escola superior de tecnologia e gestão
instituto politécnico de leiria

Product Innovation for Food Packaging Industry

Master in Product Design Engineering

Pramol Jain Mandya Nagesh

Leiria, March, 2022

escola superior de tecnologia e gestão
instituto politécnico de leiria

PRODUCT INNOVATION FOR FOOD PACKAGING INDUSTRY

Master in Product Design Engineering

Pramol Jain Mandya Nagesh

Master's Internship report held under the guidance of Professor João Matias of the Higher School of Technology and Management of the Polytechnic Institute of Leiria and Professor Fábio Simões, Professor at the Higher School of Technology and Management of the Polytechnic Institute of Leiria.

Leiria, March 2022

Acknowledgements

I sincerely thanks to Sr.Pedro, CEO of Plásticos Futura for giving the wonderful opportunity to perform my internship and all the team members of the organization for making my internship journey fruitful. I also thank Professor Fábio Simões and Professor João Matias for making an gateway to the organization and a space for exploring the industrial experience.

Abstract

This academic report is detailed with an objective of designing food packaging products for specific volume considering all the aspects required to manufacture from customer needs, design methodologies and an attempt launching the designed product to the market. This objective is carried out at an esteemed host enterprise "Plásticos Futura Lda" utilizing licensed software tools to design the product. Food packaging is a critical part of the food industry where processed food products are packaged, delivered, and displayed in retail stores. Food packaging by definition is a highly competitive industry in order to thrive, key factors such as creativity, adaptation to new technology, and patterns are important. To meet the global demand for food, advanced manufacturing technologies have enabled industry to produce complex goods in a short time frame resulting in greater benefits for both manufacturers and end users. The intern program deals with the developing of innovative products that are much sustainable and reusable in order to adhere the circular economy with the better usage of engineering methods right from product development to manufacturing of end product. Need for innovative solutions are key factors that enhances the individual thought process which assist to overcome all the obstacles in the manufacturing industry. This internship program also fulfils the need of every aspect of product design, development, economics, manufacturing methods, material selection, product performance evaluation, prototyping and testing of the product by FEA analysis to ensure the product's safety for different loading conditions which is a right way from idea to real functional product. Being said the world is moving towards the greener side and demanding for more environmentally sustainable products, the rapid developments that are being occurred in materials is being concluded that it is not impossible to develop the same product with bio based polymers for more bio-degradable, cleaner and greener environment.

Keywords: Innovation, circular economy, sustainable, FEA, Food packaging, manufacturing, prototyping, bio degradable...

Resumo

Este relatório acadêmico é detalhado com o objetivo de projetar produtos de embalagem de alimentos para volume específico considerando todos os aspectos necessários à fabricação a partir das necessidades do cliente, metodologias de design e uma tentativa de lançamento do produto projetado no mercado. Este objectivo é realizado numa conceituada empresa de acolhimento "Plásticos Futura Lda" utilizando ferramentas de software para projetar o produto. A embalagem de alimentos é uma parte crítica da indústria alimentícia, onde os produtos alimentícios processados são embalados, entregues e exibidos em lojas de varejo. A embalagem de alimentos por definição é uma indústria altamente competitiva para prosperar, fatores-chave como criatividade, adaptação a novas tecnologias e padrões são importantes. Para atender à demanda global por alimentos, tecnologias avançadas de fabricação permitiram que a indústria produzisse bens complexos em um curto espaço de tempo, resultando em maiores benefícios tanto para os fabricantes quanto para os usuários finais. O programa de estágio trata do desenvolvimento de produtos inovadores, bastante sustentáveis e reutilizáveis para aderir à economia circular com o melhor uso de métodos de engenharia desde o desenvolvimento do produto até a fabricação do produto final. A necessidade de soluções inovadoras são fatores-chave que potencializam o processo de pensamento individual que auxiliam na superação de todos os obstáculos da indústria manufatureira. Este programa de estágio também atende a necessidade de todos os aspectos do projeto do produto, desenvolvimento, economia, métodos de fabricação, seleção de materiais, avaliação de desempenho do produto, prototipagem e teste do produto por análise FEA para garantir a segurança do produto para diferentes condições de carregamento, o que é um direito caminho da ideia ao produto funcional real. Dito que o mundo caminha para o lado mais verde e exige produtos mais sustentáveis do ponto de vista ambiental, os rápidos desenvolvimentos que estão ocorrendo em materiais estão se concluindo que não é impossível desenvolver o mesmo produto com polímeros de base biológica para materiais mais biodegradáveis, ambiente mais limpo e verde.

Palavras-chave: (*Inovação, economia circular, sustentável, FEA, embalagens de alimentos, prototipagem*)

List of Figures

List of Tables

List of Abbreviations

PET - PolyEthylene Terephthalate

FEA - Finite Elemental Analysis

CAD - Computer Aided Drawing

FDM - Fused Deposition Method

HDPE - High Density PolyEthylene

LDPE - Low Density PolyEthylene

PP - PolyPropylene

PS - PolyStyrene

HOQ - House Of Quality

Contents

1 Introduction

Storing food is been inherited for humans from the ancient times, people used to store food based on the regions they live, seasonal food storage in hot zone where food availability is limited. Storing of food in a healthy environment is crucial so food products are safeguarded and maintained fresh in order to use it for the longer life cycle. In order to maintain its original freshness, restriction of environmental air contact to the food should be ensured.

As the technology and human evolution started to grow exponentially, usage of glass, wood, plastics, ceramics, metal for manufacturing of kitchen storage grew year after year. Increase in food demand gave birth to more demand for storage of food at home, once the storing food in glass was a luxury became essential habit in all economic zones of society.

Glass was the ideal choice for food storage in every household till mid 20th century, when manufacturers grasped and mastered the technology of plastic it made a revolution in the food market, plastic became the replacement of most materials (glass, wood, metal) in kitchen storage at every household across the globe.

1.1 Food Packaging Industry and Valuation

Food packaging has progressed from food storage to an important factor in maintaining food quality [1]. The packaging keeps the food safe and prolongs its shelf life by providing a layer of shield from environment, chemical and physical damages during storage and transportation [2]. Increasing market segmentation and the development of global food and drinks supply chains have encouraged the adoption of sophisticated packaging systems[3].

A variety of improvements have been made in food quality, allowing people to enjoy a varied range of foods throughout the year. In today's world of consumerism, plastic and polymers have become the most preferred materials in the packaging sector. Plastic is the most commonly used packing material, accounting for 53 percent of all products marketed globally [4]. Plastic, on the other hand, is a lightweight materials with high relative strength, making it one of the most energy efficient, robust, and cost-effective packaging solutions available [5].

The global food packaging market was valued at USD 305.29 Billion in 2019 and expected to reach USD 464.98 Billion by 2027 and poised to grow at a compound annual growth rate (CAGR) 5.4% during the forecast period 2020 to 2027 [6], observing the forecast data,there is a huge space for innovation in packaging products and can be achieved by better understanding of market demand and good product design.

1.2 Internship Program

Internship program are being performed at **Plásticos Futura Lda** as an intern which is an part of the course curriculum. Program is designed for total of 1440 hrs, which is equivalent to working 8 hr/ day for total of 180 working days. The main objective of the program were to design the food packaging products to the specific capacity (volume), shape and built in characteristics considering all the aspects of manufacturing and design methodologies as per the customer needs.

To design and develop the products,the host company utilizes the licensed tools like 'Solidworks', 'Solidworks-Visualizer', 'Solidworks-Simulator', 'Adobe-Illustator' and 'Adobe-Photoshop'. The tasks were assigned as projects with the project timeline (Figure 1.1). To begin with, first month was mainly focused on understanding the design tools (how it works), work methodology (approach towards task), product line(range of products that are manufactured at the host company). The tasks were assigned in the consecutive months that are have explained in the further reading.

Project - Square jar was assigned with the timeline of 3 weeks, the objective is to design and develop a square shaped jar with the capacity of 1l, 1.5l, 2l, 2.5l, 3l. The challenge part of the project is to scale the existing top lid (designed for lower capacity) to fit the need of the jar without excluding any of its functionality.

Project-Protein jar was assigned with the time line of 5 weeks, the objective being to design and develop a jar that can hold a protein powders and other supplements. The design of jar to be more muscular like aesthetics, with different color options of jars and lid to choose. The task also includes to design a label which also fulfill the objective and branding logo of the customer.

Innovative **Project-Icemaker** for one of the loyal customer of the host company aiming to design and develop the innovative product to enhance the brand image globally. A time line of 4 weeks were assigned for creation of complete product concept with inclusion of product rendering and 3D modeling as well. The development process of the project is discussed in chapter 4.2.

Project-Giga 195, as name goes, the objective of the project to design and develop the jars of higher capacity - 2l, 3l, 4l and 6l.The project timeline of 3 weeks for design development

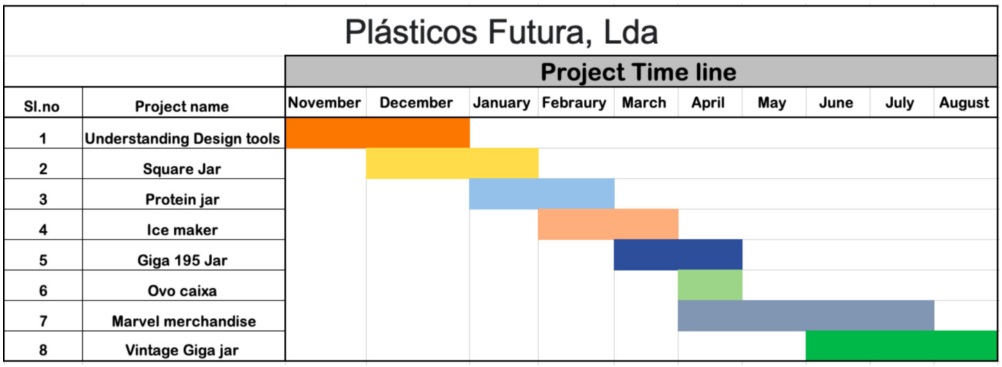

Figure 1.1: Project Timeline

process were assigned. The project also requires the design of labels to showcase the products that can fit the jar being designed.

Project-Ovo caixa, the aim is to design the innovative storage box to store and transport the eggs with the timeline of 2 weeks. A concept were developed and proposed to the customer. The challenge is to design the box so as to reduce the breakage of eggs when stored and transported to supermarkerts.

Project-Marvel merchandise, the aim of the project is to design the four products that is lunch box, fruit-box, water bottle, dry fruit box with the time line of 10 weeks with the challenge of showcasing three concepts for each product that have been described. The project demands for innovation, the project were showcased to the customer with all the innovative concepts that were being developed. Far most the challenging project of the entire internship program.

Project-Vintage giga jar, the aim of the project is to design and develop the vintage style jars. The timeline of 8 weeks for concept development, product rendering, label design for the same product showcasing the products that can fit the jar. Detail development process is discussed in the chapter 4.1 as a part of development process.

Total of Eight projects were being carried out in the internship program, two of which are explained in detail in the current report work. Some of the information are not described/showcased because of the confidentiality and disclaimer agreement between customer and host company. Further reading describes the report structure and product that have been developed in detail.

1.3 Report Structure

The work is covered in seven chapters and glimpse of work is stated as below.

- Chapter 1 is detailed with the food packaging and global valuation and the aim of the entire work carried out.
- Chapter 2 describes the host company regarding the milestone, mission, vision, quality policy and other technological features.
- Chapter 3 describes the usage of best technologies in manufacturing facility, the aim of this chapter is to explain the technologies that are being utilized to manufacture the products.
- Chapter 4 describes the design and development stages, as saying goes "Design is the best ambassador of your brand". The chapter covers the entire design and development stage of two products that are designed as a internship program from concepts to 3D modeling being abbreviated.
- Chapter 5 describes the analysis of the designed product performance as per the required specification, the product is analysed using FEA (Finite Element Analysis) analysis so further manufacturing errors can be easily mapped. Analysis also boost the confidence in the designed product. Buckling test, Squeeze load test and factor of safety test is simulated as analysis.
- Chapter 6 is focused on prototyping of the designed products using rapid prototyping technology (FDM-Fused deposition Method). A economic way of prototyping to understand the product shape and size in real world scenario.
- Chapter 7 contains a brief conclusion for the better design approach.

2 Characteristics of Host company

Plásticos Futura is specialized in developing innovative packaging and also manufacturer of products for the Medical, Pharmaceutical, Cosmetics and food industries. The establishment took place in the year 1977 (Figure 2.1). The firm utilizes advanced manufacturing technologies in injection moulding, blow moulding and thermoforming as a way of manufacturing process. It is located at Rua José Alves Júnior, S/N, Cumeiras, Marinha Grande, 2430-350 Leiria, Portugal.

The company is equipped with integration of advance robotics and automation systems in order to fulfil the demanding orders on time with the highest possible quality. The company is having their market footprints in Europe, North America, South America, Africa, Russia resulting over four hundred plus happy customers and adding more. The company also specializes in product design and product prototyping using the advance rapid prototyping technology.

Figure 2.1: Manufacturing facility of Plásticos Futura [7]

2.1 Company Quality Policy

The quality policy settles in conceiving and manufacturing plastic packaging and medical devices which satisfies client's requirements, food safety and the current legal requirements, at the lowest cost ensuring the sustainability of the business.

Plásticos Futura Lda Management System is managed in accordance with the normative references **ISO:9001, ISO:22000** and **ISO:13485**. While executing the standard **IFS PAC** Secure. Design and development of a product or service is a vital process, and the accuracy of the output from this phase has a significant impact on the quality of final product or service. Design and development planning, capturing design and development inputs, review, verification and validation, documenting design and development outputs, and managing any modifications to design and development are all specific requirements which are stated by above mentioned ISO norms.

2.2 Company Service

Constant innovation is what makes company sail in the business. From the stage of idea to the final product, there is a defined team that trace every stage of development so that no details are missed out in phase of the project movement. A complete product service road map are listed which includes the set of manufacturing technologies implemented, prototyping methods, certification obtained for producing the products. The company also allocate a dedicated team for development and prototyping for certain customers.

- Product conceptual development
- Prototyping using the 3D printing/ Rapid prototyping manufacturing technology Selective laser Sintering (SLS) and Fused Deposition Method (FDM)
- Production of injection moulded parts, blow moulded and thermo-forming parts
- Production capability from low to high volumes
- Clean room with **ISO:6** certification for manufacturing of Medical products
- In-house facility for sticker/ label integration for the product using advance automation for achieving the micron level standards
- A dedicated designing team for designing the stickers/ labels for the produced products with close collaboration with customers.
  " You imagine we create" that's the motto.

2.3 Company Technological Capabilities

Company utilizes the cutting-edge automation system integrated to every injection moulding machine that are utilized for better productivity with less lead time, repeatability and high-quality products with negligible defects (Figure 2.2).

Figure 2.2: Automation and Robotics at Plásticos Futura [8]

Automatic centralized plastic granule (raw material) feeder system for every individual machine as an efficient and effective method advantaging in saving material (adequate material is supplied) and improves the quality of the final product.

Machine and mould maintenance are the key factors that plays a crucial role in quality of product. So, every mould is inspected and monitored very carefully as a part of quality control and safety of the product. Inspection of machine and moulds are carried out in a set frequency.

Injection machines are used to produce majority of the product line with all shapes and volumes. Blow moulding machines are also been utilized for production of high-volume capacity jars which are cylindrical in shape.

In order to maintain hygiene [9] which is very important factor, Utilization of robots for product handling is much safer than the intervention of humans (COVID-19). Though implementation of automation and robotics seems expensive at first glance, its more reliable, efficient, hygiene considering the current situation of unhealthy world. It always turn out to be boon for the organization itself.

2.4 Product Line

The product line accounts to two hundred plus products and still adding up, the product size ranging from small size tubes for medical purpose to larger size jars. When it is come to storing of food at kitchen or store the food products at your shop the jars of different size and volume for most requirements are available (Figure 2.3) Capacity ranging from 100ml to the 4$litre$ so food from small size nuts to apple size can accommodate inside the jars that are being manufactured.

Figure 2.3: Jars [10]

Having food at your picnics place or at the marriage function or at office party, plates, spoon, fork, cutter, bowls are essential things to be on table. Company offers of all size of bowls for soup to the deserts, plates for serving or plates for eating food company offers varies size and shape (Figure 2.4). The largest plate for mass serving is 48cm in diameter to small plate of 6cm size. The 100% recycle plastic material are being used which are non-reactive to food items as well.

Figure 2.4: Catering products [11]

While organizing the music events or organizing the college beer parties the cups are the one which is used to fill water or beer or your favourite gin or a shot vodka. Cups are more attractive when customizing possibilities are available. The host company provides the customizing options for various cups that are available from the product line. "You imagine we create" is the motto of company for the customers who wants more personalized cups for their events. Cups size from 30ml (shots) to the 500ml (beer glass) are available (Figure 2.5).

Figure 2.5: Party events cup [12]

Whether it's your birthday or marriage anniversary or Christmas, it is one of the happiest moment that mankind celebrates. It is the moment to share your love and happiness with your family and friends. Chocolates, dryfruits, sweets are foods that are shared during the happy moments. There are range of products available to share happiness (Figure 2.6). The medicines are one of the important basic need as food to mankind itself. The capsules are usually packed in small size bottles depending on the packing size. The medium size and large size capsule bottles are also manufactured to pack the energy capsules or fat burner capsule. Range of products (Figure 2.7 are manufactured in 'clean room' with ISO:6 certified

Figure 2.6: Seasonal Packaging products [13]

manufacturing facility at the host company). Pharmaceutical products like vaginal cannula, rectal cannula are also included in the product line.

Figure 2.7: Medical and pharmaceutical products [14]

3 Technology Background

Currently high degree of accuracy with the larger volume production are the trending requirements for the manufacturers across the globe. When it comes to food industry the demand for packaging is growing year on year, in order to fulfil the greater demands with economical cost is the challenge. One such technology that can be used to produce at larger volumes with accuracy and economically is the molding process. Moulding technology have evolved over the years. The products such as water bottle, storing containers, packaging for food transportation, take away containers, toys and many more are produced in large scale with the high accuracy and challenging shape at affordability. The host company utilize two major technology to produce the entire product range and with the advance manufacturing technology that are currently being used in the market. The technology used for manufacturing are discussed in this chapter.

3.1 Injection Moulding

3.1.1 Introduction

Injection moulding is used to create complex shape parts with thin walls in a variety of sizes. Cups, containers, toys, plumbing fittings, electrical components, telephone receivers, bottle caps, and automotive parts and components are just a few examples of parts that are produced using injection molding process [15]. The advantages for producing such a wide variety of size and shape products makes almost every manufacturing sector to adopt the process.

3.1.2 Injection Moulding Process

The injection moulding process uses a granular plastic that is gravity fed from a hopper and material is pushed into a heated chamber called a barrel (Figure 3.1), where it is melted using a screw type plunger. The plunger continues to move forward forcing the polymer through a nozzle at the barrel's end that is pressed against the mould. A gate and runner system will allow the plastic to enter into the mould chamber. To accommodate the material shrinkage as it cools, a holding pressure is maintained after the cavity is filled. At this same time, the

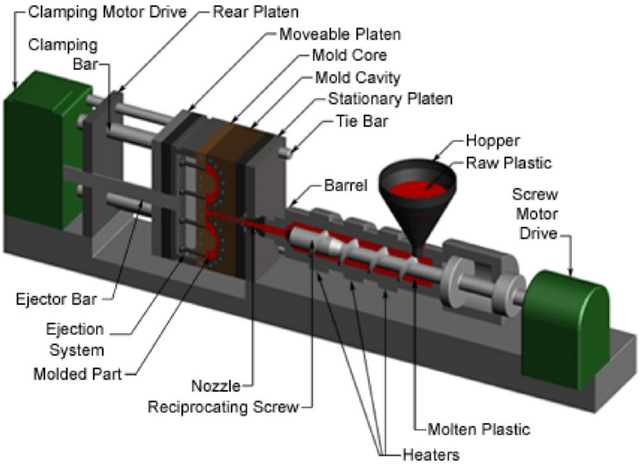

Figure 3.1: Injection molding machine line [16]

screw turns so that the next shot is moved into a ready position, and the barrel retracts as the next shot is heated. Because the mold is kept cold, the plastic solidifies soon after the mold is filled. Once the part inside the mold cools completely, the mold opens, and the part is eject [17]. The next injection molding cycle starts the moment the mold closes and the polymer is injected into the mold cavity.

3.1.3 Design Rules for Injection Molding

One of the most significant advantages of injection moulding is the ease with which complex geometries may be created, allowing a single part to perform multiple tasks. These intricate parts can be duplicated at a minimal cost after the mould is created. However, changing the mould design later in the development process can be highly expensive, so getting the optimum results the first time is crucial. To avoid the most common injection moulding flaws, the following design guidelines is important [18]:

Use of constant wall thickness: At all possible, keeping the wall thickness constant throughout the part and preventing thick section is necessary because non-uniform walls can cause the part to warp when the melted material cools. If different thicknesses are required, using a fillet which makes the transition as smooth as possible, this way the material will flow more uniformly inside the cavity, ensuring that the entire mould is thoroughly filled.

Hallow out the thick section: Warping and sinking are two common faults caused by thick portions. It's critical to keep the maximum thickness of any section of the design to the acceptable values by hollowing it out. Usage of ribs to design structures having equal strength and stiffness but reduced wall thickness to improve the strength of hollow sections. Designing ribs with maximum thickness equal to half times the wall thickness. Designing ribs with maximum height equal to three times the wall thickness.

Round all edges: The uniform wall thickness restriction also applies to edges and corners:for good material flow, the transition must be as smooth as possible. Use radius at least half times the wall thickness for internal edges. Add a radius equal to the inner radius plus the wall thickness to the outer edges. This ensures that the thickness of the walls is uniform throughout the part (even at the corners). Furthermore, sharp corners provide stress concentrations, which might lead to weaker parts.

Add draft angles: A draft angle must be applied to all vertical walls to make ejection of the part from the mould easier. Because of the high friction with the mould during ejection, walls without a draft angle will have drag marks on their surface. A draft angle of at least two degrees is ideal. A good rule of thumb is to increase the draft angle by one degree for every 25 mm. Ribs require draft angle as well, also said that adding an angle may reduce the thickness on the top of the rib, it is important to ensure design meets the minimum wall thickness requirements.

3.1.4 Advantages of Injection Molding

Various advantages of the process have made huge impact in manufacturing industry to adapt this technology for mass production of products.

- The fundamental benefit of this method is that complex shapes with thin walls (5-15 mm) can be moulded and removed from the die without causing damage.
- Injection moulded parts have a high degree of dimensional accuracy.
- The main advantage of this approach is that it produces relatively little scrap when compared to other techniques.
- Parts produced by injection moulding contend with those made by investment casting and parts that require complicated machining.
- In comparison to other procedures, this process has a high production rate.

3.1.5 Disadvantages of Injection moulding

Being so widely used process across all the manufacturing sector, it possesses some few disadvantages as well.

- Due to the design, testing, and tooling associated the whole process, the initial cost / setup cost is pretty high.
- Injection moulding is usually limited to only a few types of materials, such as thermoplastics and some thermosets.
- High tooling costs, i.e. because the mould is manufactured through multiple processes and testing, the total cost of creating a single mould is very high.

3.2 Blow Moulding

3.2.1 Introduction

Blow moulding is a process for producing hollow objects, primarily from thermoplastic materials. The most common uses for blow molded parts are in bottles and packaging. The blow moulding industry uses over 80% of polyethylene (PE) and a significant percentage of polyethylene terephthalate (PET) materials for bottles and packaging [19]. Many additional products, such as components utilised under the hood and on the exterior of cars, are produced using blow moulding. Blow moulding is also used to create gas tanks, structural panels, toys, and double-walled cases. Polypropylene, polyvinyl chloride, poly-carbonate, and fluoropolymer are just a few of the polymers that are employed in these applications. .

3.2.2 Basic Process

The first phase requires the production of a heated tube, referred to as a parison a term derived from the glass industry. This can be made in one of two ways: extrusion or injection, as stated. Preform is the term used in the injection case. The heated parison or preform is placed between the two halves of blowing mould which closes and clamps around it (Figure 3.2). When the heated tube is blown against the wall cavity, the molten plastic or resin cools and takes the shape of the mould. The part is released from the mould when it has cooled. For further finishing, the flash (excess plastic around the part) must be removed in the case of an extruded attribute[20].

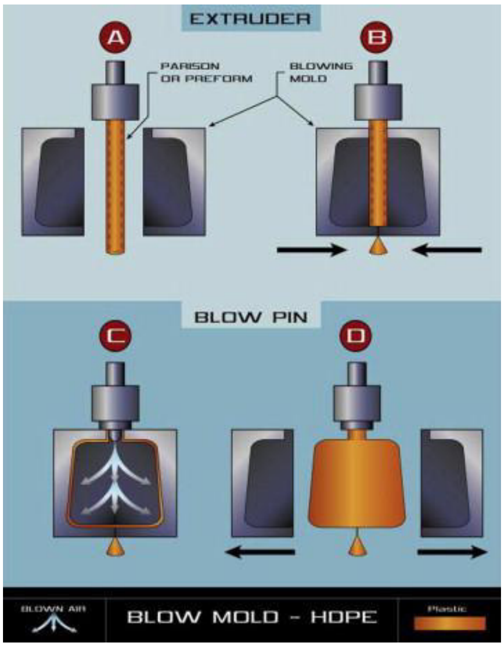

Figure 3.2: Extrusion Blow moulding process [21]

3.2.3 Injection Blow moulding

Injection blow moulding produces a parison with a pre-formed bottle neck and threads to final dimensions. Small pharmaceutical and personal product containers are the most common applications for this method [22]. The economics of such containers necessitate a large number of cavities (up-to 10), one set for injection moulding and one set for blow moulding. Injection blow moulding is used on larger bottles where tolerances in the neck and closure thread area are critical (Figure 3.3).

For small parts with high production volumes and better quality specifications, this method is preferred over extrusion blow moulding. Injection blow moulding creates a hollow test tube-like shape by injecting a thermoplastic material into a cavity and around a core rod (preform). The blow mould receives the moulded preform that is still attached to the core rod. The preform is clamped in the mould, and air is blown into the cavity to shape it. The preform is injected onto a support pin or core, which generates a neck with threads that are cut to the necessary size. The preform is then blown into its final shape against the cavity wall.

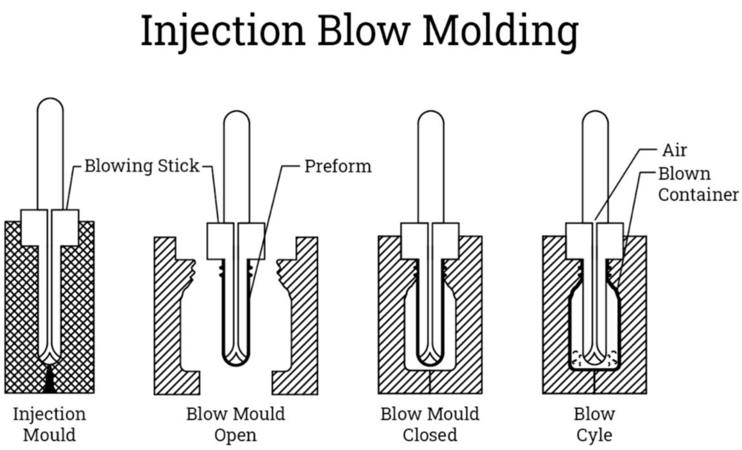

Figure 3.3: Injection blow moulding stage by stage [23]

3.2.4 Stretch Blow Moulding

Stretch blow moulding became known in the blow moulding industry with the introduction of the soft drink bottle. Stretch blow moulding [24] is a type of extrusion blow moulding that has been modified. It entails heating (conditioning) a formed and cooled preform to a certain temperature, sealing it in the blowing mould, and extending it in two directions, length and diameter, very quickly. (Figure 3.4) The polymer molecules are biaxially oriented as a result of this. A rod is frequently used to stretch the heated preform in the axial direction, followed by air pressure to stretch it in the radial direction. Impact strength, transparency, surface gloss, gas barrier, and stiffness qualities are all improved by doing so. Polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), and polyacryonitrile (PAN) are the four most regularly used plastics, with clear or coloured PET soda bottles being the most typical application for stretch blow moulding.

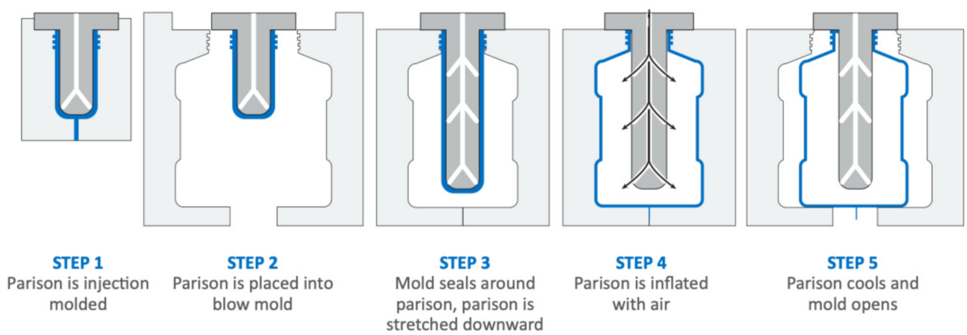

Figure 3.4: Stretch blow moulding stage by stage [25]

Advantage of Blow Moulding Process

- The neck finish and details are very accurate and of high quality
- Production speed is much higher
- Produces high repeat-ability and consistent product quality
- The ability to stretch the preform in both the hoop direction and the axial direction
- No process weight variation

Disadvantage of Blow Moulding Process

- Production setup time is longer for first production part
- Limited to produce the hallow products
- challenges for producing complex geometrical shapes
- The process is not suitable for products which contains handle

3.2.5 Design guidelines for Blow Moulded Parts

Achieving uniform thickness in blow moulding is of challenging side. The usage of a minimum blow-up ratio to minimise nonuniform walls is one of the first guidelines to accept in part design. A maximum ratio of 5:1 should be followed, and if at all possible, all work should be done in a 3:1 ratio. The relationship between the maximum part diameter and the diameter of the extruded parison is known as the blow-up ratio [26].

To avoid neck pinch-off scars in applications such as containers, the parison size must be no greater than the container's neck size; however, this restriction applies to just a few other uses. Excess material usage to meet minimum wall thickness criteria might occur from using an incorrect parison to component ratio. When a part is designed with a shape like a pyramid or cone, injection blowing process is preferred

Details of design, such as angles, edges and comers, are of significance in blow molding.sharp angles and edges should be avoided, and in all corners and ribs, fillets and rounds should be used. In all of these design regions, a large radius will prevent excessive thinning of the plastic and molded-in tensions. It is critical to use a large chime radius in applications like detergent containers to avoid thinning. Stress cracking of the container might occur when the bottom pinch-off section is heavy and the bottom comer is thin.

4 Product Development

The development begins with the market opportunities that is being identified with the dedicated team to survey and propose a need of specific market or customer needs. The requirements are transferred to the design team, bundles of data are collected and a hierarchy is generated according to the specific customer needs and other necessary needs which makes up the product. The product cycle chart generated for easy roadmap (Figure:4.1).

- The **Product Planning** address an portfolio of product development projects, resulting in a product plan with a mission statement. To achieve these mission statements few things are considered as said below.
  1. Identify opportunities (generate, recognize, evaluate the ideas across the enterprise)
  2. Evaluate and prioritize projects
  3. Collect available resources
  4. Pre-project planning
  5. Results

  Potential product development projects are evaluated based on the organization's competitive strategy, technological methodologies and product platform plans [27].

- **Identifying Customer Needs** is an integral part of the concept development phase of the product development process. The subsequent customer needs are utilized to guide the team in establishing product specifications, generating product concepts, and selecting a product concept for further development which includes gathering and interpreting raw data from customers, organizing and establishing the needs into hierarchy[28].

- **Product Specifications** are generally covered at least twice after identifying the customer needs. There are several process to achieve it before the firm knows the constraints of the product technology.
  1. Prepare the list of metrics
  2. Gather bench marking information
  3. Set an ideal target values
  4. Results

  The product specifications process is facilitated by several simple information systems that can easily be created using conventional spreadsheet software [29].

- A product **Concept Generation** is an approximate description of the technology, working principles, and form of the product which begins with a set of customer needs and product specifications and results in a set of product concepts which will be finalised by the enterprise. An effective development team will generate hundreds of concepts, out of which 5 to 20 will be considered during the subsequent concept selection process [30].

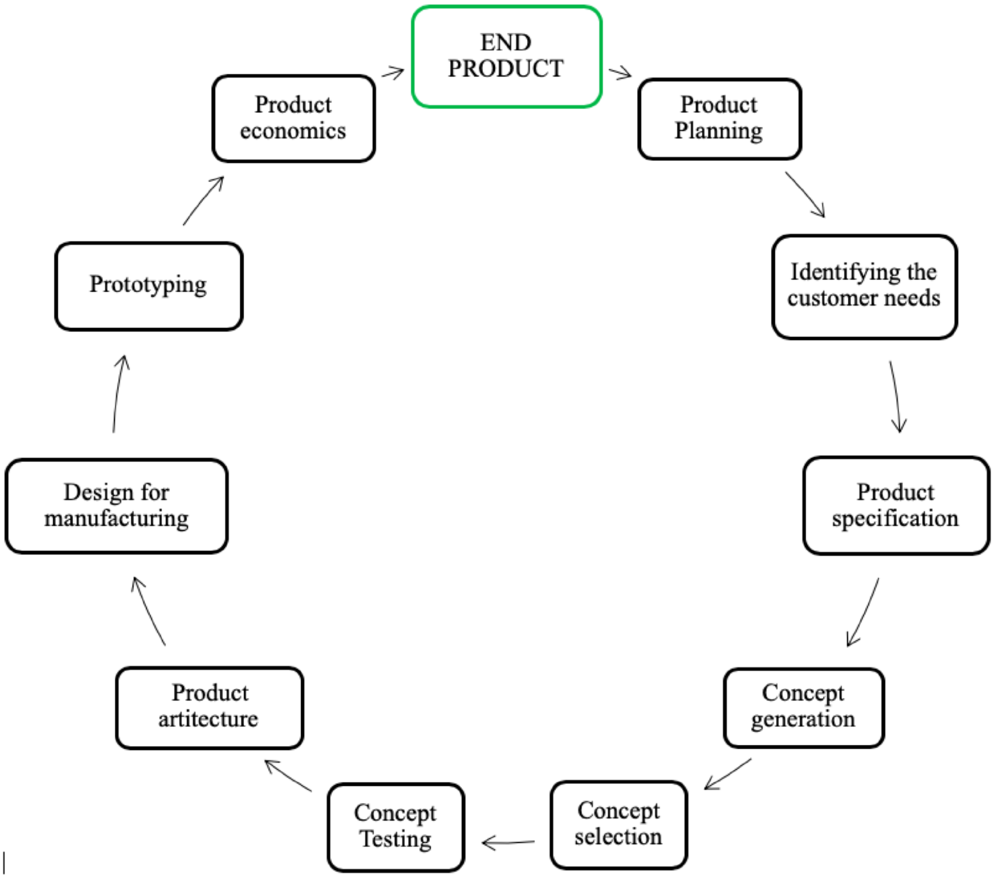

Figure 4.1: Design development stages

- **Concept Selection** is most common way to evaluate and identify customer needs by comparing relative strength and weakness of the concepts and shortlisting the ideas for further investigation and improvement [31].
- **Concept Testing** is a direct response to description of the product concept from the customers in the market. It will make ensure whether the customer requirements have been met by the product concept and gather customer information for further refining of the product[32].
  Product testing concepts are shown below
  1. Define purpose of concept test
  2. Survey population and format
  3. Communicate the concept and measure customer response

4. Interpret the results.

- **Product Architecture** is a plan by which practical elements of the product are organised into physical blocks and is established during concept development and design development stages. Due to heavy implementations of architectural decisions, inputs from marketing, manufacturing and design are essential in this part of product development [33].
- **Design for Manufacturing** of the product explains the advantages to the quality of the product and how it is gonna carry out. The primary motive is to design the aspects of the product that relates the customer, aesthetics and ergonomics by reducing manufacturing costs while simultaneously enhancing the product quality, time and cost.
- Product development always requires building and testing the final product's **Prototype**. Physical prototypes are utilized for learning, communication, integration and milestones which will lead to reduction in the risk of costly iterations [34].
- **Product Economics Analysis** is a tool for analysing the decisions made during product development stage and to calculate the expected payback time and financial outputs[35].
  It has 4 steps as shown below
  1. Build a base financial model to compute expected profits
  2. Perform sensitivity analysis to understand key assumptions of model
  3. Use sensitivity analysis to understand project trade-offs
  4. Consider the influence of qualitative factors

4.1 PRODUCT: Vintage Giga Jar

Aim: To design and develop a Vintage style Giga jar

The necessity is the key factor for any innovation, as said its demand for food storage jars are increasing rapidly (discussed in chapter-1 about the market size). Currently jars/containers that are being used in kitchen for storing food items are made up of glass in the market, the fragility of glass material, cautious away of handling makes limitations for usage of glass jars at kitchen. So, the challenge here is to design and develop a jar which looks elegant, stylish, durable, more safe to handle and can use confidently at the kitchen on daily basis. That being said, plastics are one which is an alternative to glass material because it provides transparency and looks same as glass but with less weight advantage as well. The goal of the product is to add classical design approach which resembles and functions like glass jars with higher storage capacity.

A detail development cycle of 'Vintage Style giga jar' is described step by step in this chapter which includes customer needs, product concept creation until final product rendering.

4.1.1 Customer Input

Before designing the consumer focused product, a thorough customer feedback/ input is required in order to design and deliver a useful product which makes the customer happy and manufacturer keep sailing in the business. A survey was taken targeting the age group 25 to 60, inputs from both the genders involving 14 men and 14 women were made. Survey was done with the questionnaire **"What are the considerations you make before you buy the food storage containers/ jars at home?"**
The respondents were being asked to answer via email so that the requirements can be understood in detail. The below statements are derived directly from the survey.

- **Customer voice 1:** Transparent, which helps to identify the food inside the container at a single glance. It should be air tight. If the container has measurement markings or tools then it is a plus. The material should be food-grade and long lasting, as this is an investment that lasts a year. The design should also be timeless and space saving.
- **Customer voice 2:** Storage containers are meant to store stuff expect neither anything fancy out of it nor expect any technology put into it which makes the product little expensive. It should be robust and easy to maintain.
- **Customer voice 3:** Storage capacity, carries no stain (easily washable), scratch proof, air tight, good appearance, design (shape), fancy color options would be added point.

- **Customer voice 4:** Material should be degradable plastic and the overall design of the product should be attractive and practical to use.
- **Customer voice 5:** Leak proof, storage capacity, look and feel, air tight.
- **Customer voice 6:** Locking for maximum freshness.
- **Customer voice 7:** There should be no chemical reaction of plastic over the food stored inside the jar/container.
- **Customer voice 8:** Should look classy, needs good design and good quality.
- **Customer voice 9:** It should be air tight and very ergonomic in design.
- **Customer voice 10:** Leak proof, withstand the impact upon free falling, easy to open/close.
- **Customer voice 11:** Good quality, eco friendly/ recyclable.
- **Customer voice 12:** Unbreakable and easy to maintain.
- **Customer voice 13:** The lid should be air tight.
- **Customer voice 14:** Food grade and unbreakable.
- **Customer voice 15:** Good quality, space saver, more durability and airtight.
- **Customer voice 16:** Transparency in box.
- **Customer voice 17:** Air tight, good and elegant looks.
- **Customer voice 18:** Quality and competitive pricing of product.
- **Customer voice 19 to 28:** Durability, airtight, impact resistance, transparency.

The response (Table 4.1) from the customers are categorized to 22 attributes, the number of customers choosing the each attributes are noted and listed with the percentage (number of customers ÷ 28). So, it simplifies to prioritize the attributes of customer needs.

Table 4.1: Number of customers choosing there requirements

Sl.no	Customer needs	Number of customers	Percentage	Priority
1	Airtight	25	92.59	1
2	Transparent jar for good visibility	25	92.59	1
3	Durability	25	92.59	1
4	Aesthetics	23	85.19	2
5	Impact resistance	18	66.87	3
6	Ergonomics of the jar	18	66.87	3
7	Unbreakable	16	59.26	4
8	Easy to wash	16	59.26	4
9	Space saving	16	59.26	4
10	Timeless design	15	55.26	5
11	Free maintenance	14	51.85	6
12	Focus towards recyclability	12	44.44	7
13	Cost	12	44.44	7
14	Storage capacity	10	37.04	8
15	Quality	10	37.04	8
16	Packing and stackability	10	37.04	8
17	Attractive lid colors	10	37.04	8
18	Usage of Food grade plastic	9	33.33	9
19	Low carbon footprint to the environment	9	33.33	9
20	Avoid absorption of stains	6	22.22	10
21	Non-reactive to the food	5	18.52	11
22	Capacity scale level indication	3	11.11	12

4.1.2 Addressing the Customer Needs

The customer need is addressed (Table 4.1) based on the ’priority’ rating obtained from the ’number of customers’ choosing the attributes that the product should hold as fundamental characteristics.

The priority is ranked based on percentage (high to low), so it is easy to identify the importance of attributes that has to be integrated to the product. For further understanding the customer needs it is further split into three main categories based on the percentage of the customer choosing the attribute. The customer needs are divided into three categories (Table 4.2). The categorized are based on the below percentage rating

- Primary customer needs (mandatory feature in the product) - (> 90 %)
- Secondary customer needs (50% - 89%)
- Tertiary customer needs (1% - 49%)

The categorization of customer needs will be an essential input for **idea generation > concept development > product development**. It is the road-map for further development stages of the product.

Table 4.2: Customer needs

Primary customer needs	Secondary Customer needs	Tertiary Customer needs
Airtight	Aesthetics	Focus towards recyclaility
Transparent jar for good visibility	Unbreakable	Storage capacity
Durability	Impact residence	Quality
—	Ergonomics of the jar	Cost
—	Easy to wash	Non-reactive to food
—	Free maintenance	Avoid absorption of stains
—	Space saving	Stack-ability
—	Timeless design	Low carbon footprint to environment
—	—-	Attraction lid colours
—	—-	Capacity scale level indicator

4.1.3 Product Specifications

After determining customer needs, its important to find technological characteristics required for the product. This relationship aims to understand the strength of the relationship between technical features and customer needs. There are three types of these relationships: stable relationships, moderate relationships, and poor relations [36]. The three types of partnership were weighted between customer desires and technical characteristics. For Stable relationship, the weight of the relationship between technical characteristics and customer needs is 9, *3 for medium relationships*, and *1 for poor relationships*. The relation is established using (Figure 4.2) house of quality.

The House of Quality [HOQ], will help you to determine "what" the customer actually needs from the product that are developing. The "value of interest" of the customer is another thing that HOQ helps with, along with road map for defining the desired technical specification that will lead to quantifying design boundaries during product development phases. According to the priority value (Table 4.1) each customer need or value of interest ("What") is mentioned in the HOQ chart. "How" each need is met technically and by what methods is also addressed.

For instance, the priority of "Transparent" is "1" (Table 4.1), which means that the material used for the design stage must be transparent and non-hazardous to food/non reactive. A strong relation of rating-9 is established, since it satisfies the need of the customer / value of interest.

Once the relation is established, for the same priority ('Transparent'), a 'Target specification' is defined. PET is the material of choice, since it meets the requirements. The level of difficulty to achieve the relationship (low, medium, or high) is also specified inside the HOQ. The other customer's needs and value are explained similarly, and the HOQ is created and the target specification is derived. ([37]» visit url from bibliography)

The boundary values or approximate values of height, weight, diameter, etc are de-

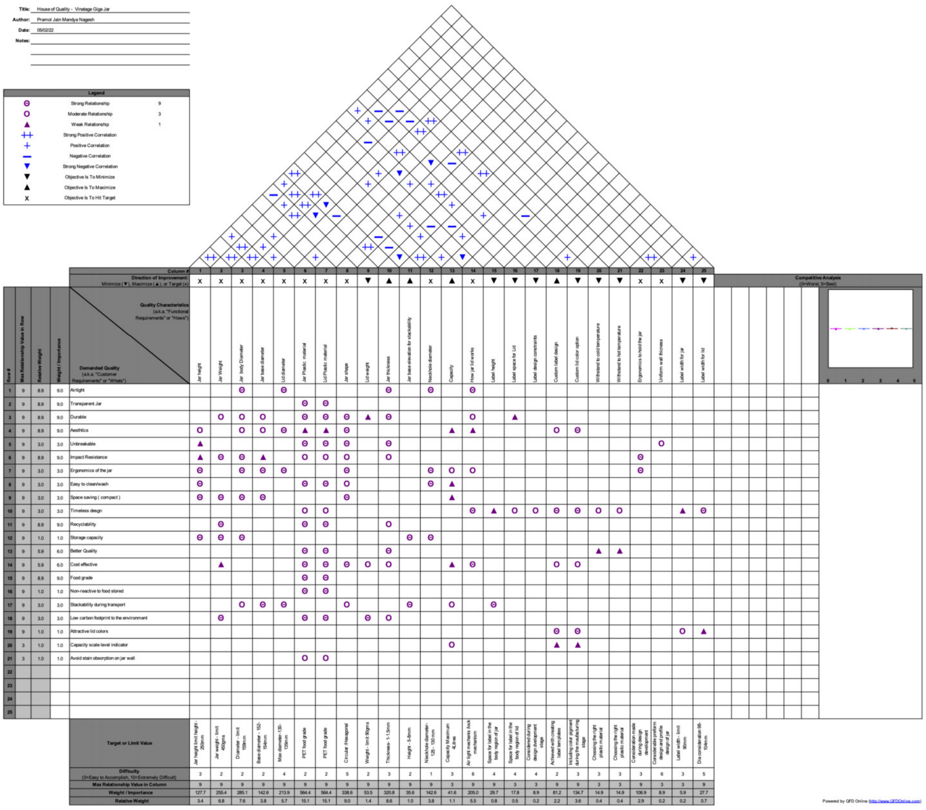

Figure 4.2: House of Quality - Vintage Giga Jar [37]

rived based on technological capabilities (manufacturing methods, machine capacity, type of mould that fits the existing machinery's, engineering capability [human resource] to develop the product), as well as the costs associated with manufacturing. The limit value for product parameters is derived from HOQ (Table-4.3). This process, which is vital, entails inquiring data from skilled professionals from the manufacturing, design, quality, and commercial departments to create the basic framework of the product specification.

Though the product's dimensions (precise) and parameters cannot be fully obtained at this stage, an approximate product specification/ limit value is obtained from the house of quality, to make design development phase much easier (Table 4.3).

Table 4.3: Limit value or Product specification

Sl.no	Product parameters	limit value
1	Jar height	<250 mm
2	Jar weight	<400 gm
3	Width	153-$160mm$
4	Lid Diameter	130-135mm
5	Jar material	PET
6	Lid material	PET
7	Jar geometrical shape	Cylindrical/Hexagonal
8	Lid weight	<90 gm
9	Jar thickness	1-2mm
10	Stack-ability height(jar bottom)	4-7mm
11	Neck hole diameter	125-130mm
12	Jar capacity	max 4.5l
13	Lid closure	thread type/Air tight mechanism
14	Provision for label in jar(height)	70-80mm
15	Provision for label at Lid	Dia 60-65mm

4.1.4 Concept Development

Inspiration for cylindrical shape in concept development

A product concept is an approximate description of the product's technology, functioning principles, and form. It is a brief summary of how the product will meet the needs of the consumer. A notion is typically represented by a sketch or a 3D model, along with a brief textual description. The quality of the underlying concept determines how satisfied buyers are with the product and if it can be effectively sold. A good concept may be poorly implemented in later stages of development, but a bad concept is rarely managed to attain commercial success [38].

The straight line arguably has a more natural association with modern humans than the curve. Daily interactions with level ground and various structures are essentially based on the horizontal and vertical principles (resembling the building,structures,products that are constructed with square or rectangular or any polynomial geometry containing edges). That being said people prefer inclusion of curved shapes along with the vertical and horizontal lines more likeable . This combination is more preferred by humans and makes psychologically happy while using the products [39]

We admire rounded forms with our senses rather than our minds. It should be emphasized, however, that there is a trend toward softer, more humanistic forms in furniture and architecture, as well as in aerodynamic modes of transportation in aircraft, cars, and so on [40]. To its relationship with the sun, moon, and stars, the shape of a circle had a great symbolic significance for primitive humans. It is still connected with all types of wheels and gears today.

Modern life on the ever-expanding scale of our daily world would be unthinkable without the ability to travel. As a result, we shall use the cylindrical form to differentiate the psychological influence on the observer [41]. The shape of circle, more than any other sign, speaks directly to the emotions. The cylindrical shape being advantageous, provides for the maximum volume with the least amount of surface. It is a particularly efficient means of enclosing items and allows each point on its surface to be as far from the center as any other point.

Unlike a cube, where the corners are farther from the center and some regions of the surface are weaker than others, this is not the case. Nature prefers low-energy states and objects with the smallest feasible surface area. This is true whether you're looking at something as small as a raindrop or a drop of liquid metal, or something on the scale of moons and stars. The World is made up of circles.

Concept Creation

The concept begins on the drawing board, where it is re-imagined with all of the considerations gathered from customer inputs (Chapter 4.1.1). It is derived by imagining the possibilities of the creations that can be generated and hand sketched freely to map the basic ideas of how the final product will appear in the real world.

Every concept is created with the product's aesthetics, ergonomics, and practical usability in mind. The goal of the product is to look classic while meeting all of the conceivable usability requirements in the real world.

Starting at the top, **Concept 1** (Figure 4.3) The concept generation speaks about a minimalist yet classic design, with a curve from the neck region to the upper body and a straight line until the lower bottom that allows the consumer to handle the product easily for any size of palm size (Avg. value - Male: 91.4 mm and Female: 78.44 mm [42]) human can grab it easily. The curves at the top and bottom makes it more beautiful and may catch the attention of people of all genders to keep one of this product on their kitchen shelf at home. The advantages of making the top and bottom curves are that even the last drop of liquid/ last piece of solid content kept is extracted entirely when stored conveniently, and the liquid/ solid food items will not attach to the walls since the curved surface will not retain anything in its path.

Concept 2 (Figure 4.3) The profile stays cyclindrical shape, but tapers as it approaches the bottom, giving it a very elegant and traditional appearance. The neck area of the body is stretched, making it easy to grab and hold the product with one hand. The inside profile is smooth and curved, to ensure that all of the product contained can be completely spilled out during the draining step. It is a antiquity design language adopted for the concept.

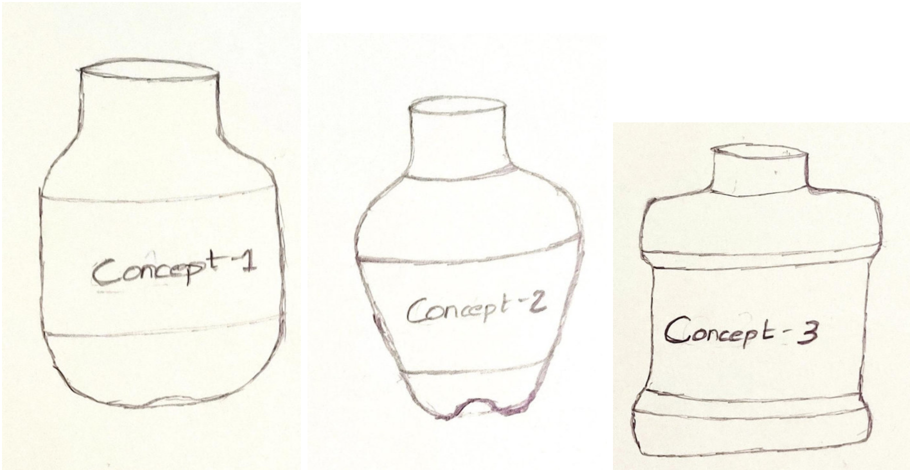

Figure 4.3: Cylindrical jar - From left Concept 1, Concept 2, Concept 3

Concept 3 (Figure 4.3) The product defines a smooth curve in the upper body and a slight tapered to look muscular as the line goes down straight and another curvy bottom to finish up the entire body. Concept depicts the muscular look, the shape makes it look like the muscular men. The wide body aids in the efficient storage of larger volume (product). The design is aimed at clients who desire a substantial product in their kitchen for storage, as well as muscular males who prefer to keep their protein/fat burner powders at the gym.

Concept 4 (Refer Figure 4.4) The slick design draws everyone's attention to look at it for once, and the elongated straight line makes it simple to pick up the product. The round profile appears to be basic and neat. The circumference allows for the customization of desired design labels to be adhered on the surface of jar, giving it a more appealing aesthetic touch. It is the most basic concept that have been developed. You can keep your favourite cosmetics, stationery, chocolate bars, and bakery items in this design. The feminine attention is drawn to the long, slender design more than the male.

Concept 5 (Figure 4.4) The concept design is based on medieval kitchen utensils with a modern twist; the top curve resembles a human's neck and shoulder line, and the curve continues straight till the bottom curve terminates the design statement. The design allows for more space to be stored, and while it appears to be a bulky in the body region.It may look narrow at the neck region it will allow to store pickles, arroz (rice), feijão (kidney beans), amendoim (peanuts) easily. Concept is the aim for creating larger volume space for the storage. Selecting the right concept for further development of product is the most crucial thing in any development phase, a small mistake would cause lot of impact on the economics of the company and also impact on the face of the organization.

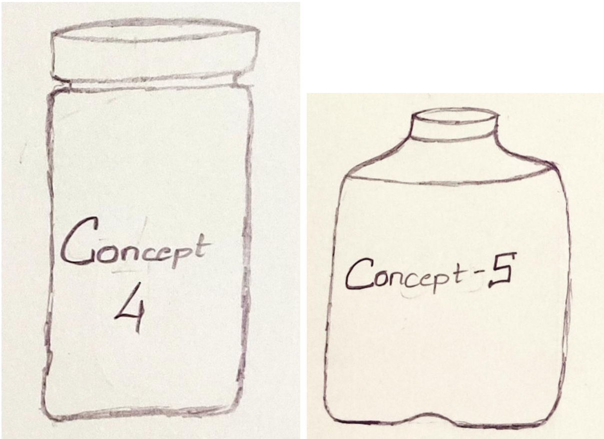

Figure 4.4: Cylindrical jar - From left Concept 1, Concept 2, Concept 3

4.1.5 Concept Selection

Each customer needs are considered carefully and addressed (Table 4.2), in order to simplify the further concept selection process, the attributes are combined to five key factors.

- Aesthetics
- Easy to manufacture
- Customization possibilities
- Product usability
- Easy to transport

To further streamline the development process, the factors (Aesthetics, Easy to manufacture, Customization possibilities, Product usability, and Easy to carry) are specified. Each concept that satisfies the established limit value/product specification is voted by a cross-functional team that includes expertise from the production, design, commercial, quality, and logistics department.

Aesthetics play a significant role in product development; most buyers purchase a product based on its aesthetics, which is what causes it to be sold on the market. The appearance and feel are given a significant priority. *Aesthetics includes the product characteristics like Transparent jar, timeless design*.

Easy to Manufacture is a critical factor for the manufacturer in order to produce the product while maintaining all of the design elements. The best design makes it simple to manufacture at a lower cost and with higher efficiency. 'Easy to manufacture' describes, whether the product is easy to handle after manufacturing (ejection), whether the product can be handled easily after ejection (operator), complexity of mold required (includes cooling) to manufacture the product.

Easy to transport in some cases, the cost of the product to manufacture is the same as the cost of transportation. To make transportation easier (and less expensive), a method of easy packing/ transportation should be addressed in every curve designed from the beginning of the design stage. Transportation should be considered from the standpoint of both the manufacturer and the final customer. Keeping product safety in mind while shipping is also important.

Based on client expectations and a rapidly changing market, **Customization capabilities** are critical when a product is placed in the mass market segment. During the design stage, it's important to keep in mind the customization possibilities. There should be room for easy label placement during manufacturing (particularly with robotics), and curves should be skilfully integrated during design so that every label design and colour contract enhances the overall appeal of the product. Customers of all age groups and genders are also attracted to customization. This improves the organization's long-term viability while also increasing the number of manufactured parts.

Product usability is the ultimate goal of any product, and its success is determined by its usability level. The product is just dead due to its poor usability. The product's usability is defined by all of the previously mentioned factors; the product should be easy to handle, easy to wash, contain no hazardous material, and be nonreactive to the food stored, and be able to endure impact load (dropping upon gravity) and compression load (during transport). The product should always be created and designed with the end user in mind.

Concept ratings/ scoring (Table 4.5) is derived from the cross-functional team , without missing any of the inputs from derived customer needs as well. Based on the scores for each concepts, the concept with the highest score will be the winner. *Winner concept* are again modified for development and detailing process. The concept rating/ scoring is done by the team based on score band between 1 to 5 (Table 4.4)

Table 4.4: Rating scale for concept selection

Rating scale	Comments
1	Poor
2	Below average
3	Average
4	Good
5	Very good

The clear winner is the *concept-1*(Figure 4.3) with the total score of 21.The concept

Table 4.5: Concept scoring for jar designs

Concepts	**Aesthetics**	**Easy to manufacture**	**Easy to transport**	**Customization possibility**	**Product usability**	Total score
Concept-1	4	5	4	4	4	21 Winner
Concept-2	5	2	2	4	3	16
Concept-3	4	4	3	4	4	19
Concept-4	4	5	3	4	3	19
Concept-5	4	4	3	3	4	18

have *'aesthetics'* rating of 4 , because of the simple but clean design language. A rating of 5 for *'easy to manufacture'* because of the cylindrical profile, the process will be every much cost effective and manufacturing molds will be much easier as well (the scaling of capacities (volume) is much easier, by varying overall height keeping other dimensions almost unchangeable). The mold cost will be significantly low because of its simple profile involved in design. The transporting will be much easier because of cylindrical shape which doesn't occupies much space(stack-ability is possible), so it is rated 4. The space availability for applying the label around the circumference of the jar (its easier if the application of label is through robots) is easier and the provision for label customization and color customization for jars is easier, so it is being rated as 4.

4.1.6 Product Development

Concept-1 was chosen over the other concepts because it received the highest score (21 points) in the concept scoring (Table 4.5). It is chosen as the winner due to its several advantages over the other concepts that were developed. The design at first glance is very smooth profile, looks classical. The concept is pushed for detailing stage (Figure 4.5) where provision for stack (easy to transport), a elevation in the bottom for easy of manufacturing, every corners are made transition for smooth retraction from the mold (Chapter 3.2.5).

The curve on the top looks elegant adding an aesthetic advantage (Figure 4.6), as the curve straightens (2/3rd of the body) till the upper bottom line and further line curves smoothly to the bottom and straightens, (to give the rigid base upon vertical stand).

To reduce errors during manufacture, the rest of the body is made of uniform thickness. The jar neck region is eliminated with threads in order to reduce the wear and tear after many iterations of usage. The neck (Figure 4.6) has been designed to be stiffer and more durable over time, as well as to withstand vertical loads (compression) with provision resembling the properties of parallel flange channel [43].

The concepts are made to look and feel practical.The concept is sketched using 3D CAD

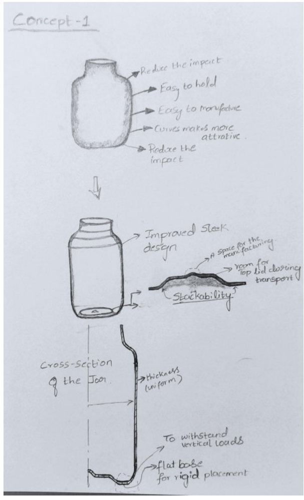

Figure 4.5: Cylindrical jar concept

software (SOLIDWORKS), and is further progressed to development stage. Initially, the concept selected is created in CAD software, the idea is turned to a more visualising stage, where product is formed to shape. In this stage the dimensions are not determined, once the 3D modelling shape is close to the concept generated, then the design is optimized for the dimensions, design for manufacturing, packaging challenges and the economics of the product manufacturing. In order to define the dimensions of the product, initially the product should be decided for which capacity (volume) it should be designed. So designing for the standard capacity (volume) which are widely used in market i.e, 1, 2, 3 and 4 litre would be much ideal.

First step is to determine the diameter of the jar that needs to be defined to satisfy the capacity, *'easy to hold'* and *'economical transportation'* as well. The average circumference of Men hand is 218.44 mm that of Female is 177.8 mm [42]. Since the product is designed for global market, shipments are generally carried through the pallets. The standard pallet dimension (Table 4.6) that are used across the globe. In order to utilize the space availability

Table 4.6: Standard pallet size internationally [44]

Pallet dimensions[WxL in mm]	**Predominate region**
1016 x 1219	North America
1000 x 1200	Europe,Asia
1165 x 1165	Australia
1067 x 1067	North America,Europe,Asia
1100 x 1100	Asia
800 x 1200	Europe

efficiently over pallets , many iterations were carried out and Ø157 mm were derived to fit the pallets of different dimensions efficiently. The diameter will be the basis for all the calculations

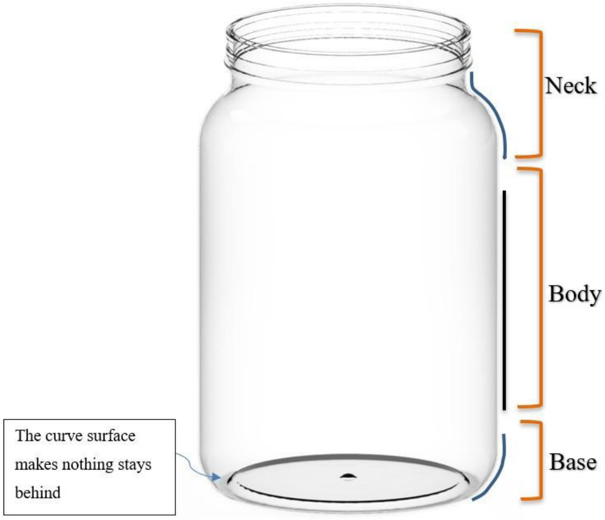

Figure 4.6: Cylindrical jar concept description

that will be considered in order to obtain the 'height', 'circumference' in to order to achieve the defined capacities(volume) that have been intend to develop.

In order to calculate the required 'volume', with the known 'diameter' that have derived, 'height' to be determined. The two cylinder (Figure 4.7) is considered *'upper body'* and *'main body'*, the height (h_1) is kept constant and height (h_2) is varied. The calculation assist in obtaining a target dimension which further simplifies the design development process in the later stage. The calculated values are tabulated (Table4.7).

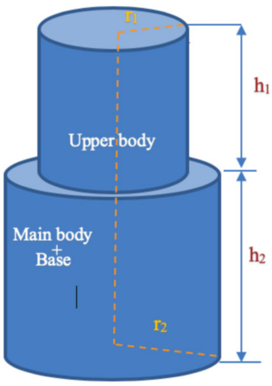

Figure 4.7: Cylinder representing the upper and main body(assumptions)

$$\text{Circumference of the circle: } C = 2\pi r \tag{4.1}$$

Where, r = radius of circle Therefore, circumference of the cylindrical jar at the 'main body'

$$C_2 = 493.23mm, \text{where } r_2 = \frac{157}{2} = 78.5mm. \tag{4.2}$$

Circumference of the cylindrical jar at 'Upper body' region

$$C_1 = 377.93mm, \text{where } r_1 = \frac{120.3}{2} = 60.15mm \tag{4.3}$$

$$\text{Volume of the cylinder,} V = 2\pi\, r^2 h \text{ where, } r \text{ = radius, } h \text{ = height of cylinder} \tag{4.4}$$

Using Eq(4.4), the upper body volume is determined ,

$$V_1 = 2\pi \times 60.15^2 \times 46,\ V_1 = 0.522l \tag{4.5}$$

Table 4.7: Height(h_2) calculation table

$V_1(l)$	$h_1(mm)$	$r_1(mm)$	$V_2(l)$	h_2-calculated(mm)	r_2 (mm)	Combined(h_1+h_2)
0.522	46	60.15	0.70	36.15	78.5	82.15
0.522	46	60.15	1.48	91.84	78.5	137.84
0.522	46	60.15	2.48	143.49	78.5	189.49
0.522	46	60.15	3.48	195.15	78.5	241.15

The Calculated values give us the overall picture of product where dimensions will fit in exactly and makes life easy in modelling the 3D. The value of combined height $(h1 + h2)$ gives the theoretical value of the Jars dimensions. Using this values the 3D is generated and the dimensions are slightly altered to fight the volume (capacity) required. The theoretical values wont bare difference more than the ±2% of the actual product itself. The dimension boundaries are defined, in the section 4.1.7 the material is selected for the development later on the section 4.1.8 the product modeling is done and dimensions of the product is obtained.

4.1.7 Material Selection

One of the most popular plastics which is widely used for the food packaging when it comes to jars/ carbonated bottles is PET. PET stands for polyethylene terephthalate and it is a transparent, robust and lightweight plastic from the polyester family. As an engineering plastic when combined with other materials such as glass fibre or carbon nanotubes to significantly increase the material's strength [45] . It's a naturally colourless, semi-crystalline material.

Figure 4.8: PET recycle Symbol [46]

Water resistance, a high strength-to-weight ratio, nearly shatterproof nature (it won't shatter like glass packaging), and widespread availability as a cost-effective and recyclable plastic (resin identification code "1") [Figure 4.8] are just a few of its most remarkable characteristics [47].

- PET is easily injection molded and is often available in pellet form for this purpose
- PET must be dried before it can be used in a molding machine because it is hygroscopic
- PET shrinkage is very low (less than 1 percentage), however it varies depending on a variety of factors such as holding pressure, holding time, melt temperature, mold wall thickness, mold temperature, and the proportion and kind of additives.

The properties of the PET is shown in table 4.8, the melt temperature, density, shrinkage rate are some of the important properties to be considered before choosing the material for the product.

Table 4.8: PET material properties [48]

Technical name	Polyethylene terepthalate (PET or PETE)
Chemical formula	$C_{10}H_8O_4$
Melt Temperature	260$°C$
Typical mold temperature	100-110$°C$
Tensile strength	152 MPa
Flexural strength	221 MPa
Density	1380 Kg/m^3
Shrink rate	0.1 -0.3%

The PET material is selected as a choice of material for this current work, the advantages being the material can-be recyclable, manufacturing process advantages, expertise in the manufacturing of PET products at host company makes a ideal fit.

4.1.8 Product Modelling and Prototyping

After the material selection, 3D modelling is done keeping the material property in mind which assist in defining the dimensions, draft angles, radius (where ever applicable), thickness and other parameters during manufacturing and designing stage. The process is progressed from concept to modelling and test stage.

Table 4.9: cylindrical Jar specification

Capacity (l)	**Height (mm)**	**Weight (g)**	**Max diameter (mm)**	**Thickness (mm)**
1.2	96	109.36	157	1
2	137	137.7	157	1
3	191	168.5	157	1
4	244	212.4	157	1

The product is modelled to fit the capacity and the specification of jar is listed in the table 4.9 and the detailed engineering drawing of jar.The model jar is tested for its performance and it is discussed later in the chapter 5. To better understand the product being designed,renders are generated (section 4.1.10).

4.1.9 Lid Design/ Top cover design

The product is incomplete without the usage of top lid. Lid has a important role on maintaining the total freshness of the product. The lid design is very much important as the jar itself. Many aspects of aesthetics, functionality, durability, easy to manufacture are the key essential aspects to be kept in mind while generation of concept and design. Some of the concepts were generated to derive the best solution for maintaining a maximum freshness (air tight) of food items inside the jar.

Concept generation

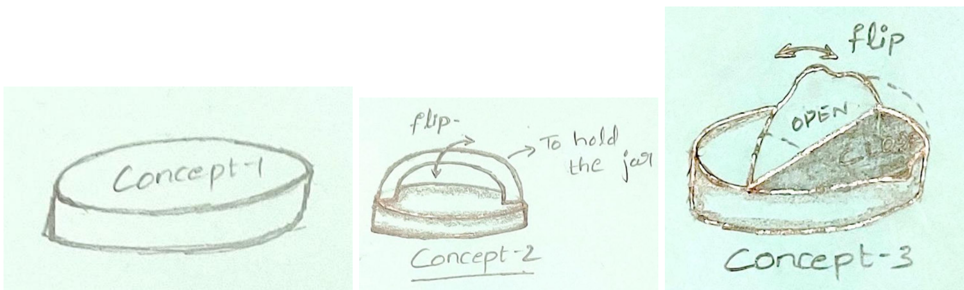

Figure 4.9: Lid concepts from left Concept-1,Concept-2,Concept-3

Starting from the **Concept 1** (Figure 4.9), the design is simple, which makes it more easy and economical in terms of manufacturing and cost of product. The concept is widely used in most of the jars currently available in the market. The possibility of customize label application over the surface of the lid is possible, lid color customization is also possible. Further the concept can be made more attractive by providing the knurling texture around the circumference of the lid. The concept is already being used by the current product by host company.

Concept 2 (Figure 4.9) has a grab handle that allows users grab and hold, as well as a flip mechanism that permits users to close and open it to save space and make it much easier to transport. The grab handle makes grasping the entire jar using three fingers effortless. Flip handle looks more attractive and also more functional as well. The concept allows to customize the different color options for flip handle and lid, since its two entity. The application of label over the top of the lid would be little challenging as flip mechanism exist.

Concept 3 (Figure 4.9) originally inspired by the pelican bird, which also has a single-piece architecture with an opening and closing mechanism (resembling the beak) [49]. The open/ close mechanism has significant advantages, including the reduction of the need to open the complete lid whenever products from the jar were required. Access to stored products is much more convenient and quicker. There is no need to be bothered about leaks because the lid is secured with a click lock mechanism when closed. The convenience makes to access the food products like jelly beans, almonds, cashew nuts and many more of this size food items.

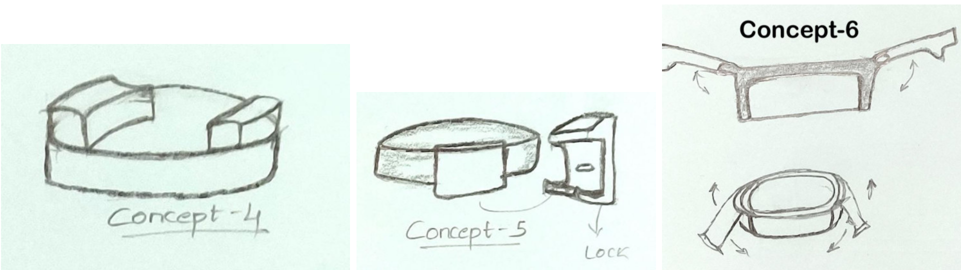

Figure 4.10: Lid concepts from left Concept-4,Concept-5,Concept-6

Concept 4 (Figure 4.9) The idea is simple, a heavy-duty lid with extra thickness for greater toughness and durability. The two mirrored ribs (knurling texture) generates traction, so that the fingers can easily spin to open and close the lid. The strong ribs absorb the first impact of falling, reducing the chances of the lid breaking. The advantages being strong with the cost of increase in weight results in increase in consumption of more material. There may be little challenge during the transport of lid + jar because of the extrusion provided. Possibility of applying labels are less due to less surface area availability in the lid.

Concept 5 and 6 (Figure 4.9) The objective of this design is to create an airtight cover with two locking mechanisms on either side. A considerable thick silicon seal will be provided so that, when closed, the lid and jar region are completely sealed, preventing air from entering the jar. There are also no possibilities of spillage from the jar. The lid looks elegant with more practicality in usage. Both the concepts looks identical and functions same, only difference is the shape and size of the interlocks that have been integrated.

Concept 7, shown on Figure 4.11 is patterned on the Japanese Pagoda, an earthquake-proof temple constructed in the 7th century AD [50], which is structurally designed to withstand the extremes of wind, sun, rain, and massive earthquake magnitudes. A Smidgen of inspiration is sparked, and it is sketched according to the requirements. During the concept development, structural strength and exquisite aesthetics are considered. The design looks distinctive from all the other concepts that are being generated. The unique design style have the potential to grab customers eyes. The top surface also enable space for application of label, space for stack ability of jar base during the transport and storing at warehouse.

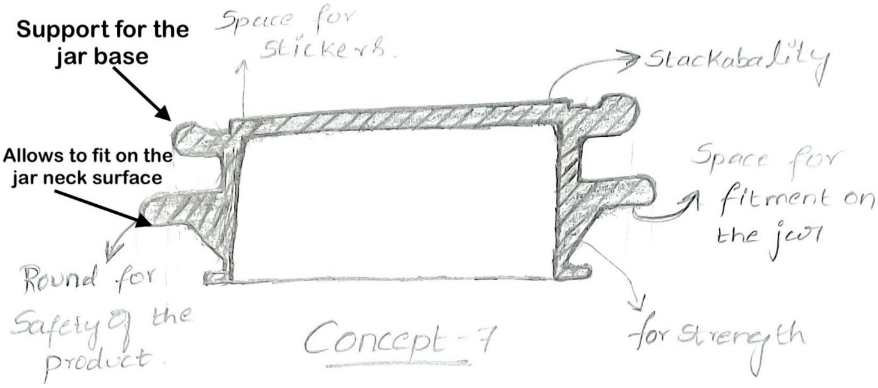

Figure 4.11: Lid concept-7

This is a one-of-a-kind design in terms of beauty and practicality. There are two flange style extrusion, the first with a smaller diameter on the top (support for the jar base) and the second with a larger diameter (allows to fit on the jar neck surface).

Concept selection

Total of seven concepts are generated,the best one is selected for future development. The considerations for selection consists of 'Aesthetics','easy to transport','easy to manufacture', 'Customization possibility', 'Product usability'. The explanations holds good as chapter 4.1.5, team members from manufacturing, design and commercial will review the concepts based on there experiences in there relative field and suitable scores are being given for easy concepts (Table 4.10).

Table 4.10: Concept scoring for lid design

Concepts	Aesthetics	Easy to manufacture	Easy to transport	Customization possibility	Product usability	Total score
Concept-1	3	5	4	4	3	19
Concept-2	3	3	4	3	4	17
Concept-3	3	3	4	3	4	17
Concept-4	3	4	3	3	4	17
Concept-5	4	3	3	4	4	18
Concept-6	4	3	3	4	4	18
Concept-7	5	4	4	4	4	21 Winner

Concept-7 is the clear winner with the score of 21. The hand sketched concept is transformed in to 3D model. The target dimensions or limit value were previously obtained (Table 4.3) so it makes the modeling process much smoother. The 3D model (Figure4.12) is designed and rendered to get a overview of the lid.

Figure 4.12: TOP LID 3D modeled

Initially the lid was designed aiming for maximum air tightness, this can be achievable by providing adequate silicon seal across the wall, so it creates the vacuum upon closure. Advantage would be more cost effective. There may be a possibility of wear and tear of silicon seal over period of time after long cycle of usage. Rethinking is essential to resolve this possible wear out. So, a sub-assembly parts are designed which may solve the possibilities of the above stated problem and also aiming for reliable solution.

The sub-assembly parts which were modelled to overcome the possible wear and tear problems which were addressed and it would be an ideal solution which went in mind and the outcome are lock wire (Metal wireform) (Figure:4.13 and 4.14). The lockwire is designed using wire form technique because it provides the flexibility, strength and durability. The geometry looks complex in-terms of design, but it can be manufactured and it is one of the economical solution. The only challenging thing is manufacturing the wire-forms because of spring-back effect and to achieve proper radius. The manufacturing will be quite an expensive till the parts are achieved to required specification. Once stream line the parts are way more cheaper and faster to manufacture.

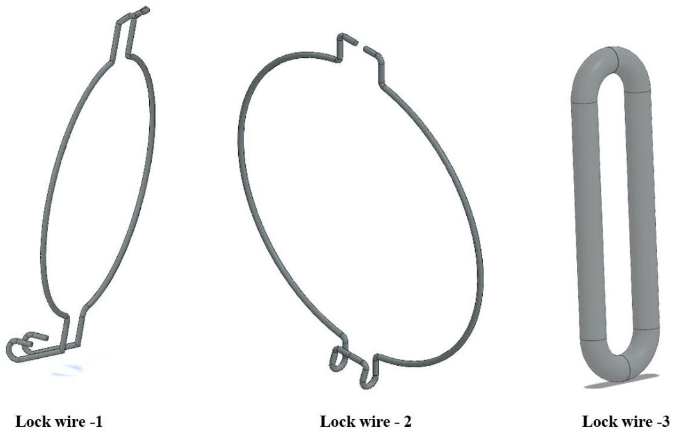

Figure 4.13: lock wire-1,lock wire-2 and lock

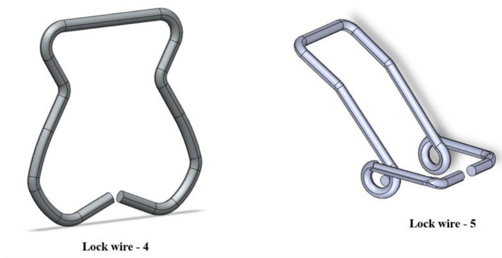

Figure 4.14: lock wire-4 and lock wire-5

The engineering drawings are drafted and ready for the manufacturing, the concepts are modelled to actual manufacturing models and are listed in appendix B.

4.1.10 Product Render

The renders (Figures 4.15 and 4.16) represent the final product. The concept stage is completed and prototype is also generated to feel the real size of the product in hand. The renders allows to view if there exist any aesthetics and other 3D modeling defects that can occur.

For the further comparison of Cylindrical jar (Chapter 4.1.11), a hexagonal jar of similar capacity is also developed, because hexagonal shape makes advantageous during packing (six sided wall) with no wastage of space forming honeycomb shape to form structurally strong. Also to examine for any possible advantages then the existing concepts developed so, we can conclude the best product to be launched to the market [51].

Figure 4.15: Cylindrical Jar render 1 litre and 2 litre capacity

Figure 4.16: Cylindrical Jar render 3 litre and 4 litre capacity

4.1.11 Hexagonal Giga Jar

The hexagonal is believed to be the strongest structure because of its six faces and all the edges inclined to angle of 120º. The design language remains identical to the Cylindrical vintage jar to the previous jar developed expect the Cylindrical shape there will be introduction of the hexagonal shape. Dimensions will be little varied because of the shape, all though the many considerations are taken so not to exceed much difference among this to designs. The concept development and briefing of the jar development procedure is skipped because, it's the same identical explanation as the cylindrical jar itself. Figures 4.17 and 4.18 shows the rendered hexagonal jars of identical capacity to the cylindrical jars.

Figure 4.17: Hexagonal Jar render 1.5 litre and 2 litre capacity

Figure 4.18: Hexagonal Jar render 3 litre and 4 litre capacity

4.2 Product: Bola de gelo (Icemaker) - Licor Beirão

Aim: To design an innovative ICE MAKER with the inclusion of customer logo on it

4.2.1 Customer input

The customer input is the most important aspect before design/developing any product. A set of data are collected from the costumer.

Customer need 1: The ice maker to be unique in design and more attractive.Also it should be different from the competition.

Customer need 2: The product should be easy and ergonomic to use.

Customer need 3: Ice cube should not result in breakage/ any damages during release from ice maker.

Customer need 4: Logo of the customer to be evident on ice and icemaker. The outside color should match the heritage of brand.

Customer need 5: The material usage to be nontoxic/nonreactive to ice.

Customer need 6: The ice should be little larger but should fit inside the glass.

Due to very minimum customer inputs and many confidential agreements the data obtained is very minimal. Although the data shared by customer is minimum, the design development is little challenging, but the strong desire to satisfy the customer needs. So efforts are made to understand the needs and target specification will be defined.

4.2.2 Converting customer needs to product specification

In order to realize the customer needs, it is important to understand 'what' is really need for customer, so a better product can be designed on defining the target specification of the product, which is a guideline for design and development. Table 4.11 is created to answer 'What' is customer needs and 'How' can it be achieved.

Table 4.11: Converting Customer needs to product specification

Customer Need	What's	How it is achieved	Specification
1	Unique and attractive design	unique design approach is required	scale-1 for poor, scale-3 for average, scale-5 for excellent
2	Easy and ergonomic to use	defining the target dimension	dimension <75x75x75 mm, weight < 120 g
3	Avoiding ice damage during removal from icemaker	Taper design or spherical design of icemaker	Taper angle 5 ° to 9°
4	Customer logo on ice	Logo inclusion in mirrored fashion on surface of ice-maker	Extrusion of logo (height < 2.5 mm)
5	Material of icemaker to be intoxic	BPA free plastic or silicon material	Food grade material
6	Ice should be larger but should fit inside liquor glass	Dimension should be defined for ice	Target dimension <30x30x30 (cubical)mm, spherical < $\phi 30mm$

4.2.3 Concept Generation

Concepts are free hand sketched initially. The concept shown in Figure 4.19 holds good, meeting the specific requirements of the customer stating the logo on ice cube, compact design/ ergonomic, easy to use. But while evaluating closely there is a possibility of eruption in logo while removing ice cube from the ice maker (which might be a bad sign) since there will be a twisting effect during the collection of ice cube from icemaker.

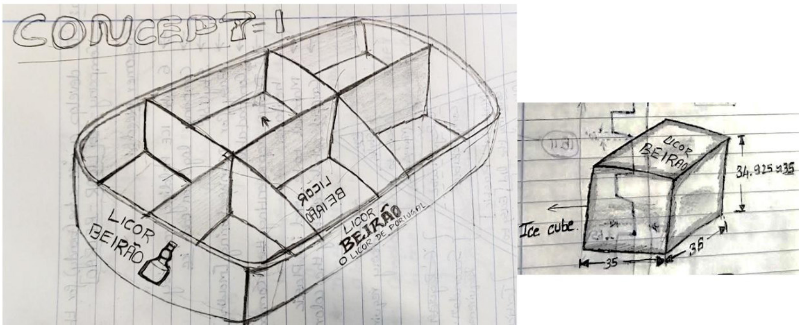

Figure 4.19: Licor Beirão - Concept-1 sketch

The concept 1 doesn't satisfy the customer needs, so it is very essential to generate other concept which satisfies all the customer needs. The customer also needs the product to be unique and distinctive. A spherical shape would be a choice for concept development, the advantage being it looks attractive, the absence of corners make much easier to retrieve ice from icemaker. The large size ice can also be achieved as well. The other advantage of spherical ice is it appears to melt slowly [52], keeps the drink chilled and dilutes the drink (alcohol).

Figure 4.20: Licor Beirão - Football concept

The concept 2 is generated based on the world's most played sport "football"/ "futbol" (Portuguese). In Portugal, football is 'Passion of a nation', people respect and support the sport like no other (superstitious). A true inspiration drawn to create a product like football. The people enjoy the drink mostly on watching football sport. The football shaped ice in a glass of drink makes sense. The idea here is to conceptualize both the Ice maker and ice in the shape of football.

The concept of football (concept 2) was generated as shown on Figure. 4.20. A true passion towards sport make a product special and impact on end user and also enhance the brand value of the customer (Licor Beirão).

In order to enhance the brand image of the customer, the concept is further expanded with the challenging of imparting a world map on the surface of the ice maker, representing the brand image to the global market initially originated from Portugal. Many iterations are carried out to impart a world map on the spherical surface of the icemaker. It was also a challenge to design because of the space availability on the sphere. After crossing many hurdles, finally concept 3 was developed. Figure 4.21 shows the array of concepts being generated in order to level up the project to the next phase.

The world map on the exterior represents footprints of the product globally. The logo (Licor Berao) is also evident on ice. This concept also holds good and satisfies all the requirements stated in table 4.11. The concepts 2 and 3 fit all the customer requirements and *further development process is not been explained because of the disclosure agreement between host company and customer.*

Figure 4.21: Licor Beirão-worldmap concept

The final concept features of the product designed are briefed in figure 4.22.

The product usability is explained in portuguese and to put in contrast in english. The steps-how product can be used are as follows: **Step-1:** Close the top lid > **Step-2:** Fill the water on top hole provided > **Step-3:** Freeze it > **Step-4:** Twist the top lid to open > **Step-5:** Enjoy the large ice with Licor Beirão.
The product data description is also limited due to confidentiality.

Figure 4.22: Licor Beirão ice maker concepts description

5 Product Analysis

The analysis is very important aspect for development process of the product. FEA (Finite Elemental Analysis) is performed to check the possibilities of failure mode that can product experience upon different loading circumstances. The analysis is done prior to the manufacture of part because, it will determine the existence of failure that can possibly occur during the manufacturing, transport and other various factors. The loop hole in the design can be easily determined and corrected so it can save lot of energy and resource. Analysis also benefits organization to determine the failure modes/ weaker sections of the product before the manufacturing,where significant rejection cost can be avoided.

The analysis is performed for Hexagonal and Cylindrical jars that have been designed earlier (Chapter 4). Two types of analysis is carried out for both the jars to determine the load bearing capacity in axial load condition and horizontal load condition. The key focus of the analysis is to determine the better geometrical design among the two jars designed.

Buckling Test: Jars are subjected to compressing load during the transport, storing at the warehouse where product is stacked one upon other. A minimum load needs to be bared by the product so it is not experiencing any failure mode, so in order to check the load bearing capacity, a buckling test is performed. Buckling test/ top load test determines how much axial load can a vertical product can withstand before deformation/ slandering occurs.

Static Load/ Gripping force: The jars are flexible (inheritance property of PET), in practical the jar are grabbed in wrist, so adequate force is exerted on the walls of the jars which results in stress. The aim of the analysis is to examine the amount of stress experienced by different capacity jars with the product factory of safety. A detailed comparison is done between cylindrical vs hexagonal jars to determine which geometry showcase the better results in withstanding axial and horizontal loads.

The geometry modelling and simulation is carried out in 3D CAD tool SOLIDWORKS 2021. *Buckling load test* and *Static load test* are performed for each geometry developed. FEA considerations for meshing is done with the element size of 0.54 mm (after many iterations and geometrical constraint consideration), and the element type is 3D (tetrahedral). The material chosen is PET and a uniform jar thickness of 1mm is considered.

Mechanical properties of PET are shown in table 5.1. Considering the properties, the designed jars are tested for its factor of safety to ensure designed products are under the safe working load conditions.

Table 5.1: Mechanical properties of PET.

Technical name	Polyethylene terephthalate (PET or PETE)
Youngs modulus	2950 MPa
Tensile Modulus	152 MPa
Flexural Strength	221MPa
Density	1380 kg/m^3
Shrink rate	0.1 - 0.3%

5.1 Buckling test/ Top load test

The analysis is carried among all the capacity variants that have been designed, to get the clarity of how the same geometrically designed product with variations in its volume and height behaves with same boundary conditions.The table 5.2 gives the dimensions of height of the jars, used in simulations.

Table 5.2: Cylindrical jar and Hexagonal Jar height

Capacity	Cylindrical Jar Height (mm)	Hexagonal Jar height (mm)
1.2 litre	96	124.4
2 litre	137	154
3 litre	191	214
4 litre	244	274

In buckling analysis, the value of buckling factor (Table 5.3) determines the safety of the equipment. To anticipate the bottle's buckling quality under pressure, a finite element analysis was carried out. In preparation for a numerical simulation, the relationship between shape parameter (bottle diameter, height, and thickness) and buckling load was investigated.

A vertical load of 100 N is applied (Figure 5.1) assuming the bottle is exposed to various loading circumstances during packing, stacking and transport. Buckling factors greater than '1' determines the jar is safe under the loaded condition. The analysis also helps to determine the weak zone that jar can buckle when load bearing capacity is exceeded.

The analysis carried out for all capacities for both cylindrical and hexagonal jars.

Table 5.3: Buckling load factor [53]

Buckling load factor	Remarks
<1	Failure occurs
=1	Needs modification
>1	Safe zone

The buckling test is carried out and the resultant output is the buckling factor. For cylin-

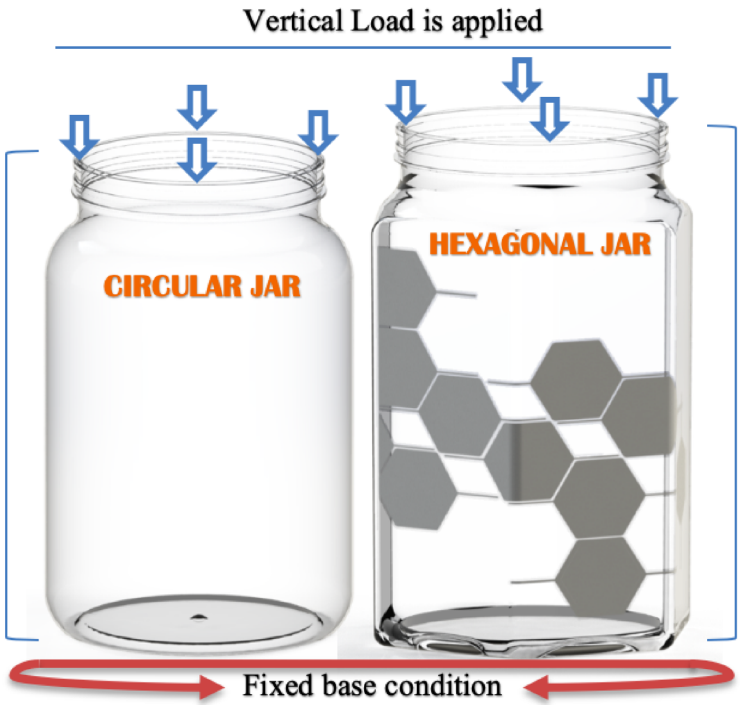

Figure 5.1: Boundary condition

drical jar the buckling factor is 42.55 and for hexagonal jar is 21.27. The buckling factor is greater than 1 for both the cases its under safe load condition and product is safe - Figure 5.2.

The same boundary conditions are applied to the 2 l, 3 l and 4 l cylindrical and hexagonal jar, the buckling factor results are tabulated (5.4).The figure (7.7),7.8 and 7.9) shows that there is no sign of occurrence of buckling in any of the jars that being analysed.

The moment of inertia is calculated for hexagonal and cylindrical jars. The jars are subjected to compressing load. A hexagon with an equal cross-sectional area to a circle of radius r and (thin) wall thickness t must have side lengths of

$$a = \frac{1}{3}\left(\pi r + \sqrt{3}t\right) \tag{5.1}$$

The wall thickness of both the Cylindrical and Hexagonal jars are same and bending stiffness can be calculated i.e, *EI*, where E = Young's modulus , I = second moment of inertia of cross-section,

Moment of inertia of cylindrical jar[54]

$$I_c = \frac{\pi}{4}((r_o)^4 - (r_i)^4)r_i \tag{5.2}$$

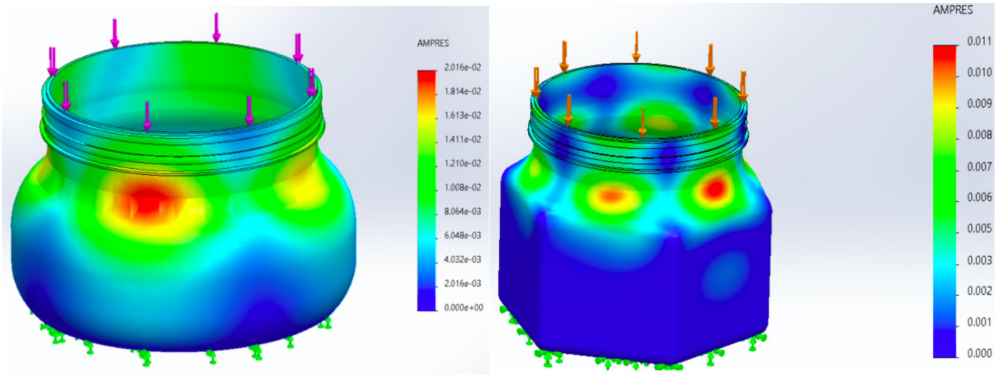

Figure 5.2: Buckling test 1.2litres

Moment of inertia of hexagonal jar [55]

$$I_h = \frac{5}{18}t\left(9a^3 - 9\sqrt{3}a^2t + 12at^2 - 2\sqrt{3}t^3\right) = \frac{5}{54}t\left(\pi^3r^3 + 3\pi rt^2\right) \tag{5.3}$$

The final equation (5.3) is derived from substituting value of a from equation (5.1). The engineering drawing are derived and dimensions of the respective capacity is also derived (Figure 7.1 for cylindrical jar and Figure 7.6 for hexagonal). The radius values (r_o=78.5 mm, r_i=77.5 mm) for the cylindrical jars is noted and substituted in equation 5.2 and moment of inertia for cylindrical profile is derived Substituting values we get $1.52 \times 10^6 mm^4$. Similarly the value of r= 72 mm is substituted with the t=1 mm to the equation (5.3), therefore Moment of inertia of hexagonal Jar = $1.06 \times 10^6 mm^4$. The moment of inertia of cylindrical jar is greater than the moment of inertia of hexagonal jar.

The critical buckling load is given by Euler's formula [56]:

$$P_cr = \frac{\pi^2 EI}{L^2} \tag{5.4}$$

Where, P_cr = Critical buckling load , E = Young's modulus (MPa) , I = Moment of inertia (mm^4), L = Length of the column (mm)

Table 5.4: Buckling test summary table

Capacity	Buckling factor-Cylindrical Jar	Buckling factor-Hexagonal Jar
1.2 litre	42.55	21.27
2 Litre	22.34	19.62
3 Litre	19.66	12.39
4 Litre	16.53	9.88

From the equation (5.4) it is clear that, chance of buckling are high with increase in length. The buckling factor values for cylindrical jars is more than the value of hexagonal jars of all capacity. Top loading strength is known to be higher in bottles with a smooth curved (cylindrical jar) and continuous body wall [57]. As a result, bottles with a curved and rounded body structure are typically chosen for top loading strength over bottles with abrupt transitions that generate relatively "polygonal" profiles and provide little resistance to top load forces. The jars of two geometrical shapes doesn't experience any buckling, cylindrical being the highest load bearing capacity when compare to hexagonal jar of same capacity.

5.2 Squeeze Load test

The test is carried out to simulate the horizontal forces that jar can handle when it is gripped with certain force of an human hand and also the wrapping/ packing forces exerted after manufacturing. The force defined based on the force an human hand can grip the product. [58] A force of 30 kg can be exerted by a muscular men. Corresponding this data force of 300 N is applied all across the body of the jar where force can be applied by hand [59].

For analysis, the top and bottom of the jars are fixed, a load of 300 N (representing human hand) is applied across the side walls of the jars (Figure 5.3), the simulation were simulated.

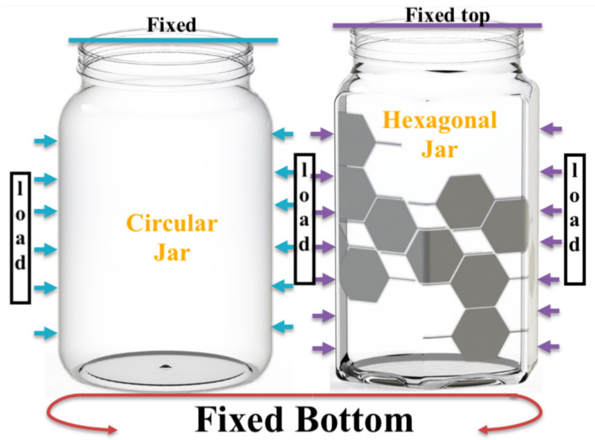

Figure 5.3: Boundary condition - Squeeze test

The stress distribution were mapped, the maximum stress imparted is about 5.23 MPa in case of cylindrical jar and 0.5327 MPa in case of hexagonal jar. (Fig5.4) This is because the cylindrical geometry has no edges all the load applied is distributed across the circumference, in case of hexagonal the side edges provides a stiffness, hence load distributes across and all along the body neutralizing the stress concentration thus minimum stress accumulation per unit area. Similarly the jar capacity of 2l, 3l and 4l are also subjected to the same boundary condition and tested, the stress distribution are can be evident in figure 7.10, 7.11 and 7.12.

Table 5.5 shows the stress acted upon the cylindrical jar and hexagonal jar when subjected to horizontal load. It is evident that the stress acting on the higher capacity jar is less in

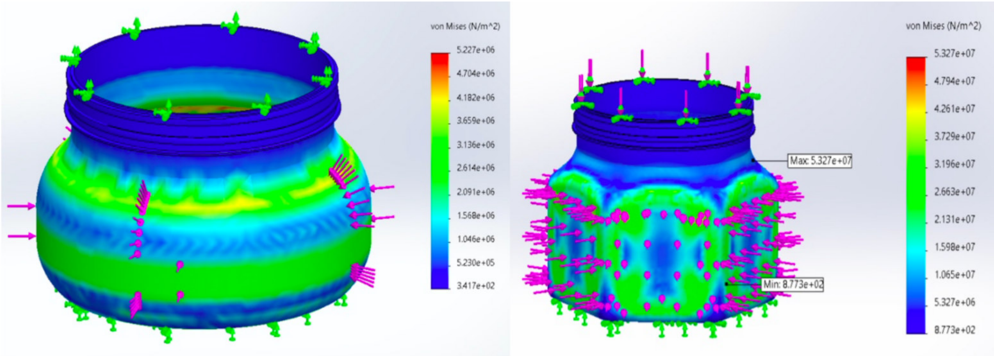

Figure 5.4: Stress test - 1.2 Litre jar

Table 5.5: Max.Stress experienced value table

Capacity	Max.Stress (MPa)-Cylindrical Jar	Max.Stress (MPa)-Hexagonal Jar
1.2 litre	5.23	53.52
2Litre	0.89	51.23
3Litre	0.47	44.57
4Litre	0.32	37.42

both the cylindrical jar and hexagonal jar type. The cylindrical jar with 4l experience the least stress of 0.32 MPa due to more surface area and the explanation holds good for hexagonal with the stress 37.42 MPa. The cylindrical jar of all capacity jars experience the lower stress compare to hexagonal, hence load bearing capacity jars of cylindrical are higher.

5.3 FOS-Factor of Safety

A factor of safety is the load-carrying capacity of a product beyond what the product actually supports. For reliability, products are typically built stronger than necessary. This is in case a products experiences a heavier-than-expected load. This is a factor of safety. Ultimately, the amount of stress and overload a product can handle comes down to the material used to build it. The FOS is determined while simulating the squeeze load test (boundary condition remains same [Figure 5.3]). It determines whether the product can withstand the load without occurrence of permanent deformation. Figure (5.5) shows the FOS of the two jars and the FOS of cylindrical jar is 9.8 and that of hexagonal jar is 1.15 the stress accumulation is higher in hexagonal than in cylindrical jar.The figure 7.13,7.14 and 7.15 shows the FOS characteristics of the jars of different capacity.

The table 5.6 shows the FOS value of hexagonal jar and cylindrical jar of all capacity,as it is evident that the FOS value is highest in the 1.2l jar which corresponds to value of 9.8 that means jar can withstand the load of 9.8 times the corresponding load applied (100 N) before

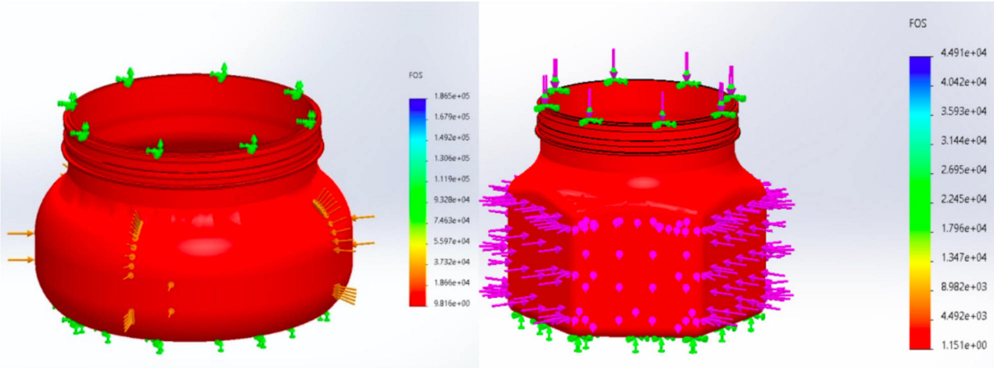

Figure 5.5: FOS - 1.2 Litre jar

occurrence of permanent deformation.Whereas the hexagonal jar of same capacity with FOS value is 1.15 is just safe with the applied load (100 N). So, if the hexagonal jar exceeds the load of 120N there can be evidence of deformation found in the jar. Similarly the explanation holds good for all the other capacity cylindrical and hexagonal jar.

Table 5.6: FOS summary table

Capacity	FOS-Cylindrical Jar	FOS-Hexagonal Jar
1.2 litre	9.8	1.15
2 Litre	8.9	1.29
3 Litre	3.5	1
4 Litre	2.38	1.4

Weight of the Jars

In packaging industry, weight of the product is very crucial. The increase in every gram of the product increases the overall weight of packing weight and gets added up to more transportation cost. The product cost will also add up because more raw material is consumed. Considering the 'circular economy', the recycling cost of the product will also increase. Table 5.7 displays the jar weight of cylindrical and hexagonal.

Table 5.7: Weight comparision cylindrical jar v/s Hexagonal jar

Capacity	weight-Cylindrical Jar (gm)	weight-Hexagonal Jar (gm)
1.2 litre	109.5	139.65
2 Litre	137.7	161
3 Litre	168.5	203.3
4 Litre	212.4	256.6

The cylindrical jar satisfies all the requirement that consumer needs which looks elegant, airtight, easy to wash because of smooth cylindrical face and large neck diameter, also very much durable because it is designed more than the working load, light weight, easily recyclable.

6 Prototyping

Prototype approximates the product in its true dimension. Prototype resembles the how the product looks and feel in the real world. Developing a prototype is like precautionary measure (to avoid mistakes) before manufacturing of actual product, some of the advantages of prototyping.

- It will reduce the iteration time
- Assist in identifying possible errors that can occur in the manufactured product
- Reduces the unanticipated phenomena of finished product.
- 3D printing (Rapid prototyping) has reduced the relative cost and time required for development and reduced cost for testing prototypes [60]

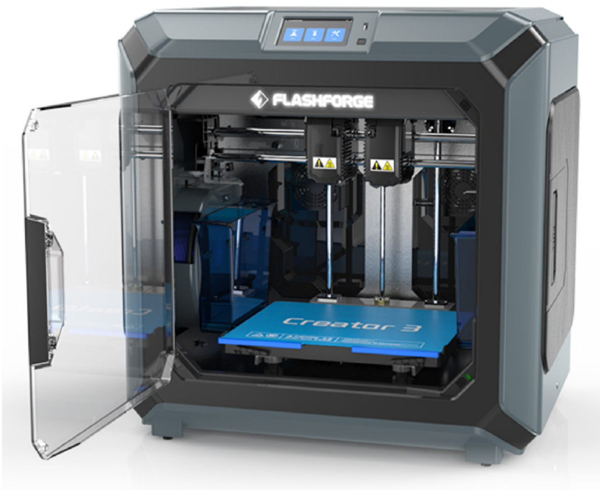

Figure 6.1: Flashforge 3D printer

Prototype can be achieved through varies technologies , in this case designed product is accomplished through the 3D printing technology called Fused Deposition Method (FDM), which is classified as the material extrusion AM technique. It is the simplest affordable and readily available 3D printing technique for polymer-based materials and it has been extensively used in various industries [61] where the product is developed through layer deposition method using the plastic filament Flash forge – PLA (polylactic acid) 3D Printing Filament 1.75 mm 0.5 kg/roll for Adventurer 3, Dreamer and Finder Series (Red) [62]. The machine used is the FLASHFORGE - Creator 3 [63] The prototypes are developed to the actual dimensions of the product itself to sense the actual dimension, size and shape of the product designed. Hexagonal Jar, cylindrical Jar, the wire-forms, lids are developed. The products are compiling the aspects of the design that were discussed earlier in the chapter 4.1.6.

The prototypes are developed and checked for the practicality and real world usability. The prototypes are checked for ergonomics, stack-ability and vertical loading capacity.

6.1 Ergonomics

The figure 6.2 and 6.3 represents prototype being easily held by one hand.The prototype is dimensional identical to 3D modeling (which is discussed in section 4.1.8). The prototype is easily accessed by one hand, (here the prototype is held by person of medium size hand [18 cm]). The neck region makes easily grab the jar in one hand and make it more convenient to handle as well.

Figure 6.2: Cylindrical Jar Prototype

The accessories are also being prototype, so each part designed is being produced. The wire-form in figure 6.4 is difficult to assemble in the prototype stage to the lid figure 6.5 because of the stiffness issue and thinner cross-section (wire-form is original produced using food grade steel). The prototype are produced to the matching dimensions to suite the original product.

The lid is being prototype to the required specification the lid fits the jar accurately. The lid functions as a load bearing member and assists in stack ability of jar.

Figure 6.3: Hexagonal Jar Prototype

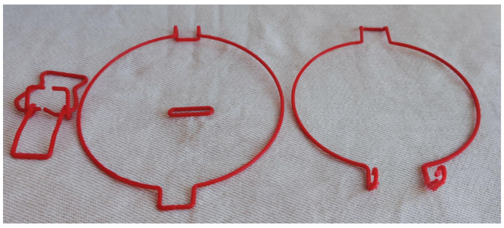

Figure 6.4: Prototype - Wire-form

6.2 Vertical Loading

Vertical loading determines the load bearing capacity of the jar during transportation, the prototype are loaded with two jars weighing 1.3 kg and 1.9 kg a total of 3.2 kg of vertical load (refer figure 6.6). The load was applied for 24 hrs and observed no sign of damage. This ensure the design is much safer in the loading condition (a analysis is made in chapter-5 top-load test, tested for 100 N/ 10 kg) and can take up the further load as well. The evidence of no damage in the prototype, is a sign of good design. Prototype proves the design and analysis carried out are true in real world scenarios.

6.3 Stackability of Jars

The stackability is the one of the major characteristics of jar. The stackability allows to save the space and provides stability during the transport. The vertical load of one jar (bottom) is distributed evenly through the lid, so the jar walls experience least load impact. The unique

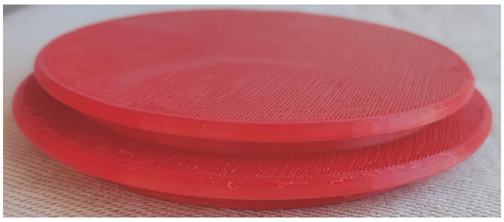

Figure 6.5: Prototype - IID

lid design allows the base of jar to fit the circumference of jar evenly. Figure 6.7 shows the stability of both the jars. The lid fits both the geometrical jars.

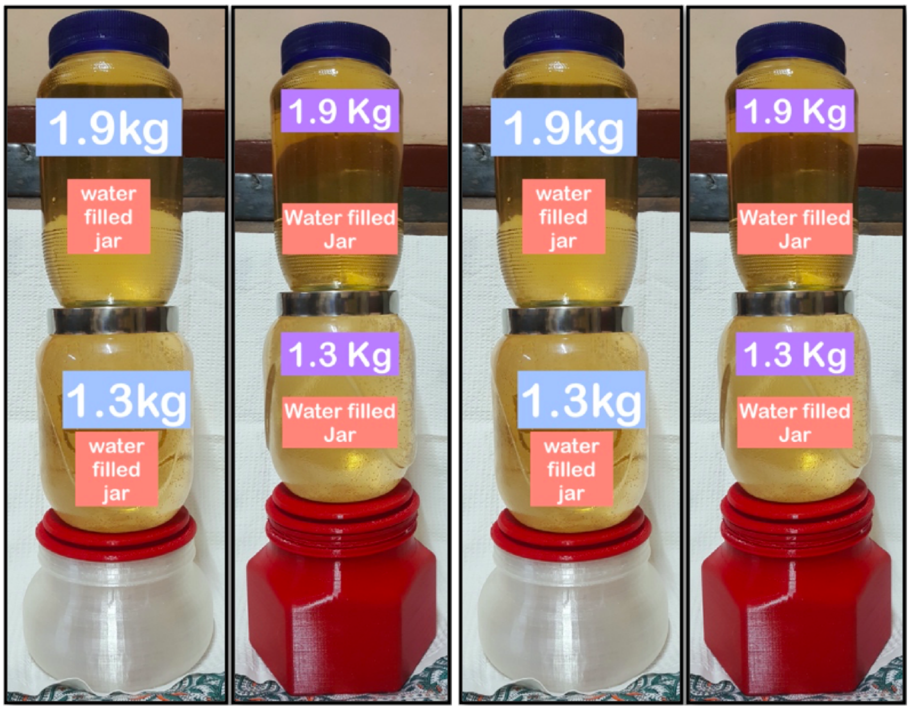

Figure 6.6: Prototype-vertical load (left -cylindrical jar) (Right-Hexagonal jar)

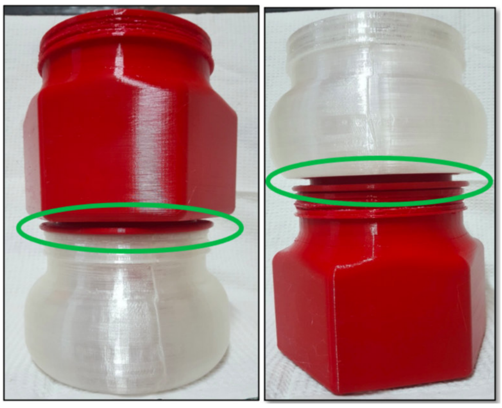

Figure 6.7: Prototype - Stack ability (left -cylindrical jar) (Right-Hexagonal jar)

7 Conclusions

Internship program is mainly focused on delivering the innovative products on utilizing most of the curriculum being taught in the academics for the sustainability of the host company- Plásticos Futura and also nourishing the student knowledge and skills to the practical world.

The internship program was mainly focused on delivery an elegant and innovative product to the market and customers who have set their standards high above the market competition.

Many marketing surveys, psychological behaviours of customer towards the products is being considered during the product development stage. Each stage of product development is closely taken care of all the aspects of manufacturing, economics of product, product placement in the market, customer requirements, economics of packing of product, economics in each curve designed.

Two product were being developed one being the "Bola de Gelo - Licor Beirao" and "Vintage Giga Jar", due to disclosure agreements and limited data availability the product "Bola de Gelo - Licor Beirao" is having limited briefing. The product "Vintage Giga Jar" is developed from the ground up considering every customers' needs in order to fulfil the complete requirement without leaving behind a pinch of the requirements. A house of quality was drawn to identify the customer needs thoroughly which assists in each stage of product development.

A total of five concepts were hand sketched for cylindrical jars, Concept-1 was chosen for the development because of advantage in shape and fulfill all the customer requirements. Calculations were made and dimensions were derived for developing the different capacity jars of 1.2, 2 , 3 and 4 litre. Each capacity jar is designed using 3D modeling software with a uniform thickness of 1 mm (keeping in mind the blow molding manufacturing process). Renders are also presented to give an view about the product being designed.

The lid is another important component of the jar, seven concepts were hand sketched and concept-7 was picked which was an design inspiration from Japanese pagoda which is earthquake proof by structure, the design is made to fit the customer requirements and needs to match the jar design outlook. The lid provides the space for label application and a elevated circumference allows jars for stack-ability, the design allows for other accessories (wire-forms) to fit for maximum tightness of lid to jar. The wire-forms are designed as a part of closure/ opening mechanism for the jar. Each is custom built, development have been hidden because of disclosure agreement. Wire-form in the other hand provides more advantage because its non corrosive, less wear-ability, aids to tighten the lid.

A analysis were carried out for all the capacity cylindrical jars. Additional a hexagonal jars were also been designed with same capacities for the comparison study between cylindrical jar and hexagonal jar. Three different tests were being carried out as a part of analysis. [Analysis were carried out in SOLIDWORKS simulation solver].

Buckling test/ top load test which is to determine the vertical load bearing capacity of an jar which aids to determine the jars resistant to buckle during the transportation in pallets or storage of jars in the warehouse. A result were drawn were cylindrical jars of all capacity experienced least deformation under load when compared to the hexagonal jars of same capacity due to higher moment of inertia in cylindrical jar compare to hexagonal jar.

The weight (because of less thickness) advantage is a huge benefit in terms of transport and recycling cost. So, the cylindrical jars would be the choice of jar that will be developed with more advantages than the hexagonal jar.

The internship program fulfils the need of every aspect of product design, development, economics, manufacturing methods, material selection, product performance evaluation, prototyping and testing of the product which right way from idea to real functional product. Being said the world is moving towards the greener side and demanding for more environmentally sustainable products, so keeping in mind the rapid developments that are being occurred in materials it is possible to develop the same product with bio based polymers for more bio-degradable, cleaner and greener environment.

Bibliography

[1] Patricia Müller etal. “Intelligent Packaging in the Food Sector: A Brief Overview”. In: *Foods* 8 (2019). ISSN: 2304-8158.

[2] Betty Bugusu Kenneth Marsh. “Food Packaging—Roles, Materials, and Environmental Issues”. In: *Journal of food science* 72 (2007). ISSN: 1750-3841.

[3] Richard Coles. *Food and Beverage Packaging Technology*. Second. John Wiley and Sons Ltd, 2011. Chap. 1, pp. 10–12. ISBN: 978-1-4051-8910-1.

[4] Lindani Koketso and etal. “Environmental Impact of Food Packaging Materials: A Review of Contemporary Development from Conventional Plastics to Polylactic Acid Based Materials”. In: *Materials* 13 (2020). ISSN: 1996-1944.

[5] Chowdhury and etal. “A Review On The Use Of Polyethylene Terephthalate (PET) As Aggregates In Concrete”. In: *Malyasian Journal of science* 37 (2018). ISSN: 2600-8688.

[6] *Food Packaging Market Size, Growth and Industry Trends [2028]*. URL: https://www.fortunebusinessinsights.com/industry-reports/food-packaging-market-101941 (visited on 02/09/2022).

[7] Plasticos futura. *Top view of the company*. URL: http://plasticos-futura.com/index.php?route=common/home (visited on 01/21/2021).

[8] Plásticos Futura. *Plásticos Futura Technology integration for manufacturing*. 2021. URL: http://plasticos-futura.com/index.php?route=information/information&information_id=9 (visited on 03/01/2021).

[9] Nitaigour Premchand Mahalik. “Advances in Packaging Methods, Processes and Systems”. In: *Challenges* 5 (2014). ISSN: 2078-1547.

[10] Plasticos futura. *Plasticos Futura product-Jars*. URL: http://plasticos-futura.com/index.php?route=product/category&path=62 (visited on 03/28/2022).

[11] Plasticos futura. *Plasticos Futura product-Catering*. URL: http://plasticos-futura.com/index.php?route=product/category&path=62 (visited on 03/28/2022).

[12] Plasticos futura. *Plasticos Futura product-Medical and pharma*. URL: http://plasticos-futura.com/index.php?route=product/category&path=62_67 (visited on 03/28/2022).

[13] Plasticos futura. *Plasticos Futura product-seasonal*. URL: http://plasticos-futura.com/index.php?route=product/category&path=59 (visited on 03/28/2022).

[14] Plasticos futura. *Plasticos Futura product-Medical and pharma*. URL: https://pharma.plasticos-futura.com (visited on 03/28/2022).

[15] E. Alfredo Campo. *The Complete Part Design Handbook*. Vol. I. Hanser Publishers, Munich, 2006. Chap. 1, pp. 25–26. ISBN: 978-3-446-40309-3.

[16] Xcentric Mold and Engineering. “Advanced Injection Mold Making”. In: (). URL: https://www.xcentricmold.com/services/injection-mold-making-system/ (visited on 02/23/2021).

[17] Douglas M. Bryce. *Plastic injection molding*. Second. Society of Manufacturing Engineers Dearborn, Michigan, 1997. Chap. 1, pp. 3–5. ISBN: 0-87263-488-4.

[18] DOMINICK V. ROSATO and etal. *Plastic Design Handbook*. First. Springer Science+Business Media New York, 2001. Chap. 4, pp. 210–212. ISBN: 978-0-7923-7980-5.

[19] Samuel L. Belcher. *Practical Guide to Injection Blow Molding*. Taylor and Francis Group, 2007. Chap. 2, pp. 5–6. ISBN: 978-0-8247-5791-5.

[20] N C Lee. *Plastic Blow Molding Handbook*. 1st ed. Springer Dordrecht, 1998. Chap. 1, pp. 17–18. ISBN: 978-94-011-6990-5.

[21] Sachin Thorat. “Blow Moulding – Process , advantages and Disadvantages”. In: (). URL: https://learnmech.com/blow-moulding-types-advantages-disadvantages.

[22] Anshuman Shrivastava. *Introduction to Plastics Engineering*. 1st ed. William Andrew Publishing, 2018. Chap. 5, pp. 146–150. ISBN: 978-0-323-39500-7.

[23] Anshuman Shrivastava. *Introduction to Plastics Engineering*. 1st ed. William Andrew Publishing, 2018. Chap. 5, p. 146. ISBN: 978-0-323-39500-7.

[24] CHARLES A. HARPER. *Handbook of Plastic processes*. 1st ed. John Wiley and Sons, 2006. Chap. 5, pp. 307–312. ISBN: 978-0-471-66255-6.

[25] Gemini Group. *Stretch Blow molding*. ©2022. URL: https://geminigroup.net/plastics/blow-molding-regency/ (visited on 03/14/2022).

[26] Michael Thielen. *Extrusion Blow moulding*. 1st ed. Hanser Publication, Gmbh, 2021. Chap. 3, pp. 147–149. ISBN: 978-1-56990-840-2.

[27] Karl T. Ulrich et al. *PRODUCT DESIGN AND DEVELOPMENT*. Fifth. Mc Graw-hill education, 2012, pp. 95–98. ISBN: 978-0-07-340477-6.

[28] Mc Graw-hill. *PRODUCT DESIGN AND DEVELOPMENT*. Sixth. Mc Graw-hill education, 2016, pp. 77–79. ISBN: 978-0-07-802906-6.

[29] Anil Mital et al. *Product Development- A Structured Approach to Consumer Product Development, Design, and Manufacture*. First. Butterworth–Heinemann publications, 2008, pp. 59–60. ISBN: 978-0-7506-8309-8.

[30] Michael G.Luchs et al. *Design thinking*. First. John Wiley and sons, 2016, pp. 72–73. ISBN: 978-1-118-97182-6.

[31] Michael G.Luchs et al. *Design thinking*. First. John Wiley and sons, 2016, pp. 75–76. ISBN: 978-1-118-97182-6.

[32] Marc A. Annacchino. *New Product development*. Sixth. Butterworth-Heinemann, 2003, pp. 147–149. ISBN: 978-0-7506-7732-5.

[33] Karl T. Ulrich et al. *PRODUCT DESIGN AND DEVELOPMENT*. Fifth. Mc Graw-hill education, 2012, pp. 184–185. ISBN: 978-0-07-340477-6.

[34] DAVID M ANDERSON. *Design for manufacturing*. First. Taylor and Francis, 2014, pp. 3–5. ISBN: 978-1-4822-0492-6.

[35] Anil Mital et al. *Product Development- A Structured Approach to Consumer Product Development, Design, and Manufacture*. First. Butterworth–Heinemann publications, 2008, pp. 370–375. ISBN: 978-0-7506-8309-8.

[36] Joseph P. Ficalora Louis Cohen. *Quality functional deployment and Six sigma*. Second. Pearson Education, Inc., 2010. Chap. 5, pp. 230–252. ISBN: 978-0-13-513835-9.

[37] Pramol Jain. *House of quality-Vintage Giga Jar*. URL: https://myipleiria-my.sharepoint.com/:x:/g/personal/2190449_my_ipleiria_pt/EYZDFS5dD_ZDmHFHRrHVwpkBNjybbaQAW YkI5WjoghkTQ?e=29Kk0t.

[38] Mc Graw-hill. *PRODUCT DESIGN AND DEVELOPMENT*. Sixth. Mc Graw-hill education, 2016, pp. 117–119. ISBN: 978-0-07-802906-6.

[39] Nadal Marcos Gómez-Puerto Gerardo Munar Enric. “Preference for Curvature: A Historical and Conceptual Framework”. In: *Frontiers in Human Neuroscience* 9 (2016). ISSN: 1662-5161.

[40] Adrian Frutiger. *SIGNS AND SYMBOLS THEIR DESIGN AND MEANING*. Second. Copyright © Weiss Verlag GmbH,Dreieich, West Germany. Library of Congress Catalogue Card Number 89-5714, 1989, pp. 45–48. ISBN: 0-442-23918-1.

[41] Marco Bertamini et al John wiley. “Do observers like curvature or do they dislike angularity?” In: *British Journal of Psychology* 107 (2016).

[42] Kadlimatti Pujari. “Correlation of Human Height with Hand Dimensions”. In: *International Journal Of human anatomy* 1 (2019). ISSN: 2577-2279.

[43] Jonathan Ochshorn. *Structural Elements for Architects and Builders*. 1st ed. Butterworth-Heinemann,London, 2010. Chap. 4, pp. 76–77. ISBN: 978-1-85617-771-9.

[44] *Standard Pallet Sizes Internationally*. URL: https://packagingrevolution.net/standard-pallet-sizes/ (visited on 04/19/2021).

[45] T Horvath M Kalman et al. “The mechanical properties of polyethylene-terephthalate (PET) and polylactic-acid (PDLLA and PLLA), the influence of material structure on forming”. In: *IOP Conference Series: Materials Science and Engineering* 426 (2018). URL: https://doi.org/10.1088/1757-899X/426/1/012018.

[46] *PET Recycleable symbol*. URL: https://www.epbp.org/ (visited on 05/24/2021).

[47] Firas Awaja. “Recycling of PET”. In: *European Polymer Journal* 41 (2005). ISSN: 0014-3057.

[48] Kristal Roman et al. “The mechanical properties of polyethylene-terephthalate (PET) and polylactic-acid (PDLLA and PLLA), the influence of material structure on forming”. In: *IOP Conference Series: Materials Science and Engineering* 426 (2018). DOI: https://doi.org/10.1088/1757-899X/426/1/012018.

[49] Julie Carrier et al. “The earliest known pelican reveals 30 million years of evolutionary stasis in beak morphology”. In: *Journal of Ornithology* 152 (2011). DOI: https://doi.org/10.1007/s10336-010-0537-5.

[50] Editors of Encyclopedia Britannica. *Britannica, The Editors of Encyclopaedia. "pagoda"*. Encyclopædia Britannica, Inc, 2019.

[51] T.X. Yu L.L. Hu. “Mechanical behavior of hexagonal honeycombs under low-velocity impact – theory and simulations”. In: *International Journal of Solids and Structures* 50 (2013). ISSN: 0020-7683.

[52] Doing science to stuff. *On the shape of ice: Spheres vs Cubes*. URL: https://blog.doingsciencetostuff.com/2013/06/15/on-the-shape-of-ice-spheres-vs-cubes/.

[53] Solidworks. *Buckling factor*. URL: https://help.solidworks.com/2012/english/SolidWorks/cworks/Buckling_Load_Factor.htm (visited on 10/28/2021).

[54] R C Hibbeler. *Mechanics of material*. 8th ed. Pearson Publication, 2011. Chap. 5, p. 362. ISBN: 978-0-13-602230-5.

[55] R C Hibbeler. *Mechanics of material*. 8th ed. Pearson Publication, 2011. Chap. 5, p. 368. ISBN: 978-0-13-602230-5.

[56] R C Hibbeler. *Mechanics of material*. 8th ed. Pearson Publication, 2011. Chap. 6, p. 381. ISBN: 978-0-13-602230-5.

[57] Koichi Maekawa et al. “Performance Comparison of Circular and Square RC Columns under Monotonic Loading Conditions”. In: *KSCE journal of civil engineering* (2018). DOI: 10.1007/s12205-018-0621-6.

[58] T Nilsen M Herman et al. “Grip force and pinch grip in an adult population: Reference values and factors associated with grip force”. In: *Scandinavian journal of occupational therapy* 19 (2011). URL: https://doi.org/10.3109/11038128.2011.553687.

[59] Newsletter. *What is the average hand size*. URL: https://www.medicalnewstoday.com/articles/318155 (visited on 10/09/2021).

[60] D Schniederjans and M Yalcin. “Perception of 3D-printing: analysis of manufacturing use and adoption”. In: *Rapid Prototyping Journal* 24 (2018). URL: https://doi.org/10.1108/RPJ-04-2017-0056.

[61] Michael Arthur Allica M et al. “Impact of the Fused Deposition (FDM) Printing Process on Polylactic Acid (PLA) Chemistry and Structure”. In: *Applied Science* 7 (2017). ISSN: 2076-3417.

[62] Flash Forge 3D Printer. *Flashforge PLA Standard Filament 1.75mm 0.5KG Spool - Red*. 2021. URL: https://www.flashforgeshop.com/product/pla-filament-500g-red (visited on 11/14/2021).

[63] Flash Forge 3D Printer. *FlashForge 3D printer-Creator 3*. 2021. URL: https://www.flashforge.com/product-detail/flashforge-creator-3-fdm-3d-printer (visited on 11/14/2021).

Appendices

Appendix A

Engineering drawing of cylindrical jars with dimensions, which is a essential part in development and manufacturing. Figure 7.1, 7.2, 7.3 and 7.4.

Technical Drawings

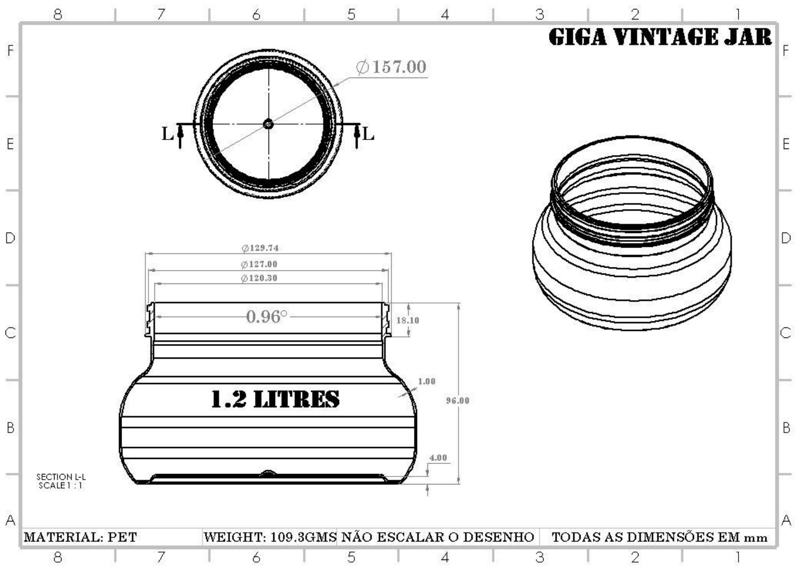

Figure 7.1: 1.2Litres Jar draft

The hexagonal giga jars are also been drafted with the all the description of drawings made available in the figure 7.5 and 7.6

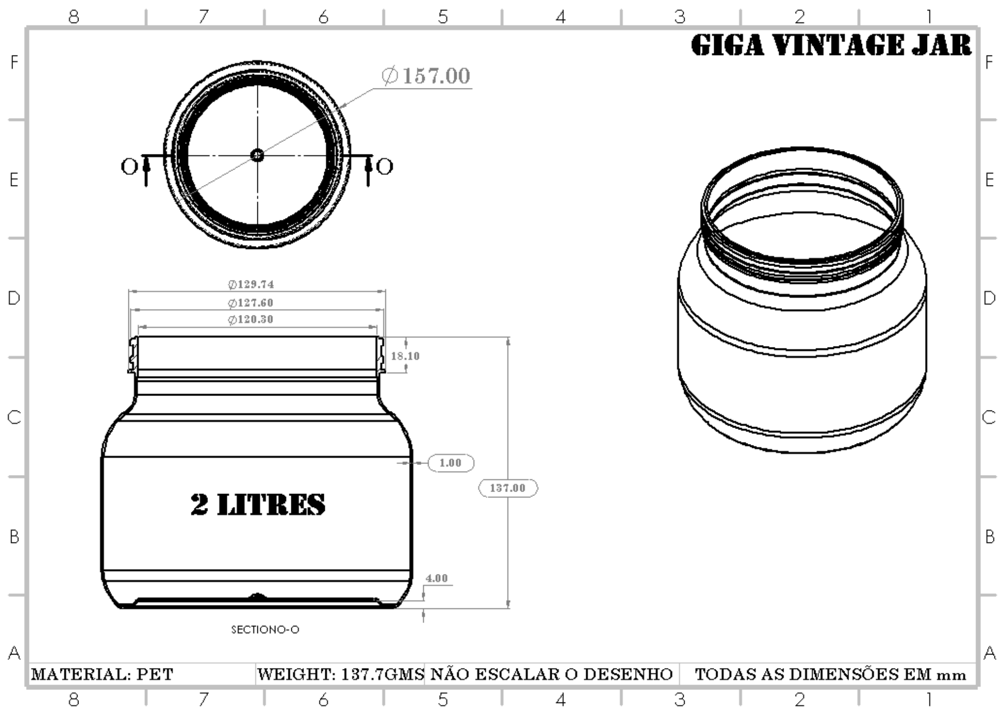

Figure 7.2: 2Litres Jar draft

Buckling analysis

Figure 7.7, 7.8, 7.9 represents the buckling test (boundary conditions are explained in Chapter-4), red color being the most possible region for failure and blue being the least affected zone. The critical and possible failures regions are concentrated in the neck region of the cylindrical jar, in-case of hexagonal jar possible failure zones are in the hexagonal faces.

Squeeze Load Test

Figure 7.10, 7.11, 7.12, represents the stress accumulation upon the squeeze load application, the cylindrical jar experience more stress due to lower stiffness and hexagonal containing edges and more of stiffer side experiences less stress.

Factor of safety test

Figure 7.13,7.14,7.15, represents the FOS property , the FOS > 1 represents the product is safe under loading condition without deformation.FOS also that the product is much safer

Figure 7.3: 3 Litres Jar draft

and can withdsatnd more load than applied. The FOS of every jar is greater than unity representing the jars are safe at defined loading condition.

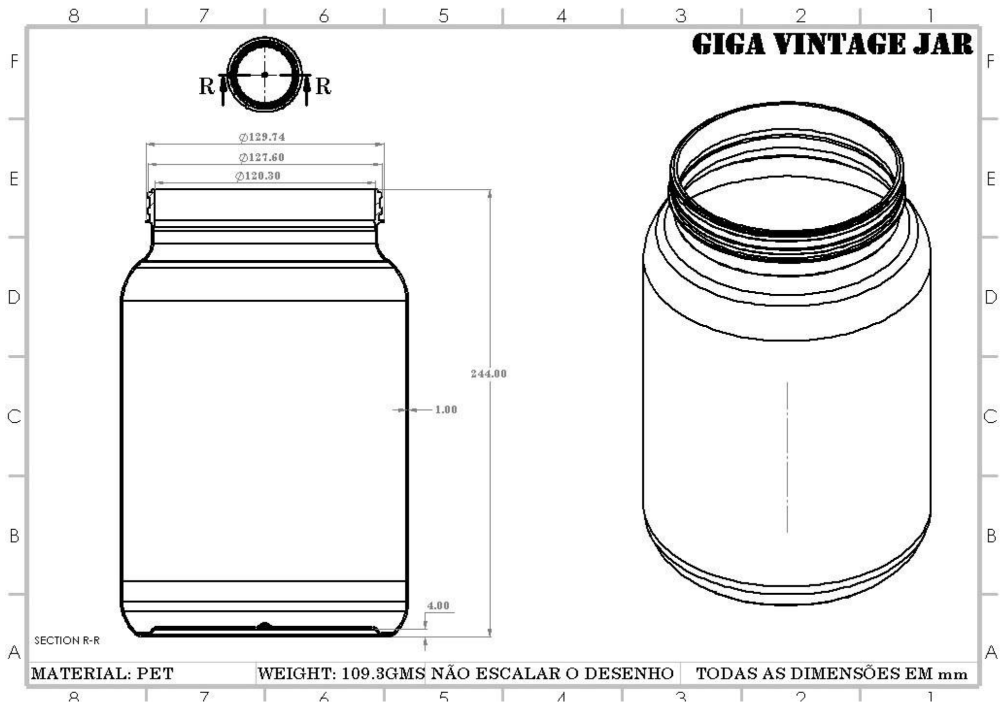

Figure 7.4: 4 Litres Jar draft

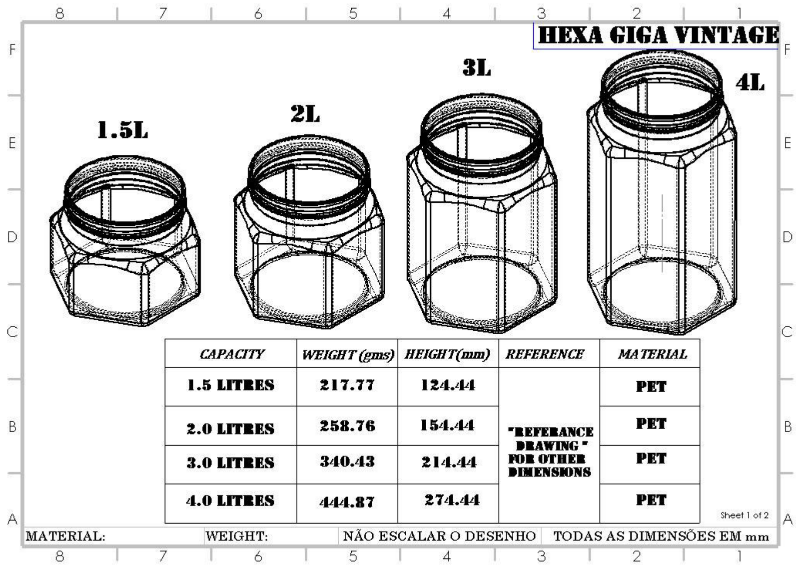

Figure 7.5: Hexa giga vintage jar draft -sheet 1 of 2

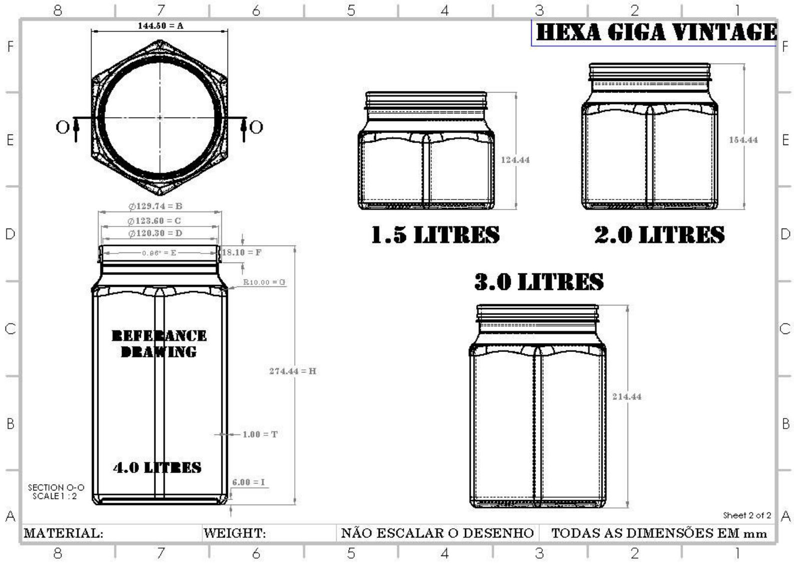

Figure 7.6: Hexa giga vintage jar draft - sheet 2 of 2

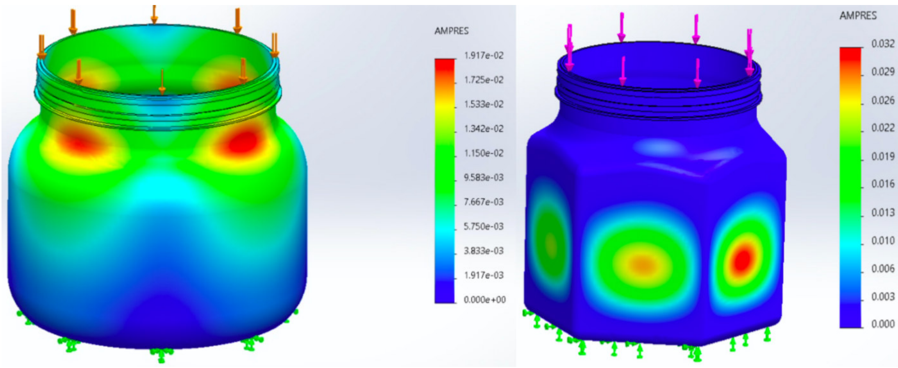

Figure 7.7: Buckling test - 2 Litre jar

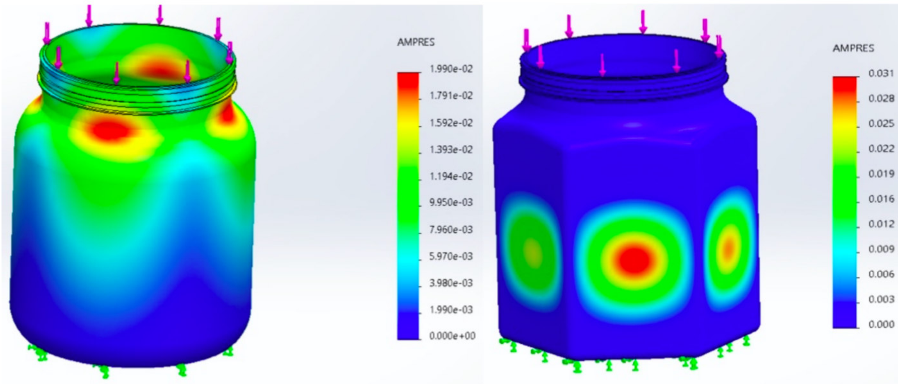

Figure 7.8: Buckling test - 3 Litre jar

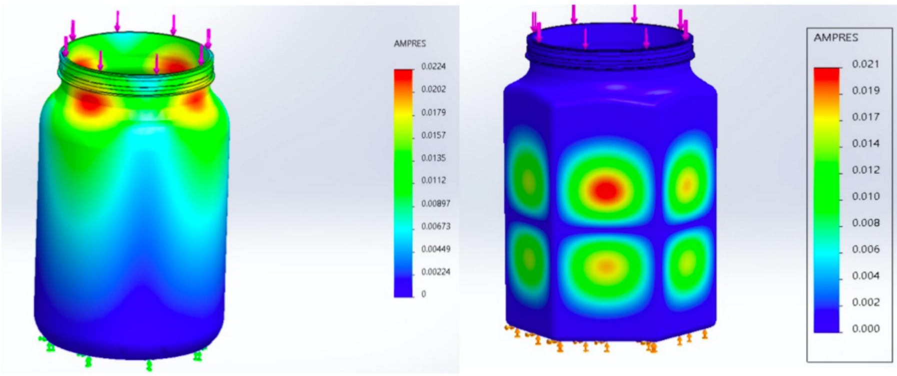

Figure 7.9: Buckling test - 4 Litre jar

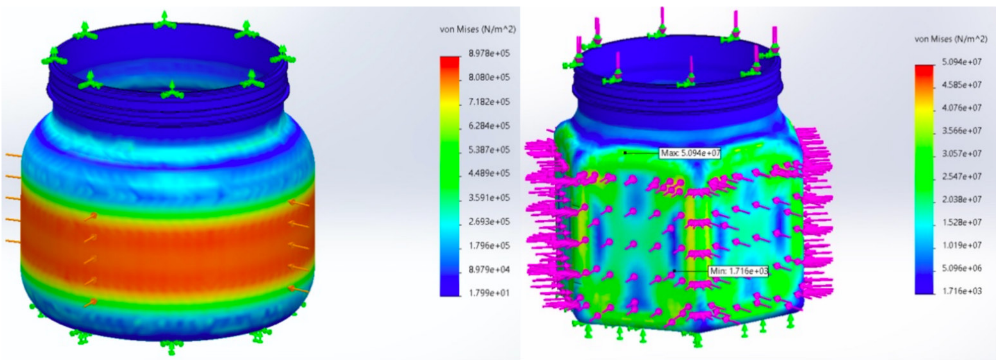

Figure 7.10: Stress test - 2 Litre jar

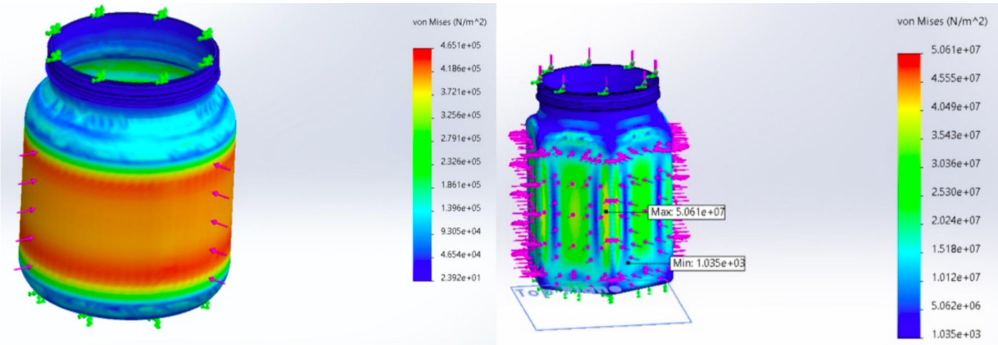

Figure 7.11: Stress test - 3 Litre jar

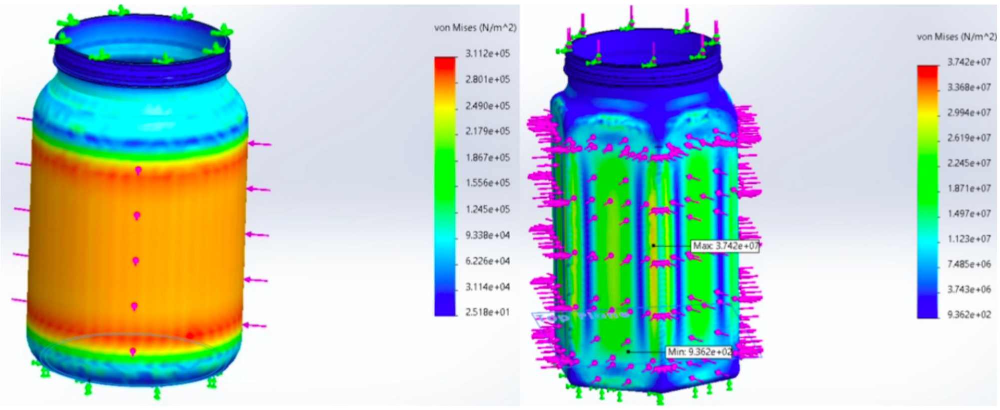

Figure 7.12: Stress test - 4 Litre jar

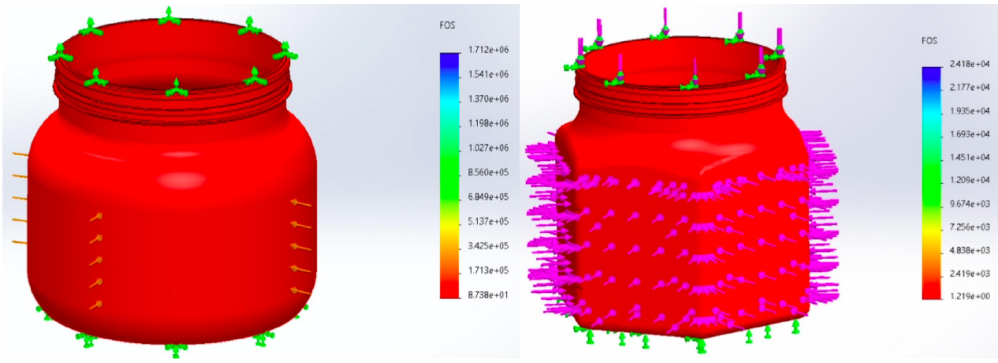

Figure 7.13: FOS-2Litre Jar

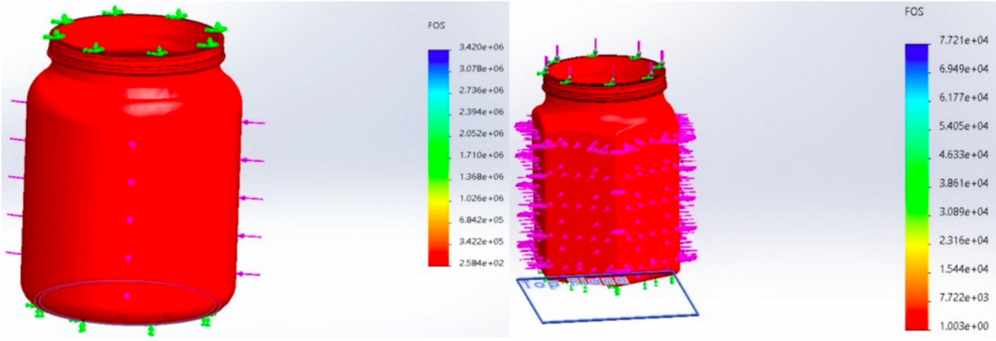

Figure 7.14: FOS-3 Litre Jar

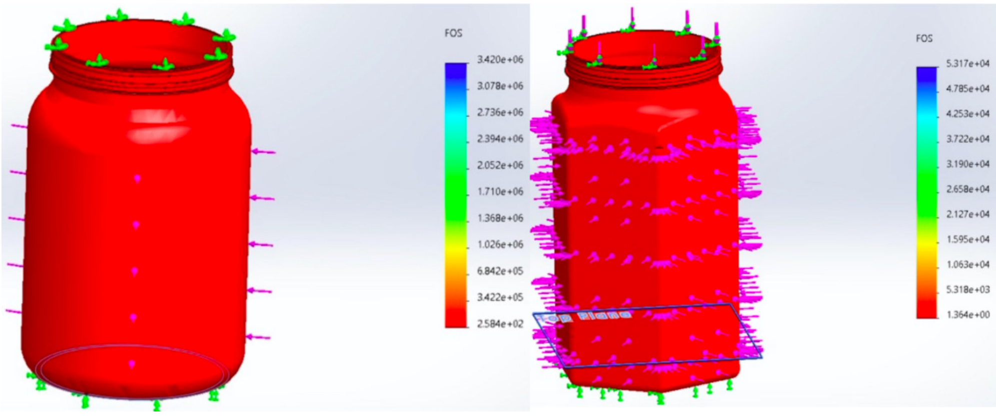

Figure 7.15: FOS-4 Litre Jar