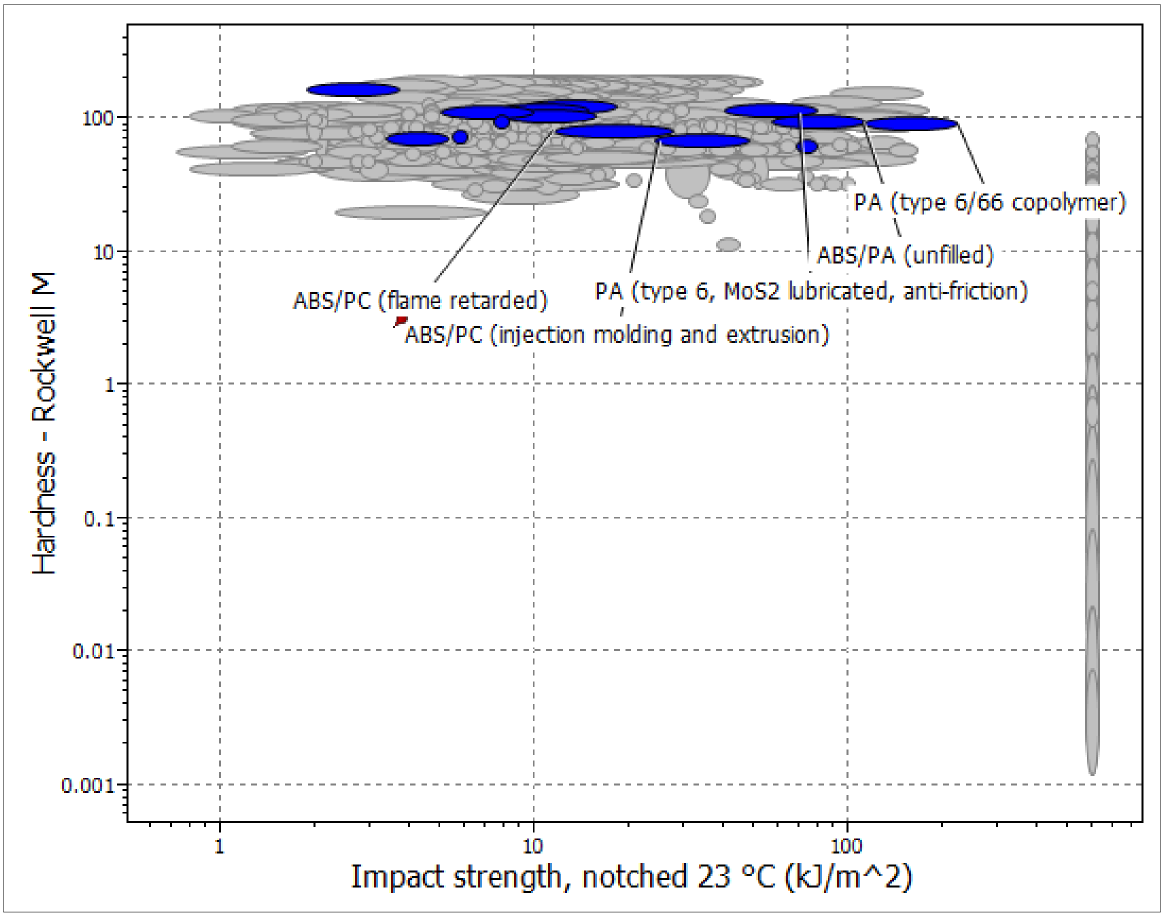
Constraints

Attribute	Constraints
RoHS (EU) compliant grades?	✔
Transparency	Opaque
Water (fresh)	Excellent
Water (salt)	Acceptable
Recycle	✔
Landfill	✔

Display & Selection settings:	
Pass when:	Any part of record within selection

Records passing: 15 of 810

Stage 3:	Impact strength, notched 23 °C (kJ/m^2), Hardness - Rockwell M	Summary



Display & selection settings:	
Results intersection:	On
Fail estimated records:	Off
Pass when:	Any part of record within selection

Records passing: 590 of 810

Stage 4:	Manufacturing process	Summary

Linked Records	Pass
[ProcessUniverse:\Shaping\Molding\Injection]	632
[ProcessUniverse:\Surface treatment\Painting and printing]	770
[ProcessUniverse:\Surface treatment\Surface coatings]	702

Records passing: 777 of 810

Stage 5:	Shape	Summary

Linked Records	Pass
[Shape:\3-D\Solid]	731

Records passing: 731 of 810

Summary – Frame sheetmetal Stage Details

1. Selection data

Database	Polymer Selector
Table	MaterialUniverse
Subset	Metals
Reference	Stainless steel, austenitic, AISI 305, wrought, annealed

2. Selection criteria (summary)

Stage	Attribute	Constraints	Pass
1	Cost per unit of stiffness		1767
	Mass per unit of stiffness		
2	ProcessUniverse	Shaping\Deformation\Sheet	1224
3	Shape	Sheet\Dished\Non-Axisymmetric\Shallow	1522
		Sheet\Flat Sheet\Cutouts	
4	RoHS (EU) compliant grades?	✔	530
	Toxicity rating	Non-toxic	
	Flammability	Non-flammable	
	Water (fresh)	Excellent	
	Water (salt)	Excellent	
	Recycle	✔	
	Landfill	✔	
5	Young's modulus (GPa)		1768
	Hardness - Vickers (HV)		

3. Selection results

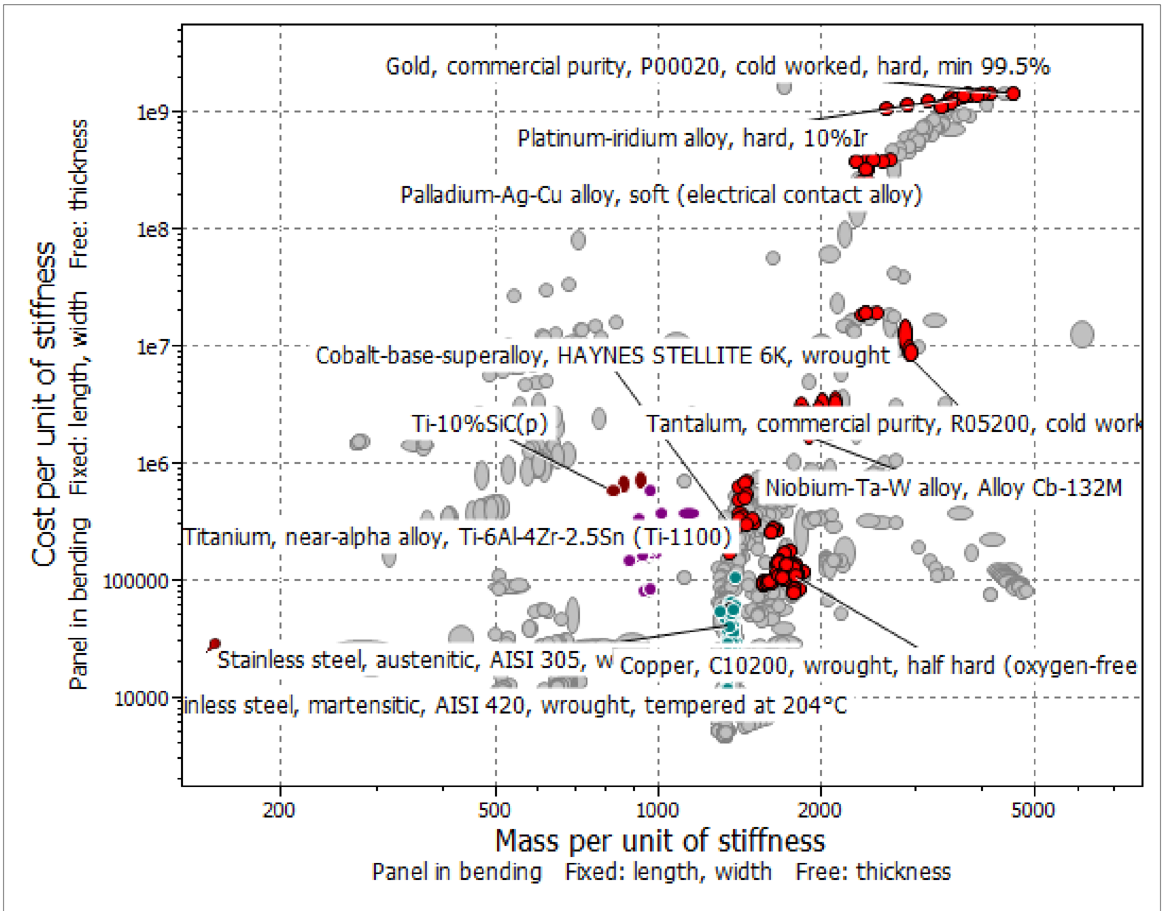
Records passing: All Stages	327 of 1769
Ranked by:	Cost per unit of stiffness
Ranked order:	Low to high

Rank	Material	Cost per unit of stiffness
1	Stainless steel, martensitic, AISI 420, wrought, tempered at 204°C	8.89e3 - 9.84e3

2	Stainless steel, martensitic, AISI 410S, wrought, annealed	9.59e3 - 1.06e4
3	Stainless steel, martensitic, AISI 410, wrought, annealed	1e4 - 1.11e4
4	Stainless steel, martensitic, AISI 410, wrought, hard temper	1e4 - 1.11e4
5	Stainless steel, martensitic, AISI 410, wrought, intermediate temper	1e4 - 1.11e4
6	Stainless steel, martensitic, 420S29, wrought	1.13e4 - 1.25e4
7	Stainless steel, martensitic, 416S41, wrought	1.15e4 - 1.27e4
8	Stainless steel, martensitic, AISI 440A, wrought, tempered at 316°C	1.29e4 - 1.44e4
9	Stainless steel, martensitic, AISI 440C, wrought, tempered at 316°C	1.29e4 - 1.44e4
10	Stainless steel, martensitic, AISI 440B, wrought, annealed	1.29e4 - 1.44e4

Change number of records to display... Stage Details

Stage 1:	**Mass per unit of stiffness, Cost per unit of stiffness**	Summary



Axis attributes or formula

Cost per unit of stiffness	[Price]*[Density]/([Flexural modulus]^(1/3))
Mass per unit of stiffness	[Density]/([Flexural modulus]^(1/3))

Display & selection settings:	
Results intersection:	On
Fail estimated records:	Off
Pass when:	Any part of record within selection

Records passing: 1767 of 1769

Stage 2:	Manufacturing process	Summary

Linked Records **Pass**

	[ProcessUniverse:\Shaping\Deformation\Sheet]	1224

Records passing: 1224 of 1769

Stage 3:	Shape	Summary

Linked Records **Pass**

	[Shape:\Sheet\Dished\Non-Axisymmetric\Shallow]	1426
	[Shape:\Sheet\Flat Sheet\Cutouts]	1522

Records passing: 1522 of 1769

Stage 4:	Limiting constraints	Summary

Constraints

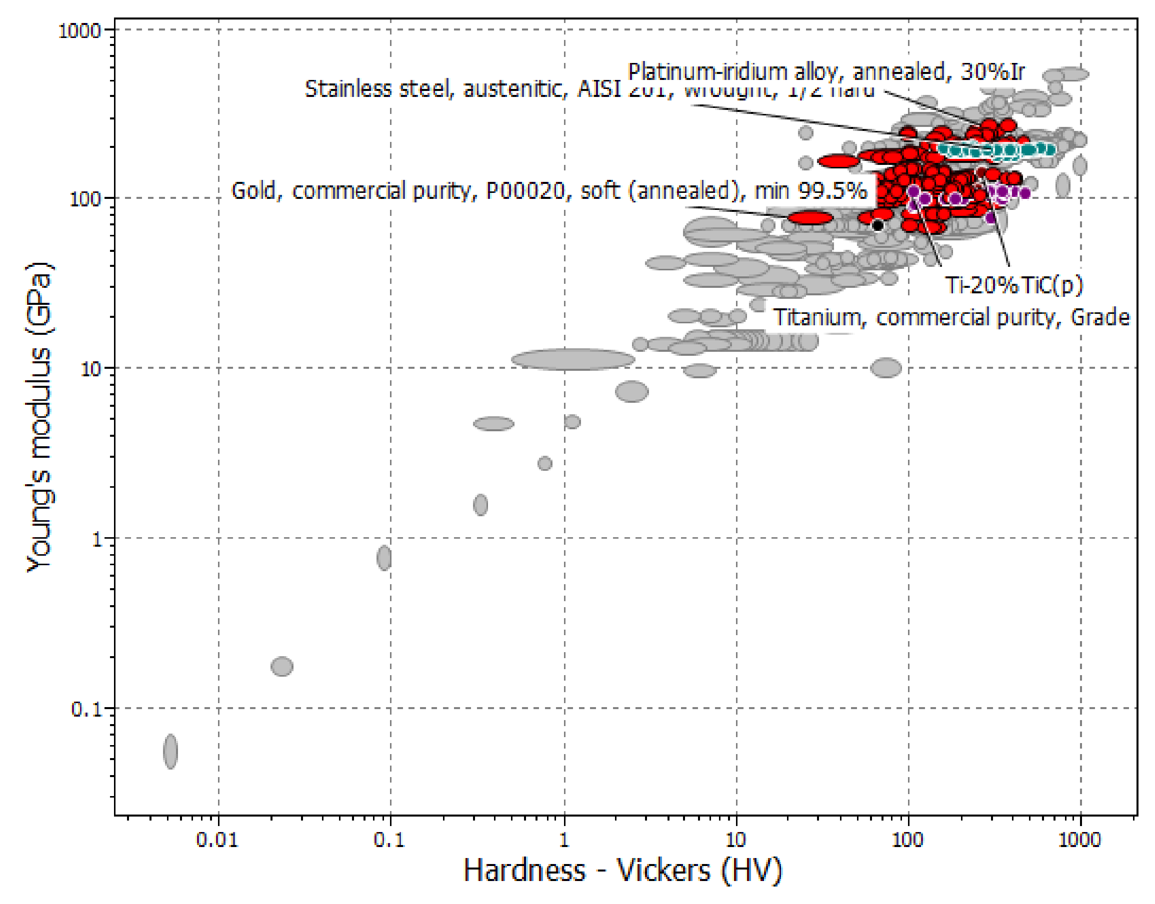
Attribute	Constraints
RoHS (EU) compliant grades?	✓
Toxicity rating	Non-toxic
Flammability	Non-flammable
Water (fresh)	Excellent
Water (salt)	Excellent
Recycle	✓
Landfill	✓

Display & Selection settings:

Pass when: Any part of record within selection

Records passing: 530 of 1769

Stage 5:	Hardness - Vickers (HV), Young's modulus (GPa)	Summary



Display & selection settings:	
Results intersection:	On
Fail estimated records:	Off
Pass when:	Any part of record within selection

Records passing: 1768 of 1769

Summary - Window

Stage Details

1. Selection data

Database	Polymer Selector
Table	MaterialUniverse
Subset	All materials
Reference	PMMA (molding and extrusion)

2. Selection criteria (summary)

Stage	Attribute	Constraints	Pass
1	Cost per unit of stiffness		3762
	Mass per unit of stiffness		
2	Shape	3-D\Solid	3282
3	ProcessUniverse	Shaping	3782
		Surface treatment	
4	RoHS (EU) compliant grades?	✓	15
	Toxicity rating	Non-toxic	
	Transparency	Optical quality	
	Water (fresh)	Excellent	
	Water (salt)	Excellent	
	Landfill	✓	
5	Fracture toughness (MPa.m^0.5)		3318
	Hardness - Vickers (HV)		
6	Cost per unit of stiffness		3634
	Yield strength (elastic limit) (MPa)		

3. Selection results

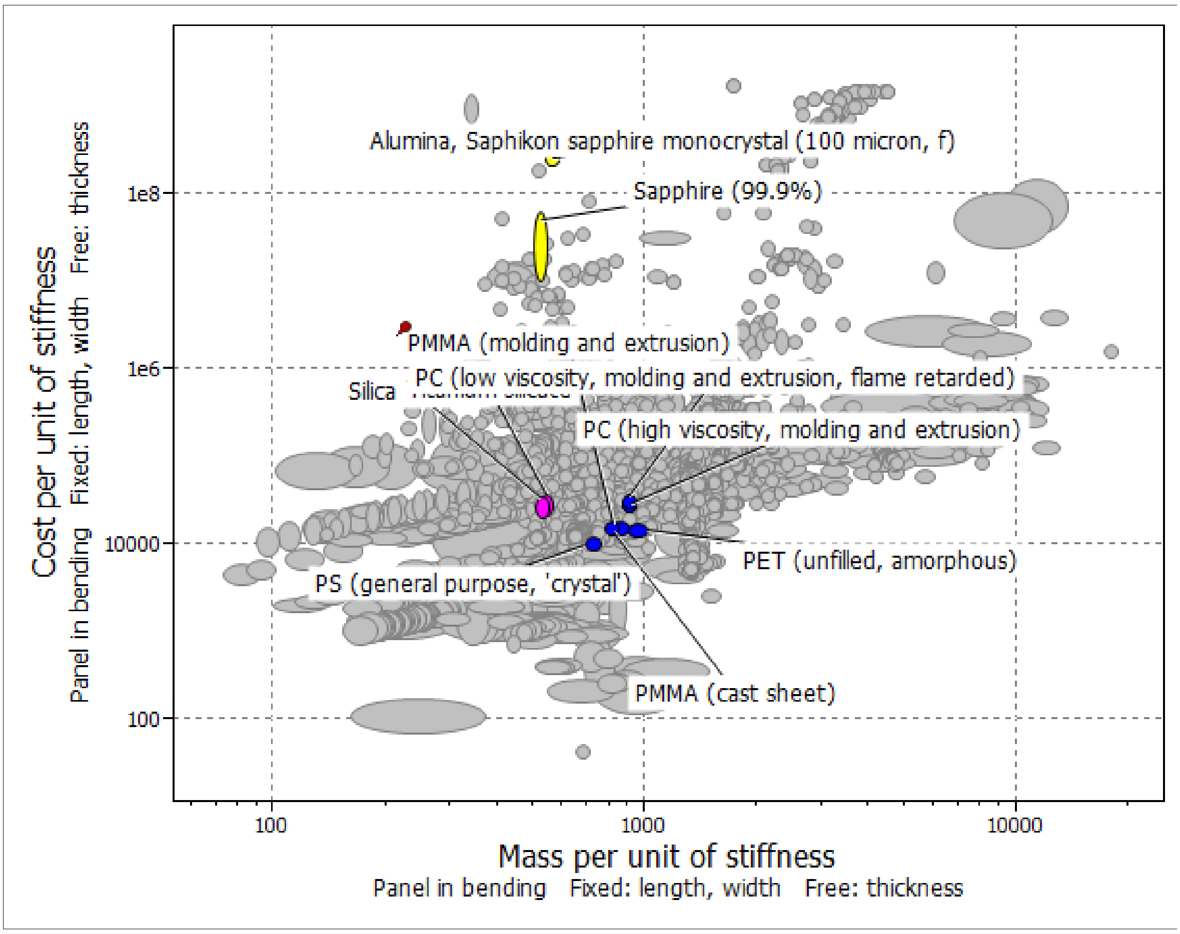
Records passing: All Stages	11 of 3836
Ranked by:	Cost per unit of stiffness
Ranked order:	Low to high

Rank	Material	Cost per unit of stiffness
1	PS (general purpose, 'crystal')	9.46e3 - 1.07e4
2	PET (unfilled, amorphous)	1.34e4 - 1.55e4

3	PMMA (cast sheet)	1.41e4 - 1.56e4
4	PMMA (molding and extrusion)	1.45e4 - 1.68e4
5	Silica (fused)	2.06e4 - 3.44e4
6	Titanium silicate	2.12e4 - 3.54e4
7	PC (low viscosity, molding and extrusion)	2.6e4 - 2.87e4
8	PC (high viscosity, molding and extrusion)	2.6e4 - 2.87e4
9	PC (low viscosity, molding and extrusion, flame retarded)	2.95e4 - 3.25e4
10	Sapphire (99.9%)	1.03e7 - 6.15e7
11	Sapphire (single crystal)	2.41e8 - 2.58e8

Change number of records to display... Stage Details

Stage 1:	**Mass per unit of stiffness, Cost per unit of stiffness**	Summary



Axis attributes or formula

Cost per unit of stiffness	[Price]*[Density]/([Flexural modulus]^(1/3))
Mass per unit of stiffness	[Density]/([Flexural modulus]^(1/3))

Display & selection settings:	
Results intersection:	On
Fail estimated records:	Off
Pass when:	Any part of record within selection

Records passing: 3762 of 3836

Stage 2:	Shape	Summary

Linked Records **Pass**

[Shape:\3-D\Solid]	3282

Records passing: 3282 of 3836

Stage 3:	Manufacturing process	Summary

Linked Records **Pass**

[ProcessUniverse:\Shaping]	3737
[ProcessUniverse:\Surface treatment]	3669

Records passing: 3782 of 3836

Stage 4:	Limiting constraints	Summary

Notes:
Sapphire crystal passes for RECYCLE switched off

Constraints

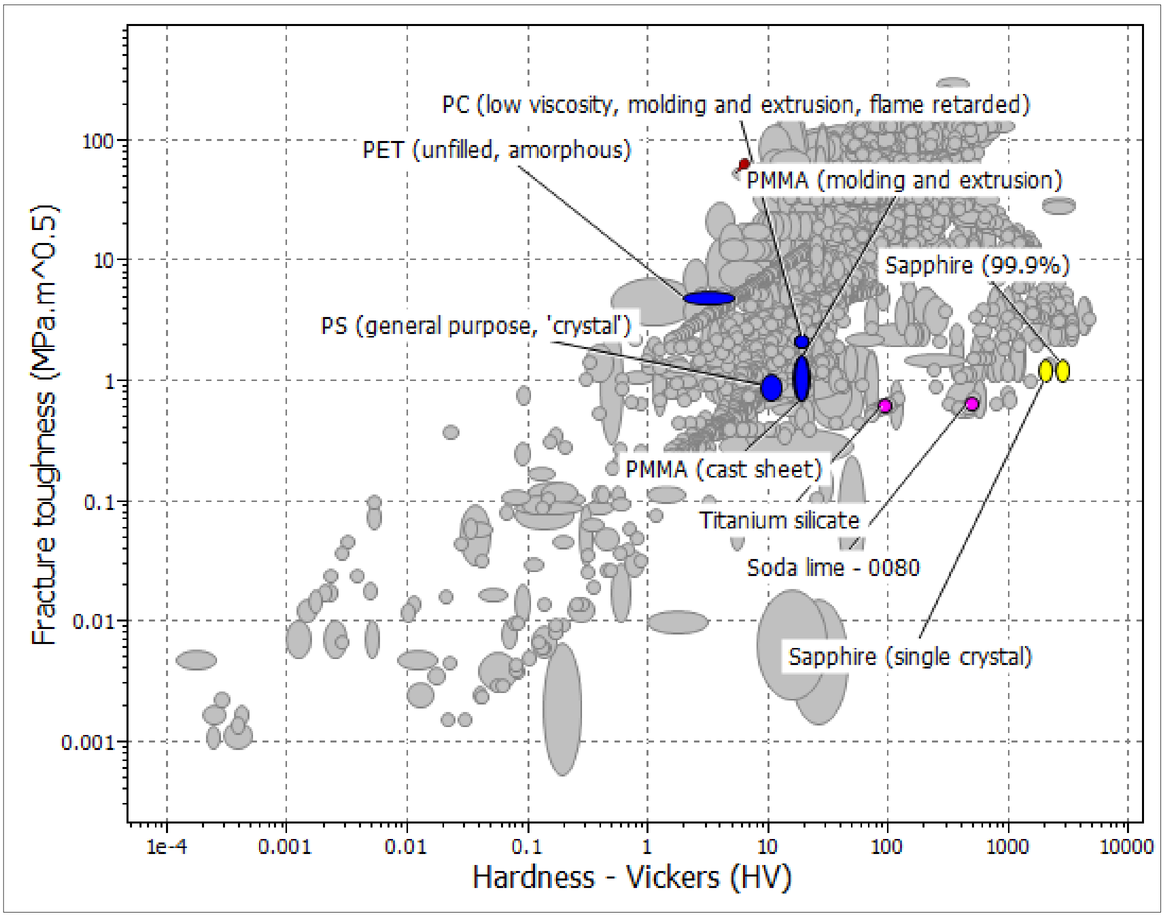
Attribute	Constraints
RoHS (EU) compliant grades?	✓
Toxicity rating	Non-toxic
Transparency	Optical quality
Water (fresh)	Excellent
Water (salt)	Excellent
Landfill	✓

Display & Selection settings:

Pass when: Any part of record within selection

Records passing: 15 of 3836

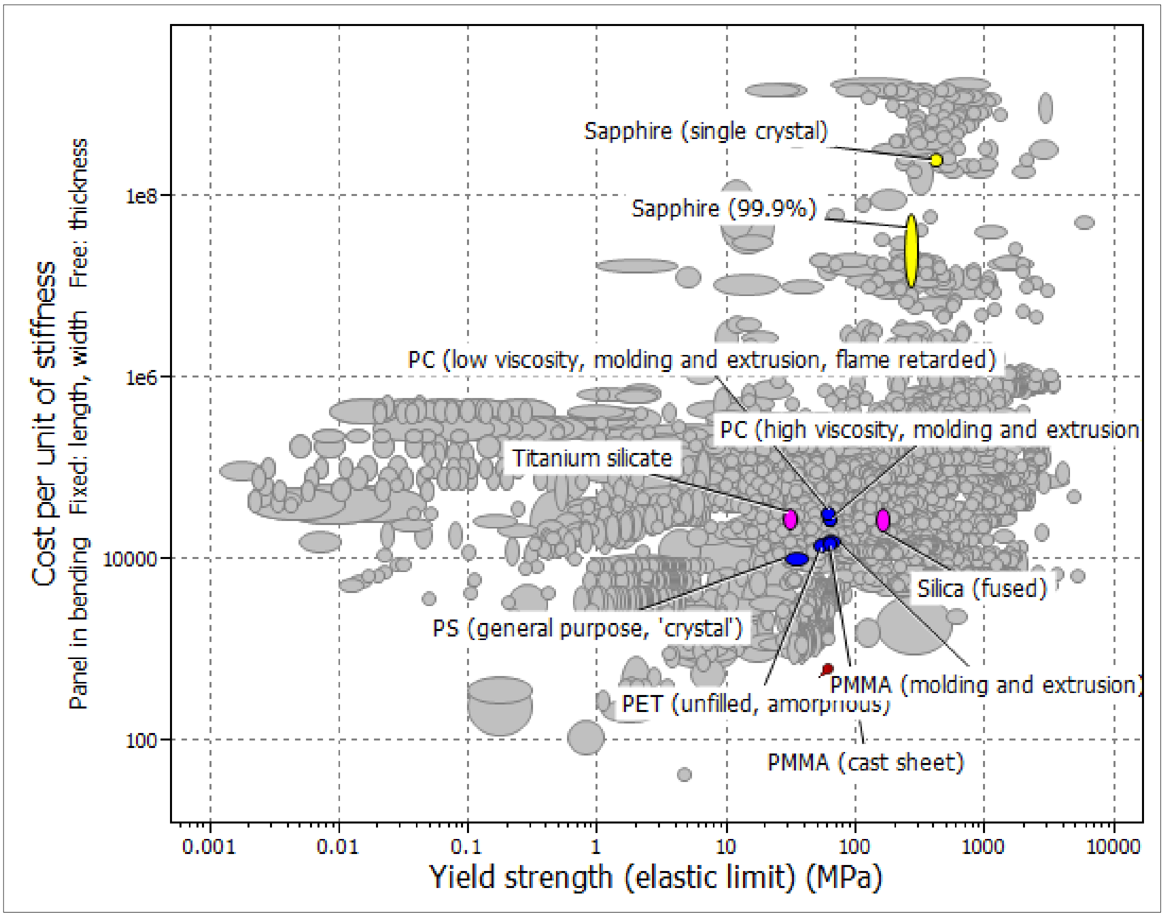
Stage 5:	Hardness - Vickers (HV), Fracture toughness (MPa.m^0.5)	Summary



Display & selection settings:	
Results intersection:	On
Fail estimated records:	Off
Pass when:	Any part of record within selection

Records passing: 3318 of 3836

Stage 6:	Yield strength (elastic limit) (MPa), Cost per unit of stiffness	[Summary](#)



Axis attributes or formula

Cost per unit of stiffness	[Price]*[Density]/([Flexural modulus]^(1/3))

Display & selection settings:	
Results intersection:	On
Fail estimated records:	Off
Pass when:	Any part of record within selection

Records passing:	3634 of 3836

Summary – Attachment clip

Stage Details

1. Selection data

Database	Polymer Selector
Table	MaterialUniverse
Subset	Polymers - All
Reference	PA (type 12, unfilled)

2. Selection criteria (summary)

Stage	Attribute	Constraints	Pass
1	Elastic flexibility		806
	Price (SEK/kg)		
2	Shape	3-D\Solid	731
3	ProcessUniverse	Shaping\Molding\Injection	777
		Surface treatment\Painting and printing	
		Surface treatment\Surface coatings	
4	RoHS (EU) compliant grades?	✔	19
	Toxicity rating	Non-toxic	
	Flammability	Self-extinguishing	
	Water (fresh)	Excellent	
	Water (salt)	Excellent	
	Recycle	✔	
	Landfill	✔	

3. Selection results

Records passing: All Stages 14 of 810

Ranked by: Price (SEK/kg)

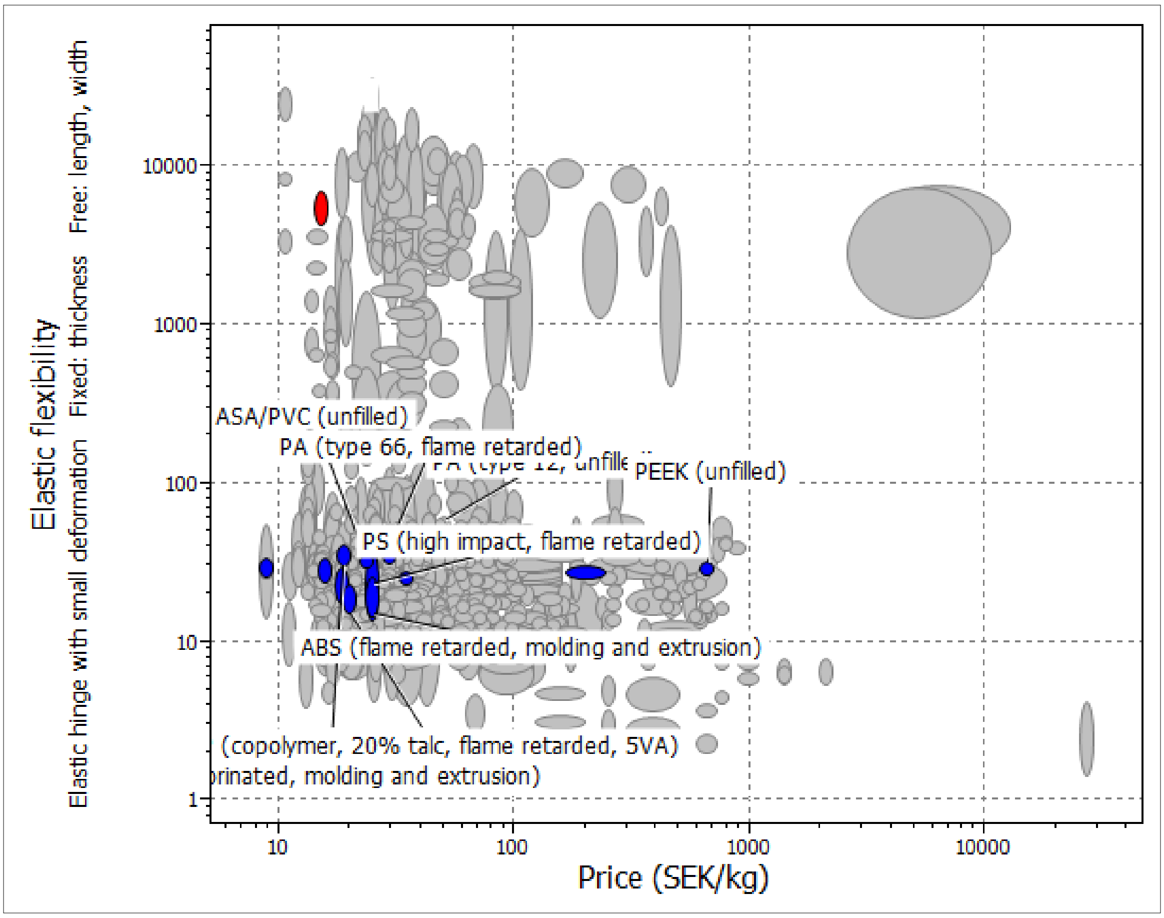
Ranked order: Low to high

Rank	Material	Price (SEK/kg)
1	PVC (rigid, molding and extrusion)	8.34 - 9.17

2	PVC-elastomer (Shore A75, flame retarded)	14.2 - 15.6
3	PVC (rigid, high impact, molding and extrusion)	14.8 - 16.2
4	PP (homopolymer, flame retarded V-0)	17.4 - 19.2
5	PVC (chlorinated, molding and extrusion)	17.7 - 19.5
6	PP (copolymer, 20% talc, flame retarded, 5VA)	19 - 20.9
7	ASA/PVC (unfilled)	22.2 - 24.4
8	PS (high impact, flame retarded)	23.5 - 25.9
9	ABS (flame retarded, molding and extrusion)	23.5 - 25.9
10	PA (type 66, flame retarded)	28 - 30.8
11	PC (low viscosity, molding and extrusion, flame retarded)	32.9 - 36.2
12	PEI (unfilled)	111 - 123
13	ETFE (unfilled)	168 - 241
14	PEEK (unfilled)	627 - 689

Change number of records to display... Stage Details

Stage 1:	Price (SEK/kg), Elastic flexibility	Summary



Axis attributes or formula

Elastic flexibility	[Flexural strength (modulus of rupture)]/[Flexural modulus]

Display & selection settings:	
Results intersection:	On
Fail estimated records:	Off
Pass when:	Any part of record within selection

Records passing: 806 of 810

Stage 2:	**Shape**	Summary

Linked Records	**Pass**
[Shape:\3-D\Solid]	731

Records passing: 731 of 810

Stage 3:	**Manufacturing process**	Summary

Linked Records	**Pass**
[ProcessUniverse:\Shaping\Molding\Injection]	632
[ProcessUniverse:\Surface treatment\Painting and printing]	770
[ProcessUniverse:\Surface treatment\Surface coatings]	702

Records passing: 777 of 810

Stage 4:	**Limiting constraints**	Summary

Constraints

Attribute	Constraints
RoHS (EU) compliant grades?	✔
Toxicity rating	Non-toxic
Flammability	Self-extinguishing
Water (fresh)	Excellent
Water (salt)	Excellent
Recycle	✔
Landfill	✔

Display & Selection settings:

Pass when:	Any part of record within selection

Records passing: 19 of 810

Summary – Sealing gasket Stage Details

1. Selection data

Database	Polymer Selector
Table	MaterialUniverse
Subset	Polymers - Elastomers
Reference	SEBS (Shore A65)

2. Selection criteria (summary)

Stage	Attribute	Constraints	Pass
1	((Yield strength (elastic limit) ^ (3 / 2)) / Young's modulus)		125
	Price (SEK/kg)		
2	Shape	3-D\Solid	81
3	ProcessUniverse	Shaping	126
		Surface treatment\Painting and printing	
		Surface treatment\Surface coatings	
4	RoHS (EU) compliant grades?	✓	35
	Water (fresh)	Excellent	
	Water (salt)	Excellent	
	Weak acids	Excellent	
	Weak alkalis	Excellent	
	Strong alkalis	Excellent	
	Recycle	✓	
	Landfill	✓	
5	Tear strength (N/mm)		109
	Price (SEK/kg)		

3. Selection results

Records passing: All Stages	33 of 126
Ranked by:	Price (SEK/kg)
Ranked order:	Low to high

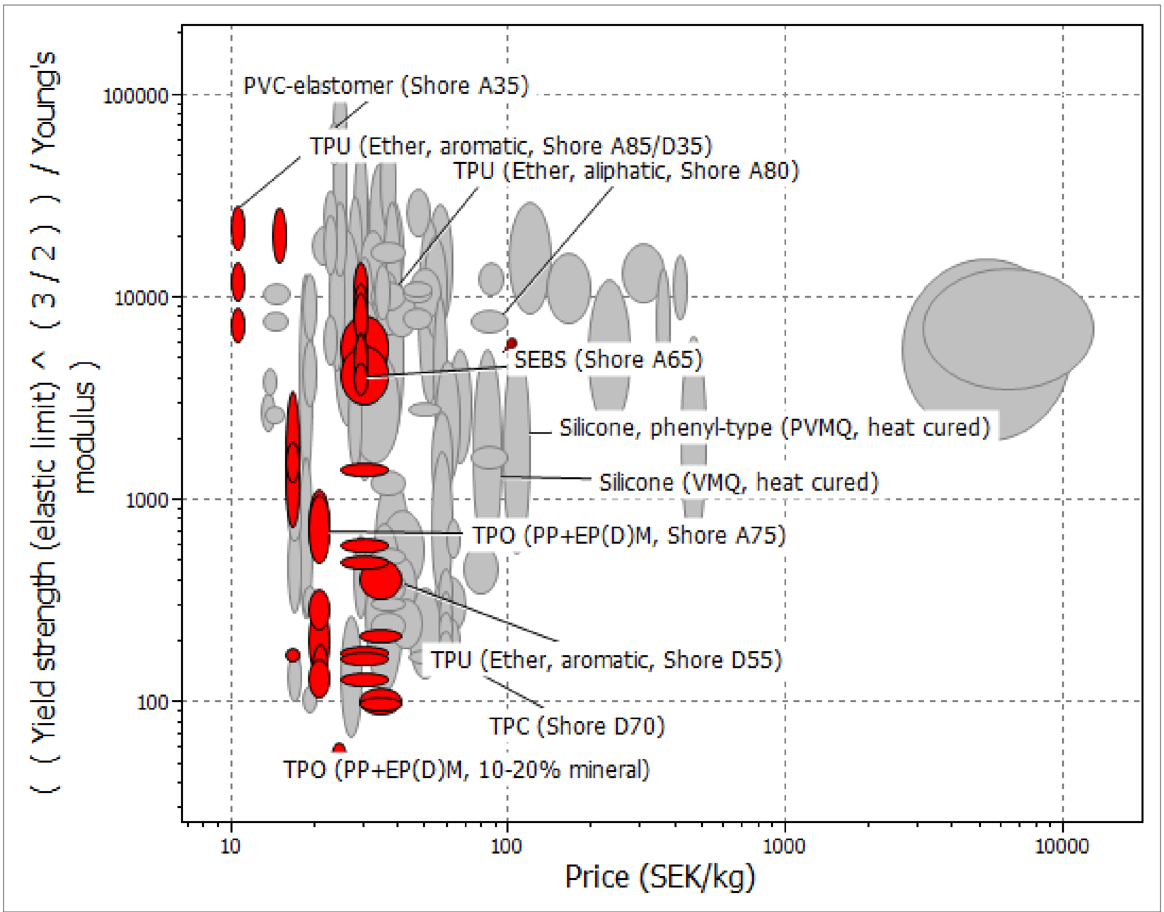
Rank	Material	Price (SEK/kg)
1	PVC-elastomer (Shore A75)	10.1 - 11
2	PVC-elastomer (Shore A55)	10.1 - 11
3	PVC-elastomer (Shore A35)	10.1 - 11
4	PVC-elastomer (Shore A75, flame retarded)	14.2 - 15.6
5	POE/POP (Propylene-based, Shore A80)	15.7 - 17.3
6	POE/POP (Ethylene-based, Shore A90/D40)	15.7 - 17.3
7	POE/POP (Ethylene-based, Shore A80)	15.7 - 17.3
8	POE/POP (Ethylene-based, Shore A65)	15.7 - 17.3
9	TPO (PP+EP(D)M, Shore D60)	19.3 - 22.4
10	TPO (PP+EP(D)M, Shore D50)	19.3 - 22.4

Change number of records to display... Stage Details

Stage 1:	Price (SEK/kg), ((Yield strength (elastic limit) ^ (3 / 2)) / Young's modulus)	Summary

Notes:

Maximize this value



Display & selection settings:

Results intersection:	On
Fail estimated records:	Off
Pass when:	Any part of record within selection

Records passing: 125 of 126

Stage 2:	Shape	Summary

Linked Records	Pass
[Shape:\3-D\Solid]	81

Records passing: 81 of 126

Stage 3:	Manufacturing process	Summary

Linked Records	Pass
[ProcessUniverse:\Shaping]	126
[ProcessUniverse:\Surface treatment\Painting and printing]	124
[ProcessUniverse:\Surface treatment\Surface coatings]	51

Records passing: 126 of 126

Stage 4:	Limiting constraints	Summary

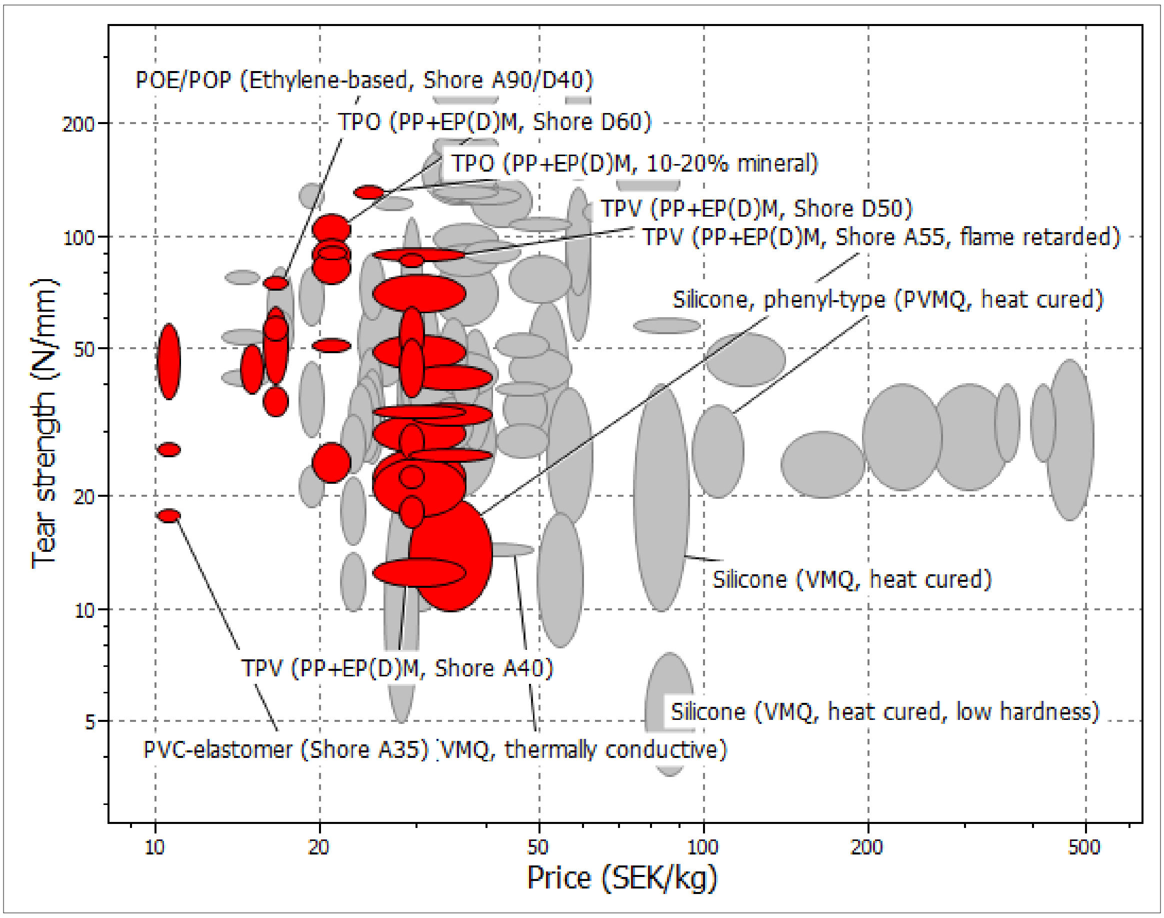
Constraints

Attribute	Constraints
RoHS (EU) compliant grades?	✓
Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Excellent
Weak alkalis	Excellent
Strong alkalis	Excellent
Recycle	✓
Landfill	✓

Display & Selection settings:	
Pass when:	Any part of record within selection

Records passing: 35 of 126

Stage 5:	Price (SEK/kg), Tear strength (N/mm)	Summary



Display & selection settings:	
Results intersection:	On
Fail estimated records:	Off
Pass when:	Any part of record within selection

Records passing: 109 of 126

12.7 APPENDIX.G – CD-ROM

Some of the content that were not possible to present it in paper format are saved in digital format along with the report and above listed appendix. The lists of contents that are included in the CD-ROM are:

1. Benchmarking reports of Sonim, Samsung, Siemens and Sony Ericsson phones
2. CAD files of three concepts in IGES and STP format
3. Material selection templates