Development of a Novel Moulding Technique

To

Produce a Unique Gummy Confectionery Product

By

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Abstract

ZURU Toys, one of the fastest growing toy companies in the world, identified an opportunity to capitalise on a unique opportunity within the growing confectionery industry by creating a product to merge a surprise toy egg with a unique gummy confectionery experience. The concept was to have a plastic surprise toy capsule shaped as an egg, which was to be encapsulated by gummy laid out in a spiral of eight distinctive colour strips. The gummy strips were to be peeled off the surface of the egg capsule and consumed to reveal the capsule housing the surprise toy.

ZURU partnered with Massey University's Engineering and Food Technology departments to explore the product opportunity further. The project was given to the Engineering Department, as there was no clear method for creating the product with existing manufacturing techniques. The client commissioned the project with virtually no constraints attached with the intention that the department would have complete freedom to explore all possible methods of manufacturing the product concept on a mass scale. The purpose of this thesis is to explore appropriate manufacturing techniques which can be used to mass manufacture the desired gummy confectionery product. To address the complexity of the client's desired confectionery product, a feasibility analysis of injection moulding techniques is investigated. To gather the necessary understandings for developing a solution to this concept, the two industries relevant to this study, Gummy Confectionery Production and Mass Manufacturing of Polymers, are explored in a literature review.

Early stage material testing was done to understand how the material behaves. This process included fabricating the first aluminium mould concept to explore the behaviours of gummy moulding in aluminium. This testing led to the development of the first mould concept. Following several mould iterations and subsequent testing, a clear understanding of how the egg could be produced at a mass scale was documented. The final mould concept was a two-part egg-shaped aluminium mould with seven spiral ribs sectioning off the eight cavities, with the toy capsule acting as a centre core. At the correct volumes, different coloured gummy could be injected into each cavity to encase the egg capsule with a spiral effect of eight distinctive strips of gummy. By following the ideal test conditions of injecting gummy at 60°C and cooling the mould for four minutes in water at 3°C it was possible to manufacture a gummy egg of the described characteristics at the scale described by the client.

The mould designs and requirements for manufacturing the product on a mass scale was subsequently delivered to the client which has since filed for patent protection on the method in select countries and implemented the solution on an automation line in a food safe factory in China in preparation for launch.

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Chapter 1

Introduction

Soft gelatine candy, more commonly referred to as gummy or jelly candy, is a category of confectionary candy made largely of gelatine, glucose and sucrose. This mixture of gelatine and sugar creates a jelly-like, chewable candy that comes in many shapes, sizes and flavours. The most popular and recognisable of these soft gelatine candies are gummy bears which were created by the German confectionary company, Haribo, in 1920. [1]

Nearly 100 years later, gummy candies are one of the fastest growing segments of the global confectionery industry, with sales growth of 4.5% in the first half of 2018 (chocolate confectionery grew 2.5%, by comparison). [2] This popularity is in part due to the seemingly infinite combinations of shapes, sizes, colours and flavours of gummy. However, the traditional methods of manufacturing large quantities of gummies did not allow for complicated or intricate shapes or features because to achieve high volumes of production, gummy candies are produced using starch or silicone two-dimensional moulds. In this way, only simple shapes can be produced, typically with one side having details imprinted into the gummy a smooth, flat surface on the other.

This project was initiated on behalf of and sponsored by the client ZURU Inc, a New Zealand-owned and operated global toy company, which produces over 600,000 toys per day and generates annual revenues in excess of $US500 million. The client employs over 5,000 staff across 18 offices globally, including a large team of automation engineers and technicians who design, develop and implement automated machinery for their owned and operated 218,000m^2 manufacturing facilities. Choosing to control this aspect of the business, compared to its competitors who outsource to third-party manufacturers, has been a major contributor to the client's successful business formula, giving them a competitive edge. It is headquartered in China, allowing ZURU to control end-to-end operations.

In early 2018, the approached Massey University with a novel confectionery product concept. The concept was a combination of gummy candy and surprise toys, similar to a Kinder Surprise or Yowie product, whereby a surprise toy is encased within an edible substance (see Figure 1).

The concept is novel in that it is the first gummy confectionery product requiring moulding around a non-edible core, meaning it could not use existing gummy manufacturing techniques. An alternative method for manufacturing the complex product had to be developed. This prohibited ZURU from developing the concept itself without extensive additions to staffing and costly expenses for researching alternative methods of manufacturing.

Figure 1: (left) Kinder Surprise [3] - (right) Yowie Surprise [4]

The product concept was described as having eight thin layers of gummy confectionery loosely adhering to a plastic capsule containing a surprise toy. Each layer would be a different colour and flavour with a requirement that the colours be distinctive with minimal contamination (colour bleed) from neighbouring colour layers during the manufacturing process.

The aim of this project is to develop a novel manufacturing technique giving the client the ability to produce gummy candy products to a high standard with detailed and intricate features, shapes and functionalities. The developed technique uses traditional moulding techniques to develop complex moulds for the innovative gummy confectionery product. The new technique will be implemented in the production of a novel gummy confectionery surprise egg product produced by the client.

In order to achieve a solution for the client within the given time constraint, it was necessary to include a team of fourth year engineering students tasked with providing research, design and prototyping assistance. Furthermore, it was necessary to employ a Food Technology Research

Assistant tasked with the research and development (R&D) of the gummy formulation. This Research Assistant used the R&D facilities of Massey Universities School of Food Technology. To further accelerate the R&D process, any extra components necessary for building prototypes were purchased from local suppliers. All prototypes were developed in house by the capable team using access to engineering workshops and high-precision machinery.

1.1 Objectives

1. Comprehend clearly the client's requirements and identify any fixed or flexible constraints.
2. Explore viable manufacturing techniques which can be used to create the desired product and meet the client's needs and expectations.
3. Understand the material characterisation and behaviour of gummy confectionery in the context of manufacturing, with a focus on injection moulding techniques.
4. Narrow the project scope by selecting the most suitable manufacturing technique as the solution to explore. Ensure the selection of a possible technique to both produce the desired product and achieve mass manufacturing scale.
5. Design moulds for testing and refinement under set conditions, and establish all necessary features needed by the manufacturing technique to produce the desired product.
6. Merge all successful features and requirements into one final mould to produce pre-production prototypes.
7. Deliver findings and recommendations to the client for further development and integration into wider automation lines.

1.2 Thesis Outline

This thesis consists of six chapters structured in chronological order of the project.

Chapter 1 - Introduction

This chapter provides a brief history of the gummy confectionery industry. Next is an overview of the new product concept which focuses on the problems faced in manufacturing the product due to current manufacturing techniques. The chapter concludes with an overview of the proposed research objectives.

Chapter 2 – Literature Review

This review presents and discusses current manufacturing methods for producing gummy confectionery. To produce exceptional gummy products, current technologies, manufacturing methods and best practices from the industry will be implemented wherever possible. This research is covered in the first section of the literature review. The following section of the literature review explores common polymer manufacturing techniques and processes. To develop an appropriate moulding technique suitable to produce the desired gummy confectionery product, existing technology must be understood. This will help determine which manufacturing technique is best suited for the innovative gummy confectionery product.

Chapter 3 - Gummy Confectionery Characteristics as a Materials Problem

This chapter discusses the characterisation of gummy to better understand why polymer manufacturing is feasible in producing the desired gummy product. It will be vital to understand the formulation of gummy confectionery. For this, a Food Technologist will be hired to assist in understanding the important role formulation will play in the development of the novel injection moulding technology.

Chapter 4 - New Product Development: Client Need to Engineering Solution

This chapter provides a detailed discussion of the development process from idea generation through to design for manufacturing. To create a feasible solution within all the constraints (both product design and manufacturability), the product idea must be developed and refined until the desired product can be achieved through the chosen moulding techniques.

Chapter 5 - Final Mould Design and Testing

Chapter 5 discusses the final mould design and testing stage of the project. This section begins by reviewing the client’s original product needs, combining them into a list along with crucial findings from previous tests. This list was used to design the final mould and testing to create successful prototypes that met the client's wants for the desired product. Presented throughout this chapter are the detailed justifications for all design changes and how the testing was conducted to ensure appropriate design and manufacturing. It concludes with a project hand-over by presenting recommendations and considerations to the client for future development and mould refinement.

Chapter 6 - Conclusion

The final chapter discusses the project's initial outcomes as outlined by the client and presents a summary of findings, tests and justifications for achieving the final mould design.

Chapter 2

Literature Review

2.1 Introduction

This review aims to provide the reader with adequate knowledge and understanding of two key industries relevant to the research. Part one covers the current practices in mass manufacturing of gummy confectionery. In particular, the review focuses on the types of moulding processes in the manufacturing of gummy confectionery to understand both the best practices and limitations of current moulding processes. Part two covers relevant literature about injection moulding to understand the uses, capabilities and best practices within that sector.

2.2 Methods Used in the Mass Manufacturing of Gummy Confectionery

Gummy confectionery was first developed in the early 1900s by Hans Riegel. Riegel was born on April 3, 1893 near the city of Bonn, Germany. He worked for several years at a local confectionary company before leaving to start his own firm. In 1920, Riegel founded Haribo, a confectionery company with a dream of creating a new confectionery product line made from gelatine. The first gummy candy to be produced was the "Dancing Bear" – a small, gold-coloured gummy candy made from fruit flavoured gummy in the shape of a tiny bear. [1]

Gummy confectionery has since become one of the largest segments in the confectionery industry, with more than 30 different gummy brands to date. With so many consumer choices, companies must distinguish their products to gain market share. A common method is to make gummy confectionery with interesting shapes, such as animals and airplanes, or by offering customers unique flavour blends and bright colour combinations. Differentiating a product while remaining competitive in a global market can only be achieved with the capabilities of modern manufacturing techniques. The following sections review how these techniques are used in the industry.

2.3 Gummy Confectionery Production

Before discussing the different gummy confectionery moulding techniques, it is important to understand the cooking processes prior to the moulding stage. This section supplies a high-level overview of this processes. Later sections discuss the relevant science behind the characteristics of the ingredients found in gummy confectionery and how they can be used with a polymer-based material, such as plastics.

The first step in making of gummy confectionery requires mixing the raw ingredients to make an unflavoured syrup. This is done in two separate parts. The first part takes the hydrocolloid ingredient – the gelling agent (such as Gelatine, Pectin or Agar [5]) – and dissolves it in water. The second part (coincident with the first) is to dissolve and cook the sugar. [6] Both processes are done in an industrial mixer machine with double layered walls (jacketed) into which steam is pumped to deliver the necessary heat energy for cooking (see Figures 2 and 3). [7]

Figure 2: Outside view of a jacketed mixer (Image captured in Shanghai, China)

Figure 3: Inside view of a jacketed mixer (Image captured in Shanghai, China)

Once the two parts are ready, they are pumped into a larger, jacketed mixer under a vacuum (see Figure 4). In this stage, two key things are happening. The first is the mixing of hot crystalline sugar mixture with the hydrocolloid mixture, causing the hydrocolloid to become viscous turning the candy jelly-like. The second is the vacuum feature in the mixer which enables the two parts to be mixed without any air introduced to the mixture. This is done to a) ensure volume control during the injection process and b) provide a quality product to the customer as fewer air bubbles are more desirable, making it a good quality criterion. [7]

Figure 4: Jacketed Vacuum Mixer (Image captured in Shanghai, China)

Following this stage, the unflavoured gummy syrup is pumped to the extruder at the depositing line. On the way to the extruder is a small, in-line mixer used to add the colour and flavour to the unflavoured gummy syrup (see Figure 5). Adding colour and flavour to large quantities of gummy syrup in a Jacketed Mixer makes it more difficult to produce multi-coloured candy, or quickly change from one flavour to another, as some mixers can hold upwards of 300 litres.

Figure 5: In-Line Colour and Flavour Mixer (Image captured in Shanghai, China)

Subsequent to the mixing of colour and flavour, the gummy is piped into a large, trapezoidal reservoir where the flavoured gummy syrup awaits depositing into moulds. Here, the mechanism is a simple pneumatic system whereby a shot of gummy is plunged through a cylindrical tube into a mould below.

Figure 6: Trapezoidal Gummy Depositor (Image captured in Shanghai, China)

This plunging process is universal in gummy confectionary production, regardless of the mould technique. The following sections will assess two moulding techniques – starch and non-starch moulding – to provide detailed insight into the moulding techniques, as this is the focus of the review.

2.3.1 Starch Moulding

Starch moulding of gummy confectionery is a technique in use for over 100 years in the industry. [9] After the gelatine has been produced, the hot mixture is pumped into a depositing machine called a mogul. The mogul is a continuous forming machine that fills trays with starch powder before a press imprints shapes or impressions of the desired gummy into the starch. [10]

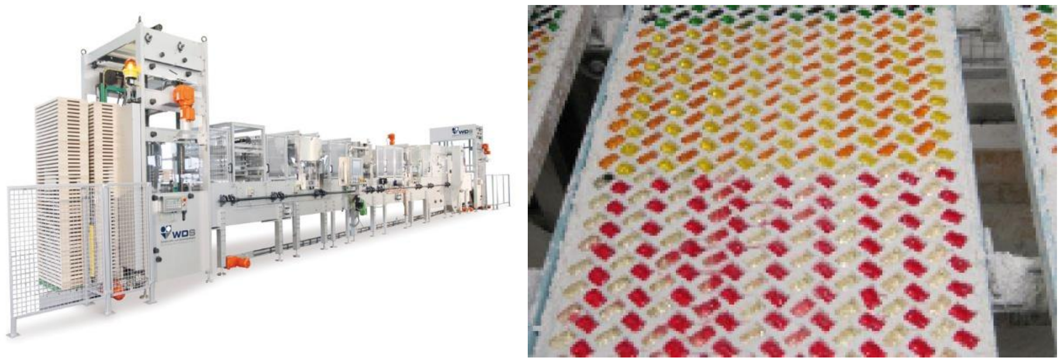

Figure 7: (Left) Starch Mogul Machine [11] - (Right) Starch Moulds [11]

Starch powder makes for a good moulding material in the production of confectionery products, as the starch can be automatically spread, flattened and imprinted with the desired gummy shape while retaining fine details. This is due to the imprinting process compressing the starch so it holds its form and doesn’t collapse on itself.

Following the imprinting process, a fine layer of vegetable or mineral oil is often sprayed over the mould surface to help retain the imprinting details and reduce the amount of dust released into the atmosphere which can be an explosive hazard. [6] Starch is commonly used because it is a low-cost powder made from readily available corn or wheat. Another benefit of starch mogul machines is that the product can be quickly changed by switching out the imprint pressboard on the machine. [6]

An array of injection nozzles matching the number of imprints then extrude the hot gummy mixture into each cavity using a simple pneumatic injector system to control the volumes. Once the cavities are filled, the trays are transported to a drying room so the gummy can set. This setting process takes between 12-24 hours, depending on the gummy recipe and the temperature and relative humidity of the drying room. [13]

Figure 8: Starch Moulding of Gummy Confectionery [14]

Once set, the trays of gummy are transported to the beginning of the mogul machine, where they are upturned to remove the set gummy onto a large, vibrating sieve. The trays are then passed through to the next stage to be filled again with starch, imprinted with the desired gummy impressions and the process is repeated.

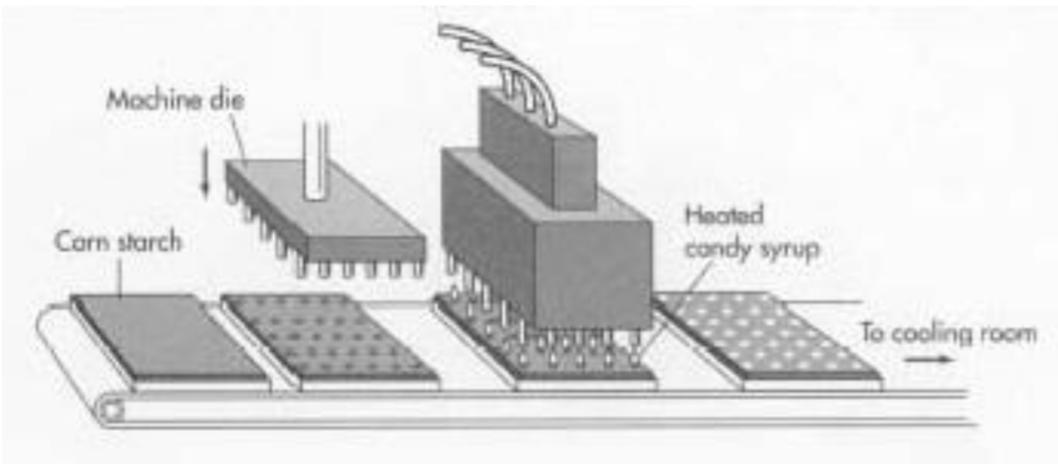

Figure 9: Simple Diagram of a Starch Mogul Machine Process [15]

2.3.2 Non-Starch Moulding

In recent years, confectionery manufacturers have turned to modern silicone moulding techniques to produce gummy confectionery. Because starch was often deemed a health and safety risk due to the fine powders' tendency to catch fire and combust, this technique removes the use of starch in the process altogether. In 2014, Ian Purvis, senior account manager of British food processing equipment manufacturer, Baker Perkins, also strongly urged confectionery manufacturers to move away from starch moulding. He cited the inability to clean the starch and uphold a sanitary factory environment as starch used in the manufacturing process is never replaced, only topped up. [16]

Non-starch moulds have been used in recent years because the starchless process is significantly more efficient in terms of capital cost, floor space, energy consumption, labour and consumables. [17] Non-starch depositing lines share many similarities with starch depositing lines. While the initial cooking, mixing, piping and extruding of gummy mixture is the same, the difference is in the moulding stage of the gummy. Here, instead of multiple trays of starch moulds, a conveyor of silicone or aluminium moulds are used. These are made from a semi-firm silicone or aluminium material which is durable for thousands of cycles before needing to be replaced. These moulds go through the following cycle.

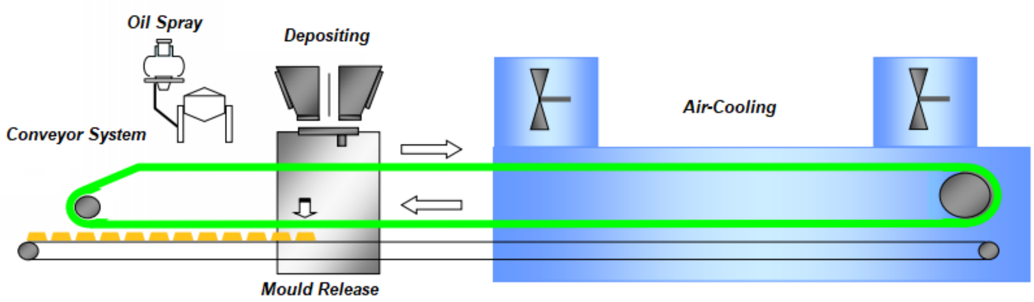

Figure 10: Silicone Mould Conveyor Process [18]

In the first stage of a starchless moulding process, moulds are lightly coated with a vegetable oil using a spray system to ensure the gummy candy releases easily during removal. The second stage is the depositing stage, where the gummy mix is extruded into the moulds. The third stage is the air-cooling tunnel which is the key difference in starchless moulding. Instead of the starch trays being taken away, stacked and set for 12-24 hours in a dry room, starchless moulds filled with hot gummy pass through an air-cooling tunnel for rapid setting. This allows the gummy confectionery to become hard enough for removal in under ten minutes, making the starchless depositing lines more time efficient compared to starch depositing lines.

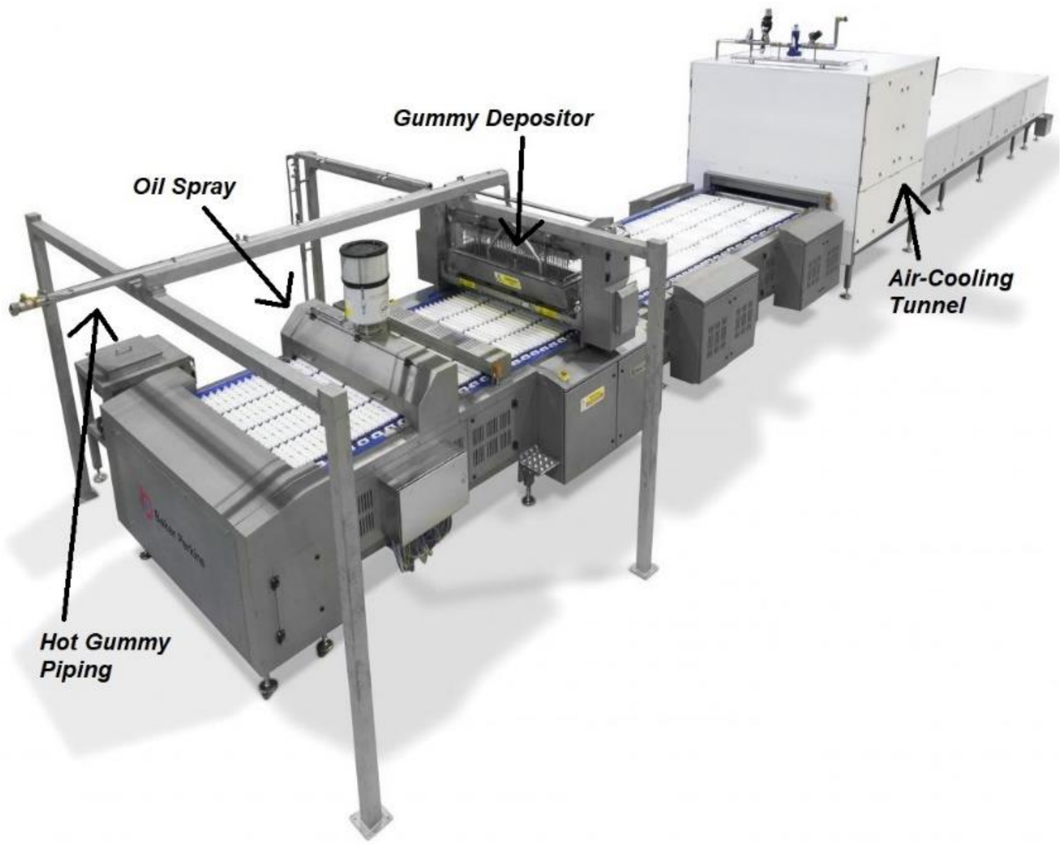

Figure 11: Starchless Depositing Line from Baker Perkins [19]

2.4 History of Mass Manufacturing of Polymers

The process of manufacturing using polymers (plastic) dates to 1868, when John W. Hyatt patented a polymer method for producing billiard balls as an alternative to ivory, called celluloid. Hyatt produced the balls by injecting hot, liquid celluloid with a plunger through a heated tube into a mould. This marked the first plastic product and the first injection moulded product. [20] Over the years, this method was refined to involve a screw in place of the plunger. This was more because the screw produces a huge amount of injection pressure and generated its own heat. [21] It wasn’t until after World War II, when the demand for inexpensive products substantially grew, that mass manufacturing of polymer-based products quickly controlled the consumer goods market. [22] Since then, the growth of polymer mass manufacturing with many more techniques have been developed. These techniques include, but are not limited to: Blow Moulding; Compression Thermoforming; Vacuum Thermoforming; Rotational Moulding; Direct

Extrusion; Injection Moulding. [23] The following sections give a brief overview on the less relevant techniques and focus on how the more relevant techniques are used in the industry.

2.5 Methods for Mass Manufacturing Polymers

In the context of this research work, the main requisites for the selection of process are: 1) the ability to mass manufacture a product at low cost, 2) the ability to mould gummy around a plastic core, 3) the mouldability of defined colour gradients around complex contours and 4) the capability to scale production.

There are various well-known techniques for mass manufacturing of polymers. Each of these are reviewed with specific commercial and technical limitations against the product criteria. The limitations are described in terms of materials, process, design, production quantity, scalability and cost.

2.5.1 Blow Moulding

Blow Moulding is the process of using a mould with the desired cavity and air to form a polymer part. This process is typically used in the production of plastic bottles, toys or hollow dolls. [24] The process begins with a hot tube of resin (the parison) inserted into an openable mould which is clamped. Air is then injected inside the parison causing the tube to expand and take the form of the mould cavity. The part is then cooled and released from the mould and the process repeats. [25] Blow moulding is commonly recommended for high melt flow index (MFI) materials (such as, Polyethylene Terephthalate or PET) [26] that can sustain its surface integrity (strength) in thin form. A benefit of Blow Moulding is its efficiency, low cost and usefulness for manufacturing hollow parts. [27]

In the context of this work, blow moulding is infeasible because 1) thin wall profiles are not required, 2) the gummy material cannot retain high blow pressure, 3) the melt flow index of gummy is not technically inclined to a blow mould, 4) blow moulding doesn't allow for centre cores and 5) blow moulding doesn't allow for defined colour separation.

Figure 12: Blow Moulding Diagram [28]

2.5.2 Compression Thermoforming

Compression Thermoforming is the process by which polymer feed stock is fed into a die which heats along with the compression to form a part. Compression Thermoforming is a closed moulding process suitable for producing high strength and high complexity parts. [29] However, this process lacks the necessary capabilities for the current project because it 1) can't get the desired three-dimensional shape, 2) is unable to mould intricate details due to limitations in "mouldable design ability", 3) doesn't allow for defined colour separation at the accuracy required and 4) the compression force would damage the inner egg capsule.

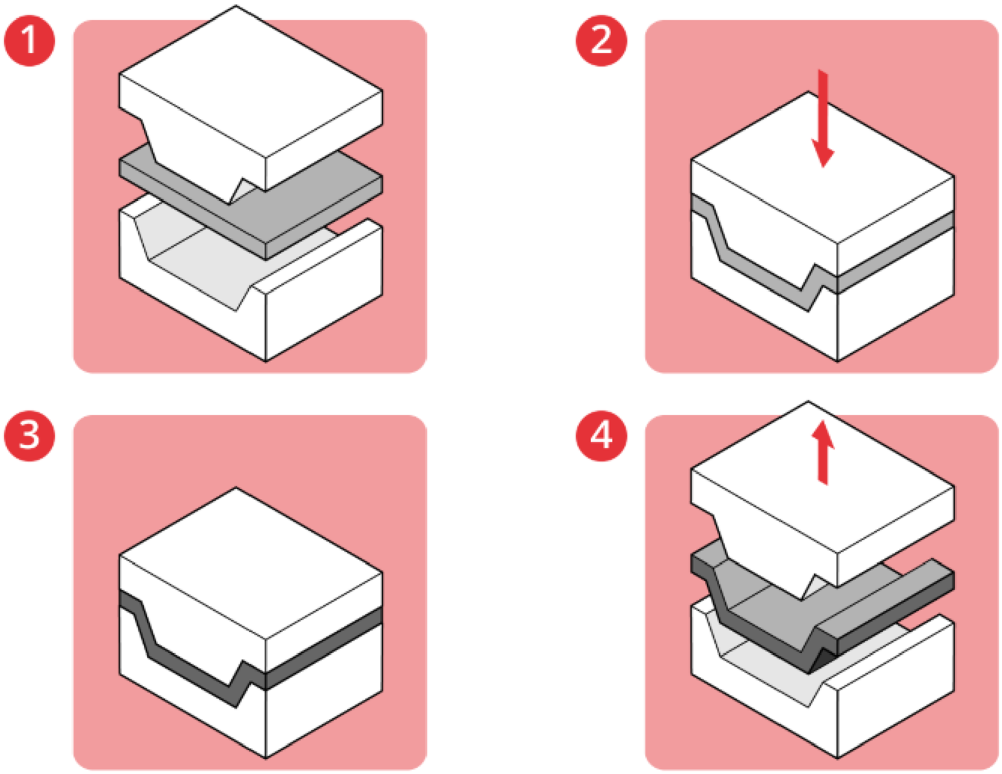

Figure 13: Compression Thermoforming Diagram [30]

2.5.3 Vacuum Thermoforming

Vacuum Thermoforming is the process of transforming a flat, thermoplastic sheet into a three-dimensional part. [31] The process is split into two main steps: heating and forming. [32, 33] The heating is typically achieved with radiant electric heaters above the plastic sheet. The heat and time cycle necessary to sufficiently soften the polymer sheet depends on the type of polymer used and the sheet's thickness. [32] The forming is achieved by applying a vacuum through small holes at the bottom of the mould, usually 0.8mm in diameter, ensuring that the surface defect is minimal. [32]

This solution is not viable for multiple reasons: 1) gummy sheets cannot be subjected to suction forces, 2) capabilities of vacuum thermoforming are limited to two-dimensional objects and can't mould completely around a capsule and 3) gummy won't uniformly shape around an object under vacuum.

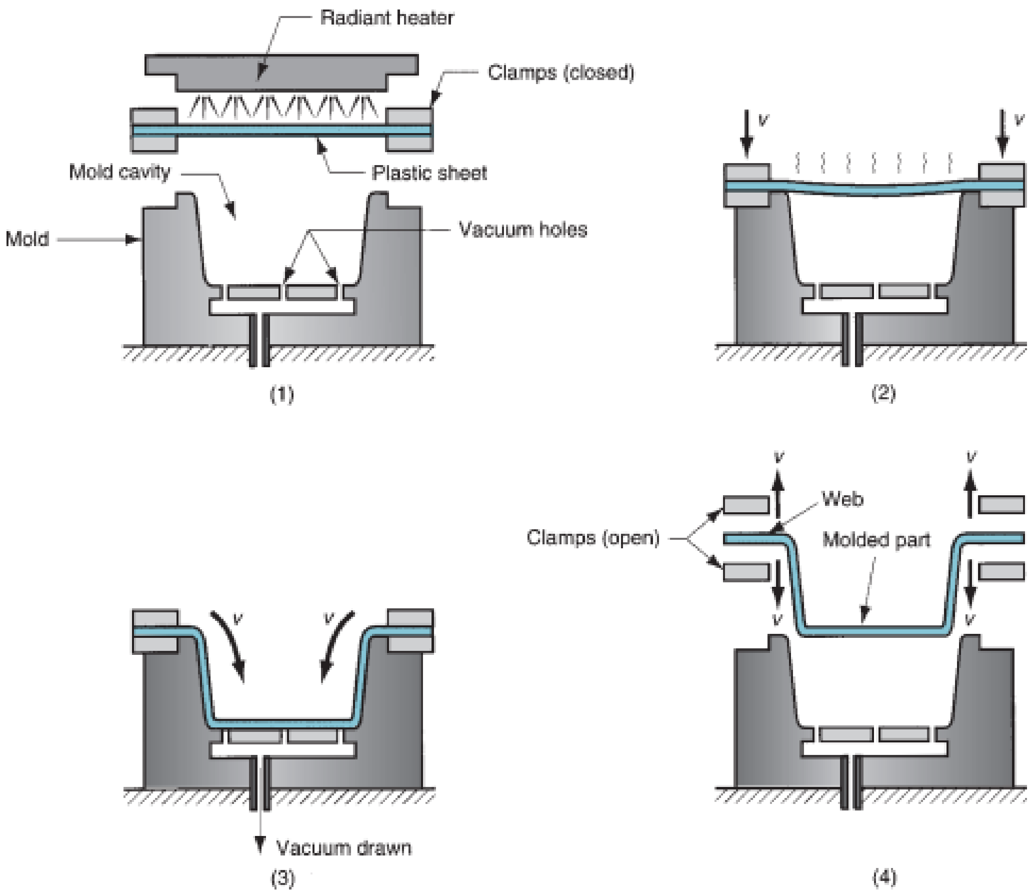

Figure 14: Vacuum Thermoforming Diagram [32]

2.5.4 Rotational Moulding

Rotational moulding is the process by which a volume of plastic powder equal to the desired part weight is poured into a temperature-controllable metal drum (shaped as the desired object). The drum is then heated and subsequently rotated at a relatively slow speed until the plastic melts and evenly distributes over the inner walls of the drum, forming the plastic part. [34, 35]

This solution is not feasible for the following reasons: 1) gummy cannot adhere to a surface like other polymers do, 2) rotational moulding doesn't allow for centre cores and 3) thin wall gummy cannot structurally support itself.

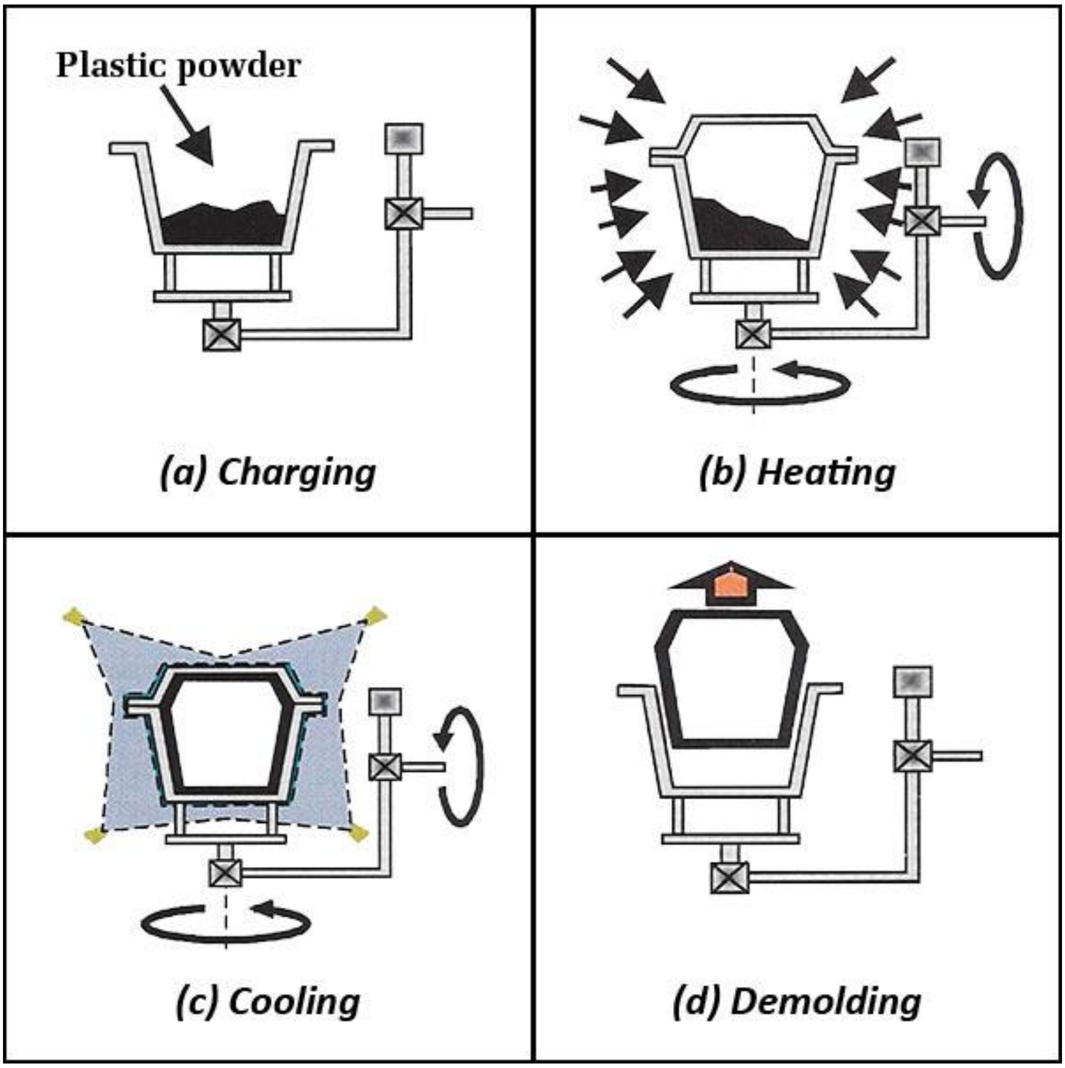

Figure 15: Rotational Moulding Diagram [35]

2.5.5 Direct Extrusion

Direct Extrusion is the process of extruding polymer lengths through an opening. This is done under high pressures using a hydraulic ram which heats the polymer to a malleable state, making it possible to forcefully extrude the polymer. [36]

This method is not feasible for manufacturing the product because it 1) cannot achieve defined colour separation, 2) doesn't provide a visually appealing surface finish and 3) the gummy doesn't set fast enough.

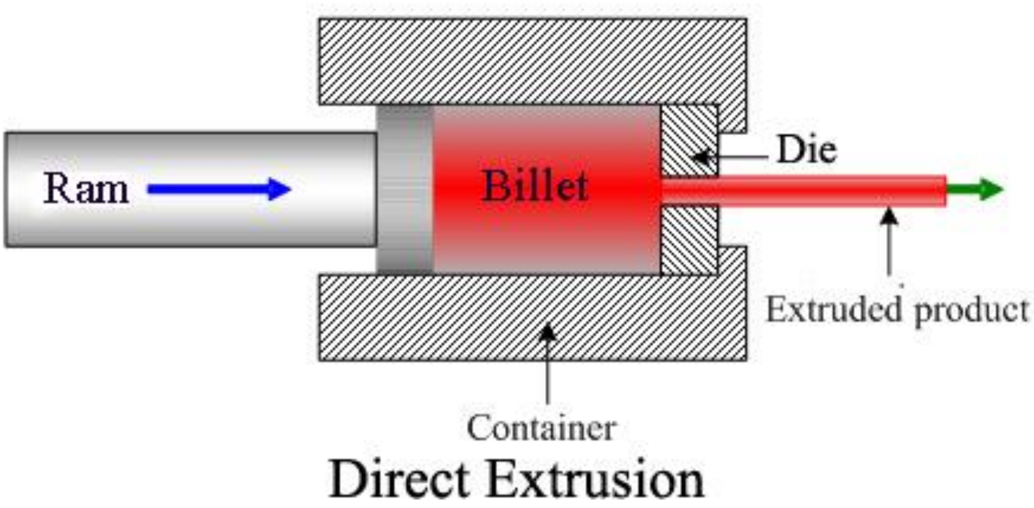

Figure 16: Direct Extrusion Diagram [37]

However, a variation of Direct Extrusion which utilised a Fused Deposition Modelling (FDM) approach was deemed possible. FDM is an additive manufacturing method most commonly found in 3D Printing. It is a technique by which a heated polymer is extruded onto a surface (typically a flat, heated platform) and builds up a model layer by layer.

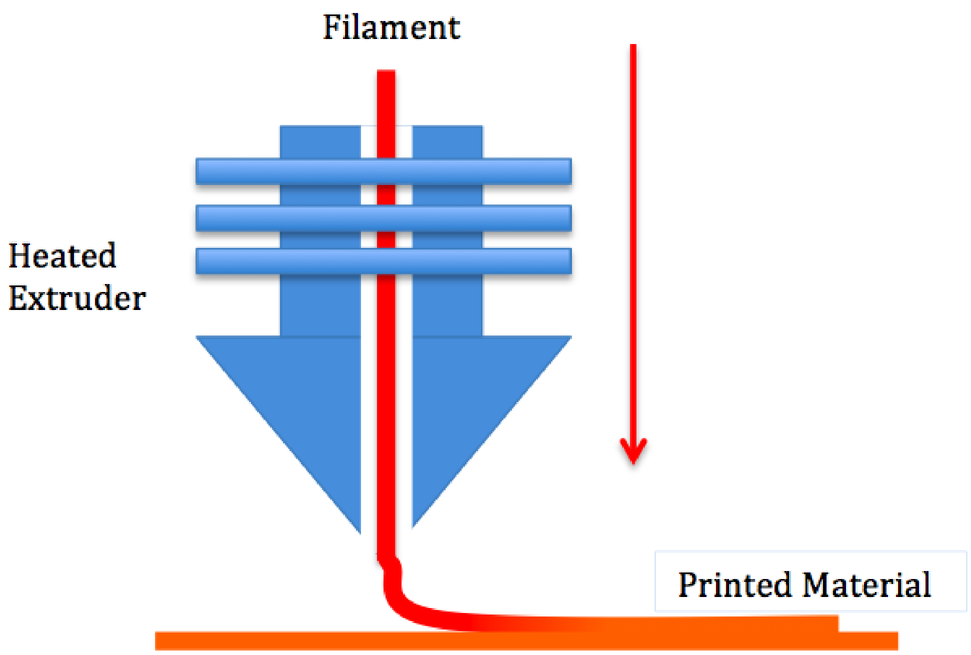

Figure 17: Fused Deposition Modelling Diagram [38]

2.5.6 Injection Moulding

Injection moulding is widely used in the mass manufacturing of plastic parts, with more than one third of polymetric parts being produced with the technique globally. [39, 40, 41] It is a process by which a polymer is melted and injected into a mould cavity or cavities to create a plastic part. [42] The mould can consist of a singular cavity or can contain multiple similar or dissimilar cavities, depending on the features needed for a specific part. The melted polymer is fed from the extrude to the cavities through a runner. [42] The process can be separated into four separate stages (see Figure 18): Plasticisation; Injection; Packing/Cooling; and Demoulding/Ejection. Amongst the four stages, the cooling stage takes between 50% to 80% of the total cycle time. [39, 43, 44]

Figure 18: Injection Moulding Diagram [45]

Injection Moulding has many advantages, such as enhanced strength, high efficiency, ability to achieve detailed features and complex geometry. [46] Although the machinery has a high upfront cost, injection moulding is highly cost-effective at large scale, [47] making it an ideal processing method for polymer manufacturing.

Therefore, based on these attributes, injection moulding was selected as the process to perform gummy moulding in the first experimental phase. During this phase, it is important to optimise process parameters such as cooling time, cooling temperature, injection speed, injection temperature of the polymer, packing pressure and others which are important to the quality, speed of production and feature capabilities of the product. [47]

2.6 Chapter Summary

The literature review covers two main sections of interest to this research. The first is focused on gummy manufacturing. This section assesses the process of producing the gummy mixture up to the point of moulding, followed by the current moulding methods for producing gummy confectionery to understanding current knowledge and best practices.

The second section focuses on polymer manufacturing techniques covering six of the most widely used polymer manufacturing techniques to select a technique. In this section, it was found that injection moulding is the most viable technique due to its ability to form complex structures, mould around a centre core and scalability. This technique will be used in the research, development and testing of the gummy product presented in this research.

Chapter 3

Gummy Confectionery Characteristics as a Materials Problem

3.1 Introduction

This chapter discusses the relevant[1] ingredients of gummy confectionery and their primary benefits in the creation of the desired product. This chapter supplies an overview of why gummy behaves like an amorphous thermoplastic and thus can be injected around a core. Included are early stage tests conducted to understand gummy behaviour when in contact with different materials, gummy drying times and observed viscosity at different pouring temperatures. Additional tests were explored to understand how gummy behaved when moulded in aluminium or deposited in an additive manufacturing approach. The desired outcome of these tests was to isolate the most viable technique for further exploration.

3.2 Key Ingredient Overview

Gummy confectionery is made predominantly from four ingredients: gelatine, sucrose, glucose syrup and water. Gelatine (hydrolysed collagen) is a gelling agent and a man-made protein derived from the skin, bones and connective tissues of animals such as pigs, cattle or chicken. Sucrose is generally referred to as table sugar and gives the gummy its sweetness. It is one of three naturally occurring sugars found in fruits, vegetables and grains. Glucose syrup, another one of the three naturally occurring sugars, is an invert syrup used to prevent the sugar contents of the gummy crystallising during its setting phase which would counteract the gelling agent (gelatine), making the texture grainy and non-jelly-like. This outcome is ideal for confectionery such as fudge, but not for gummy which must have a jelly texture. Furthermore, glucose is a humectant substance, meaning it bonds with water, to keep the gummy fresh and prevent it

[1] In relation to the proposed solution, gelatine, sucrose, glucose and water are considered the only relevant ingredients in gummy formula. However, there are other components, such as corn starch, citric acid, flavours and colours.

from dehydrating. Water plays two vital roles: it provides moisture necessary for glucose syrup bonding and for dissolving and mixing the ingredients during the preparation stages.

3.3 Understanding Gummy's Amorphous Nature

3.3.1 Crystalline VS Amorphous Materials: A Brief Overview

In materials science, a solid is typically characterised as either crystalline or amorphous materials. The Chemistry Library describes a crystalline material as a solid held together in regular ordered arrays of components through uniform intermolecular forces. [48] These "ordered arrays" give the material a defined form or structure, or crystal lattice. Common examples of crystalline solids include diamonds or ice, where the solid material has a well-defined shape. In contrast to crystalline solids, amorphous solids have a non-defined shape, comprising of malleable irregular arrays. A common example of an amorphous solid is rubber. Additionally, crystalline solids have sharp, definite melting points, whereas amorphous solids are said to be liquids at all temperatures.

3.3.2 Initial Gummy Experimentation

As discussed in section 3.2, gummy confectionery comprises four key ingredients. Before exploring possible moulding solutions, it was important to understand how gummy behaved in its solid state, liquid state and during the transition from one state to another. To do this, a range of branded gummy samples were purchased from different supermarkets. These were melted down separately to form a viscose liquid which was poured into ice cube moulds to solidify. These samples were placed in different environments to understand what happens to the product after solidification in either a fridge, freezer, lower cupboard or pantry. Each location offered different environmental factors of interest to understand on gummy solidification. For example, the fridge has a lower temperature (but above zero degrees Celsius) than a typical room (19°), which is a factor to consider in accelerating the solidification process. A more extreme example is the freezer, which has a temperature below zero degrees Celsius, causing the water content in the liquid gummy to solidify much faster than at room temperature (see Figures 19 and Figure 20 for test samples). These tests showed several key early-stage understandings:

1) Gummies are thermoreversible, meaning they can be melted when exposed to heat and then re-solidified,
2) Ambient temperature and humidity effect the texture of the gummy,
3) Exposing gummy to temperatures below zero degrees Celsius to rapidly set the gummy causes it to display undesirable features, such as firm texture and lack of smell.
4) A low fridge temperature gave noticeable benefits to the solidification of the gummy, such as decreased setting time without disrupting the gummy's texture significantly.

Figure 19: (left) Fridge Sample - (right) Freezer Sample

Figure 20: (left) Lower Cupboard Sample - (right) Pantry Sample

3.3.3 Preliminary Mould Testing

Following this experimentation of the gummy to understand its material behaviours, a simple aluminium mould was created (see Figure 21) to test the gummies ability to mould around an object and, given the material's amorphous nature, how well it supports its own weight after demoulding. This was important to understand because at this stage, injection moulding wasn't the final solutions. A possible solution involving two hollow halves of gummy, moulded separately and brought together around a capsule, could be viable.

Figure 21: Simple Aluminium Test Mould

The simple mould was designed to have a cavity between the basin and the dome of 2mm thickness – the desired thickness of the gummy layers as specified by the client. Each test involved roughly one tablespoon of hot gummy poured into the mould basin, with the domed lid inserted and pressed into the hot gummy, forcing the material to fill the cavity between the two sections of the mould. It was then left to set for 20 minutes in a fridge allowing the gummy to solidify at an accelerated pace compared to room temperatures.

Each test involved introducing and isolating (where possible) different factors which could benefit the manufacturing process. Some of these factors included: setting the gummy in different environments, using a lubricant, pouring it at different temperatures, air-assisted release of the gummy (post solidification) and testing both plastic and aluminium domes to compare material behaviour on different surfaces post solidification. (see Figures 22 and 23)

Figure 22: (left) Plastic dome in solidified gummy - (right) Unoiled aluminium dome being separated

Figure 23: 2mm thick hollow gummy dome after being released from oiled mould

Knowledge gathered from the preliminary mould testing was invaluable in narrowing down the scope of possible solutions. Key findings, such as the extent to which oil influenced the release of the solidified gummy from the mould, showed the importance of isolating these factors. Listed in Table 1 are all the key findings from the tests.

Table 1: Key Findings from Preliminary Mould Test

Factor	Tested Conditions	Effect
Oil Coated Mould	1. Mould uncoated with vegetable oil 2. Mould coated with vegetable oil	Oil had a significant effect on the release of the solidified gummy from the mould. This was expected given the ingredient formulation of the gummy and the findings of the tests conducted in section 3.3.2.
Dome Material Selection	1. Aluminium dome insert 2. Plastic (ABS) dome insert	Once solidified, the gummy adhered to each surface like glue, making a release agent necessary.
Gummy Temperature	1. Heating to 50°C 2. Heating to 60°C 3. Heating to 70°C	Because gummy is amorphous, the material became less viscous as heat increased, making it easier to transfer and displace. However, this also increased the solidification time, which is not ideal in mass production.
Environment Temperature	1. Ambient of 18°C 2. Fridge of 4°C	At ambient temperatures of 18°C, gummy would solidify over a period of 30 minutes. Whereas at fridge temperatures of 4°C, gummy would solidify over a period of 10 minutes.
Air-Assisted Release	1. Using airgun 2. Not using airgun	An airgun was used to help remove solidified gummy from the mould. Tests showed positive results. However, some samples inflated like a balloon instead of releasing, due to the gummy's amorphous nature.
Gummy Rigidity	Can the gummy dome support its own weight?	The picture taken in Figure 23 shows the gummy a few seconds after being placed on a plate. Within minutes, the dome had collapsed, showing that gummy could not support its own weight.

3.3.4 Additive Manufacturing Testing

Given the complexity of the eight defined colour layers concept, an additive manufacturing approach was considered for use in the mass manufacture of the product. This was to be determined largely after developing a proof of concept.

The testing consisted of a 3D printed egg with two holes in either end for the insertion of rods to allow the egg to be rotatable. Hot, coloured gummy was then injected onto the top surface of the egg as it was slowly rotated three times, alternating colour each time. As displayed in Figure 24, it became apparent that colour separation would not be achievable due to the gummy not setting quickly enough and bleeding into neighbouring colours.

Figure 24: Additive Manufacturing Test 1

An alternative approach was considered whereby plastic rib protrusions were added to the 3D printed egg (see Figure 25). The ribs ensure each colour would be extruded onto the surface with no colour bleed. A similar setup to the initial test was constructed, however the rods were incorporated into the 3D printed model and attached to a hand drill to ensure consistent radial velocity during extrusion. This test presented more success with colour separation, yet it struggled with the thickness of the gummy in its liquid state due to interference by the ribs, causing the gummy to drip both during and after rotating the egg. Furthermore, the ribs were not ideal as the final egg capsule needed to be smooth. Alternative concepts were considered in which the ribs were a peripheral mechanism included in the manufacturing line to encase the egg like a cage. However, this was not feasible because it effected the visual appearance of the final gummy product, ripped the gummy from the surface when removing the cage and was unable to achieve high volumes with peripheral mechanism.

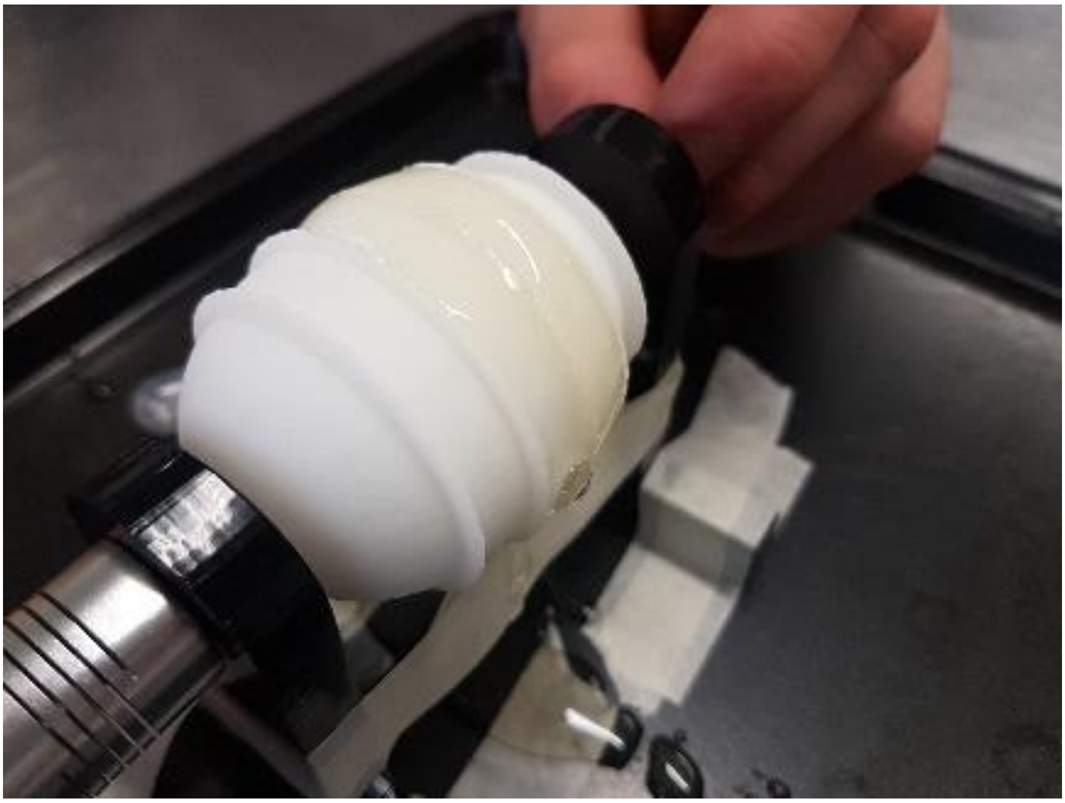

Figure 25: Capsule with Ribs Test

3.4 Chapter Summary

This chapter explored the characteristics of gummy as a materials problem to understand how gummy behaves when allowed to transition through its melting point and then to solidify under different conditions.

Three tests were developed. The first looked at melting purchased gummy product and solidifying it under different conditions (such as the fridge or pantry) to observe the effects of different environments on solidifying the gummy. It was found that cooler temperatures accelerated the solidification process, however it didn't accelerate the setting process which occurs over a different period due to the gelatine content. This was identified as a key area to address during the development of the gummy recipe, as accelerated cooling and setting times was important for mass manufacturing.

The second test looked at exploring how gummy behaves when set in an aluminium mould. It used a two-part mould with a cavity for liquid gummy and a dome to displace the gummy. After multiple tests, it was found that moulding gummy was relatively easy when following certain criteria. Most importantly, the tests found that the mould must be coated in an oil or similar release agent to assist in removal and that environment conditions for setting (such as temperature) matter significantly in reducing the time needed to remove gummy from a mould.

The third test explored an additive manufacturing option. Two tests were conducted whereby hot gummy was extruded onto the surface of a 3D printed egg to identify whether any colour bleed occurred during the depositing of the liquid gummy. The first test deposited three colours of gummy in a sequential manner onto the surface of a rotating capsule showing that the gummy had definite colour bleed between the layers, proving its unviability. A second test trialled the addition of ribs onto the surface of the egg capsule and again depositing the gummy while the capsule was rotated. Although the colour bleed issue was solved by the ribs, other issues arose such as the aesthetic nature of the final product from interaction with the ribs.

After conducting these tests, it was determined that a moulding solution was the most viable option for producing the product. The following section develops these findings further by exploring an injection moulding solution.

Chapter 4

New Product Development: Client Need to Engineering Solution

4.1 Introduction

This chapter provides a detailed discussion of the process of developing the product from ideation through to design for manufacturing.

To develop a feasible solution meeting all the necessary constraints (both product design and manufacturability), the product idea must be developed and refined until the desired product design and manufacturing technique is achieved. This was chosen to be injection moulding.

4.2 Clients Needs and Constraints Defined

Before a mould could be produced, it was important to understand both the client's fixed and flexible constraints for the product's image and how the customer would interact with it. The client was consulted directly which produced a list of constraints along with a sketch presenting the desired visuals of the product. The constraints are presented in Table 2, followed by a recreation of the original sketch (see Figure 26).

Table 2: Product Constraints as Defined by the Client

Constraint	Fixed or Flexible	Description
Eight different colours	Flexible	The product was to have eight different gummy colours/flavours.
Defined colour layers with no bleed	Fixed	Each colour layer was to not bleed into the neighbouring layers, contaminating the colours.
Colours laid out in a continuous spiral	Flexible	The product was to be peeled off the surface, starting from the top colour in one continuous gummy.

Gummy loosely adhering to a plastic capsule	Fixed	The gummy must loosely adhere to the surface of the plastic toy capsule, allowing for the product to be peeled off, exposing the toy capsule.
The gummy was to have no air bubbles in it	Fixed	Through injecting and subsequent setting of the gummy, no air bubbles should remain within the gummy. It had to be as pure as possible.

Figure 26: Recreation of original concept sketch from client

4.3 Mould Version 1: Development and Testing

Following consultation with the client, first steps were made to design and create an initial test mould. The first mould was designed similarly to the small aluminium mould used to originally explore the material characteristics of the gummy (Chapter 3).

A two-part CAD model was designed to be machined out of an aluminium block which incorporated dowels used to locate the two halves, three holes on either side for injecting the gummy and an overflow channel at the top for excess gummy to exit during injection. Aluminium was chosen as the material offers advantages in machining and conducts heat well which assists in quickly cooling the gummy.

Once the test mould was machined, it was coated in Polytetrafluoroethylene (PTFE), more commonly referred to as Teflon. A thin layer of PTFE applied to a material such as aluminium produces a non-stick coating during cooling for materials such as liquid gummy. PTFE is also resistant to wear, can sustain high temperatures and is FDA-approved food safe, [49] making it ideal for this application. See Figure 27 for PTFE-coated aluminium mould.

Figure 27: PTFE-coated aluminium test mould

During this time, the food technologist had developed the first gummy formulation, ready for testing. The recipe was drawn from traditional methods for preparing a gummy confectionery product. Once the mould and formulation were ready, the first test began.

Test 1.1 – Summary of Findings

Table 3: Parameters for Test 1.1

Mould Type	Aluminium mould coated in PTFE
Plastic Egg Capsule	3D printed ABS egg with guide rod
Gummy Recipe	Standard formulation
Release Agent Used	No
Gummy Temperature from Water bath	56°C
Mould Temperature	18°C
Gummy Colours Used	No colour applied
Cooling Mechanism	Convection - Fridge at 3.0°C

Cooling Time	32 Minutes

This test was to show if set gummy sticks to a PTFE-coated mould after injecting liquid gummy into the mould with a solid plastic egg core (representing the toy capsule) and letting it cool.

The test was conducted in a food safe kitchen at the Food Technology department of Massey University where the gummy formulation was prepared ahead of time. To mimic the egg toy encasing which acts as the centre core, a simple 3D print was made with a 'handle' jutting from the top to stabilise the egg during processing.

When the two halves of the gummy mould were brought together and aligned with dowels, a section of tape secured the two halves. Gummy was then injected into the top injection hole at a temperature of 56°C using a syringe (see Figure 28). The mould was at room temperature of roughly 18°C. When the mould had been filled, it was placed in the fridge at a temp of 3°C at precisely 11:32am. 32 minutes later at 12:04pm, the mould was removed from the fridge.

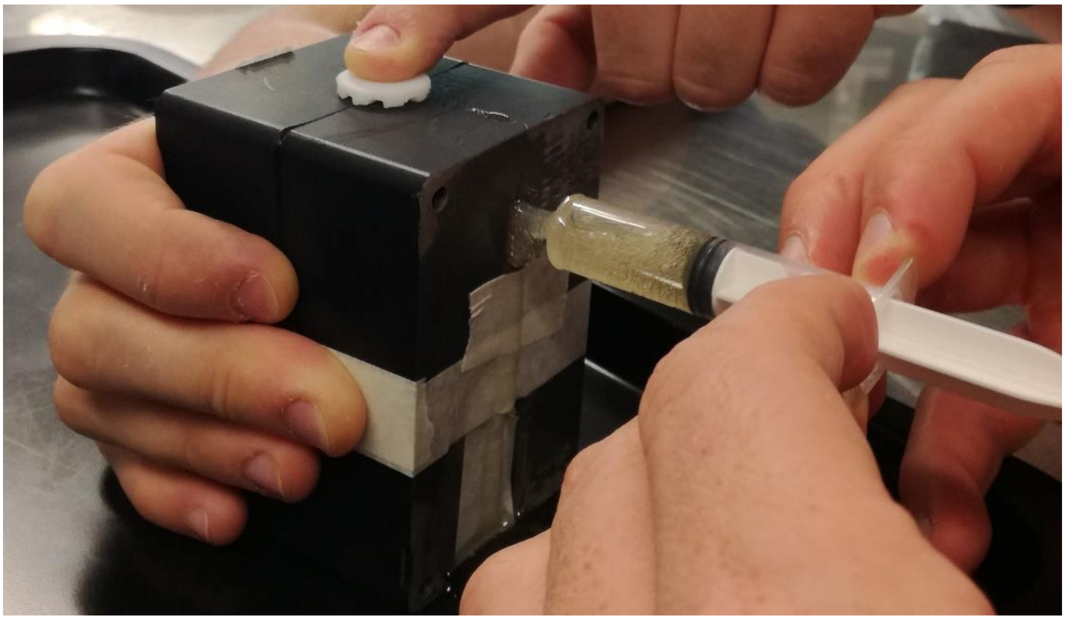

Figure 28: Gummy injecting into mould

Separating the two halves required some force but the egg did not stick to the PTFE coated mould. In fact, the halves were difficult to remove because they had created a vacuum between the gummy and the mould as the gummy shrunk during cooling. Secondly, it became apparent the max volume was not reached and the gummy failed to evenly distribute around the egg capsule (see Figure 29). This was due to the off-centre position of the 3D printed egg capsule along with an inadequate amount of injected gummy.

Finally, the gummy had a substantial amount of bubbles inside the mixture due to the liquid gummy not being given adequate time to settle when the syringe extracted the liquid from the reservoir. Another possible cause was that the syringe housed a small volume of air which was injected into the mould simultaneously with the gummy mixture. This can be solved by giving the gummy mixture time to settle to bring the air bubbles, whether originating from the reservoir or syringe, to the surface for removal.

Figure 29: Gummy egg results from Test 1.1

Test 1.2 – Summary of Findings

Table 4: Parameters for Test 1.2

Mould Type	Aluminium mould coated in PTFE
Plastic Egg Capsule	3D printed ABS egg with guide rod
Gummy Recipe	Standard formulation
Release Agent Used	No
Gummy Temperature from Water bath	60°C

Mould Temperature	18°C
Gummy Colours Used	Green
Cooling Mechanism	Convection - Fridge at 2.0°C
Cooling Time	30 Minutes

The aim of this next test was to experiment with colours and rectify some issues observed in Test 1.1. Again, the test was conducted in a food safe kitchen at the Food Technology department of Massey University, where the gummy formulation was prepared ahead of time. Similar to Test 1.1, a new 3D printed plastic egg was made with a handle jutting from the top. This handle was made significantly thicker than the first model after it broke when attempting to remove the egg from the mould. Furthermore, eight domed protrusions standing 2mm from the surface were also added (see Figure 30) to ensure the egg remained centred in the mould and the gummy could evenly distribute around the surface of the plastic egg capsule.

After the two halves were taped together around the new egg capsule, gummy was injected into the mould at a temperature of 60°C using a syringe. When the mould appeared to be full, the mould was placed in the fridge at a temp of 2.0°C for 30 minutes, removed and the two halves separated. Similar to Test 1.1, the gummy didn't appear stuck to the PTFE coated mould, but a vacuum was generated between the gummy and the mould surface during cooling. This made it difficult to separate the mould halves and for the gummy egg to be removed. A solution was proposed to use a release agent to assist in removing the gummy egg. This will be explored during the next test.

Further observations showed the max volume of the mould was not achieved for a second time (see Figure 30), showing that the volume estimation method of injecting from one side of the mould until gummy seeped from the overflow channel was not ideal as it assumed the gummy had filled the circumference before coming out of the top. A solution was to inject the gummy from both sides, ensuring both halves of the moulds filled equally before reaching the overflow.

Lastly, air bubbles also remained within the mixture, even after taking precautions. The test did result in a small reduction of bubbles but it was determined to be an issue inherent with the preparation of the gummy formulation. As discussed in Chapter 2, jacketed vacuum mixers are used in industry to mix large volumes of gummy formulation under a vacuum to ensure no air is introduced. Our food technologist's method was simply to mix small quantities in a large glass beaker which introduces air. The food technologist explored methods for reducing air bubbles by either raising the temperature of the gummy to make the formula less viscous, allowing the air bubbles to rise to the surface or to recreate a jacketed vacuum mixer.

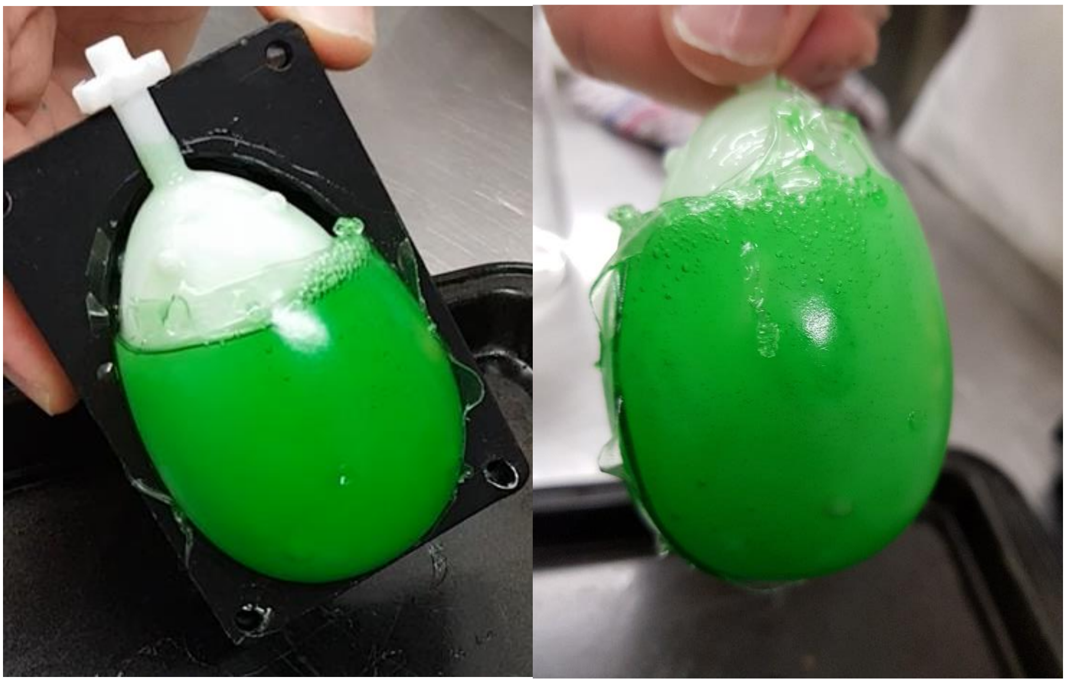

Figure 30: Gummy egg results from Test 1.2

Test 1.3 – Summary of Findings

Table 5: Parameters for Test 1.3

Mould Type	Aluminium mould coated in PTFE
Plastic Egg Capsule	3D printed ABS egg with guide rod
Gummy Recipe	Standard formulation
Release Agent Used	Yes (Coconut Oil)
Gummy Temperature from Water bath	60°C
Mould Temperature	18°C
Gummy Colours Used	Purple
Cooling Mechanism	Convection - Fridge at 2.0°C & Room Temp at 18°C
Cooling Time	20 Minutes & 30 Minutes

The aim of Test 1.3 was to experiment primarily with cooling times and environments, and to introduce coconut oil as a release agent to assist in removing a cooled egg. Again, the test was conducted in a food safe kitchen at the Food Technology department of Massey University, where the gummy formulation was prepared ahead of time. The same 3D printed plastic egg used in Test 1.2 was repurposed for this test.

Before the two halves of the mould were taped together around the plastic egg capsule, a layer of coconut oil was spread over both but not on the plastic egg capsule. Once completed, gummy was injected from both sides of the mould at a temperature of 60°C using a syringe, until it overflowed from the top to ensure the entire cavity was filled. The mould was then placed in an 18°C room for 30 minutes. This was an ideal situation to test, as if it proved successful the manufacturing process would not require a cooling step, reducing the costs of production.

After the cooling time elapsed, the mould was opened but the gummy had not cooled enough for the egg to be released (see Figure 31), showing that a much lower temperature is required to cool the gummy quickly. To confirm this, an identical test was done and the mould placed in a fridge at 2.0°C for 20 minutes (10 minutes less than previous). The mould was then opened to reveal a gummy cool enough to be removed. However, the coconut oil had no effect as a release agent. This was later determined to be due to the melting point of the coconut oil. This is discussed later in the chapter.

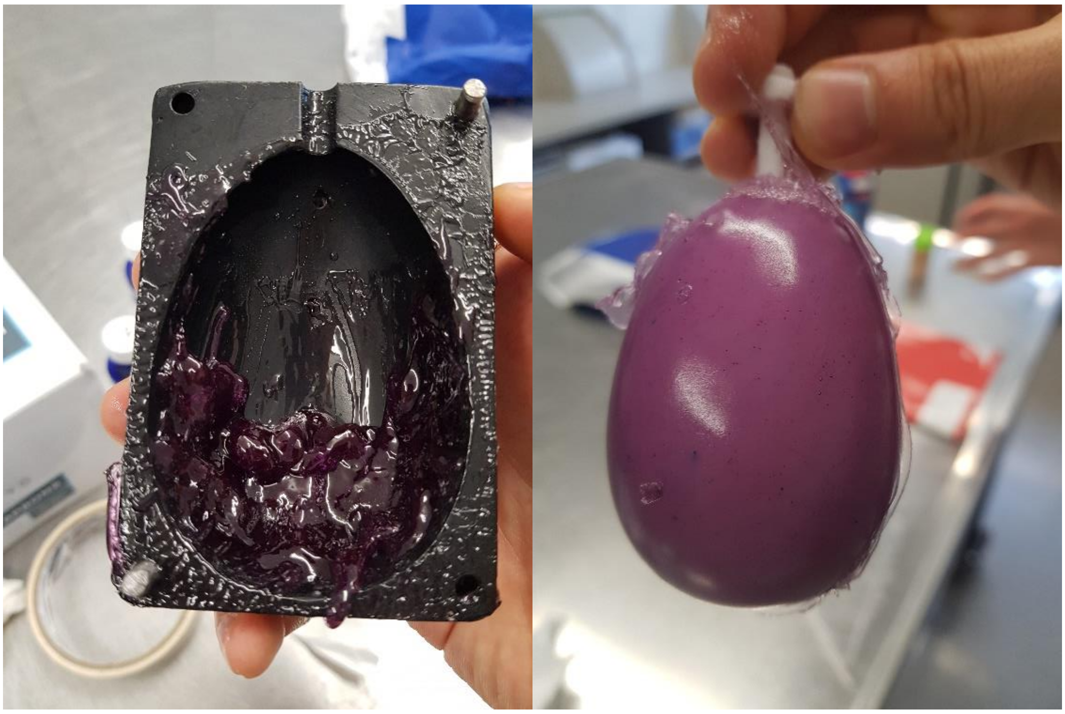

Figure 31: (left) Gummy cooled at room temperature of 18.0°C – (right) Gummy cooled in fridge at 2.0°C

Test 1.4 – Summary of Findings

Table 6: Parameters for Test 1.4

Mould Type	Aluminium mould coated in PTFE
Plastic Egg Capsule	3D printed ABS egg with guide rod
Gummy Recipe	Standard formulation
Release Agent Used	Yes (Coconut Oil)
Gummy Temperature from Water bath	60°C
Mould Temperature	18°C
Gummy Colours Used	Purple, Green and Blue
Cooling Mechanism	Convection - Fridge at 4.5°C
Cooling Time	20 Minutes

The aim of Test 1.4 was to determine the feasibility of injecting multiple colours of gummy at once with no colour bleed. Again, the test was conducted in a food safe kitchen at the Food Technology department of Massey University, where the gummy formulation was prepared ahead of time. The same 3D printed plastic egg which was used in Test 1.2 and Test 1.3 was repurposed.

Once the mould was prepared and taped together in the same way as Test 1.3, three different colours of gummy were injected sequentially from both sides at a temperature of 60°C, starting with purple in the bottom injection hole, green in the middle and blue in the top. When the mould was full, it was placed in the fridge at a temp of 4.5°C (2.5°C higher than previous tests) for 20 minutes.

The mould was then opened to reveal the first multi-coloured gummy egg (see Figure 32). After considering the fixed nature of the client's needs for the final product to have distinctive colour layers with no colour bleed, it was determined a new mould must be designed with this feature as the primary goal. Each subsequent issue, such as air bubbles in the formulation, release agent or setting environment/time, were deemed to be secondary priorities.

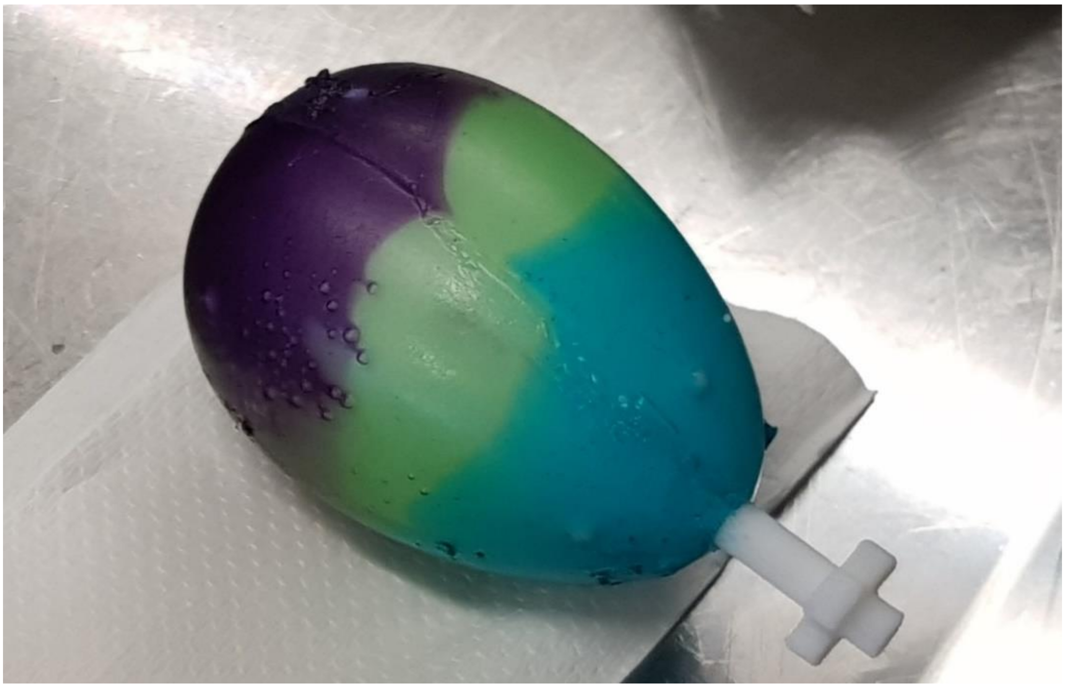

Figure 32: Gummy egg test with multiple colours

4.4 Mould Version 2: Development and Testing

Following the tests with mould version 1.0, a complete redesign of the mould and the egg capsule begun. With the client's requirement of clearly defined colour layers, a brainstorming session ensued in which multiple ideas were generated, including removable cores to allow for the sectioning of each layer during injection. This idea was deemed too complicated, as it required many different parts for a mould to produce one egg. However, it catalysed the idea that sectioned colours could be incorporated into the mould itself as one piece by way of machining ribs into the aluminium mould. These ribs would allow each chamber to be filled individually while avoiding bleed into neighbouring layers. They also ensured the egg capsule was centred in the mould so gummy can be injected evenly around the capsule (see Figure 33).

The mould incorporated two new features to simplify testing. The first feature was handles fixed to the backside of the two moulds ensuring easy separation of the two halves. The second was taped injection runners to fix pneumatic straight threaded-to-tube adapters in (see Figure 34). These adapters were the perfect size for the syringe tips to sit during injection. Once all design changes were made, the mould was machined and coated in PTFE for testing.

Figure 33: Mould Version 2.0 - Horizontal Ribs

Test 2.1 – Summary of Findings

Table 7: Parameters for Test 2.1

Mould Type	Aluminium mould with ribs coated in PTFE
Plastic Egg Capsule	3D printed ABS egg
Gummy Recipe	Modifications made in an attempt to cool gummy quicker
Release Agent Used	Yes (Coconut Oil)

Gummy Temperature from Water bath	60°C
Mould Temperature	18°C
Gummy Colours Used	Green, Yellow, Pink, Blue, Orange, Red
Cooling Mechanism	Convection - Fridge at 4.5°C
Cooling Time	20 Minutes

The aim of Test 2.1 was to determine whether the newly designed mould with ribs would avoid colour bleed. Again, the test was conducted in a food safe kitchen at the Food Technology department of Massey University, where the gummy formulation with a range of different colours were prepared ahead of time. A new 3D printed plastic egg was designed to fit the redesigned mould which included removing the redundant handle feature.

In preparation for testing, the mould was coated with coconut oil using a small brush to ensure all surface areas has even coverage. The egg capsule was then placed into the mould with clamps holding both halves together. Clamps were superior to tape for ensuring no gummy leaked from between the two halves of the mould during testing.

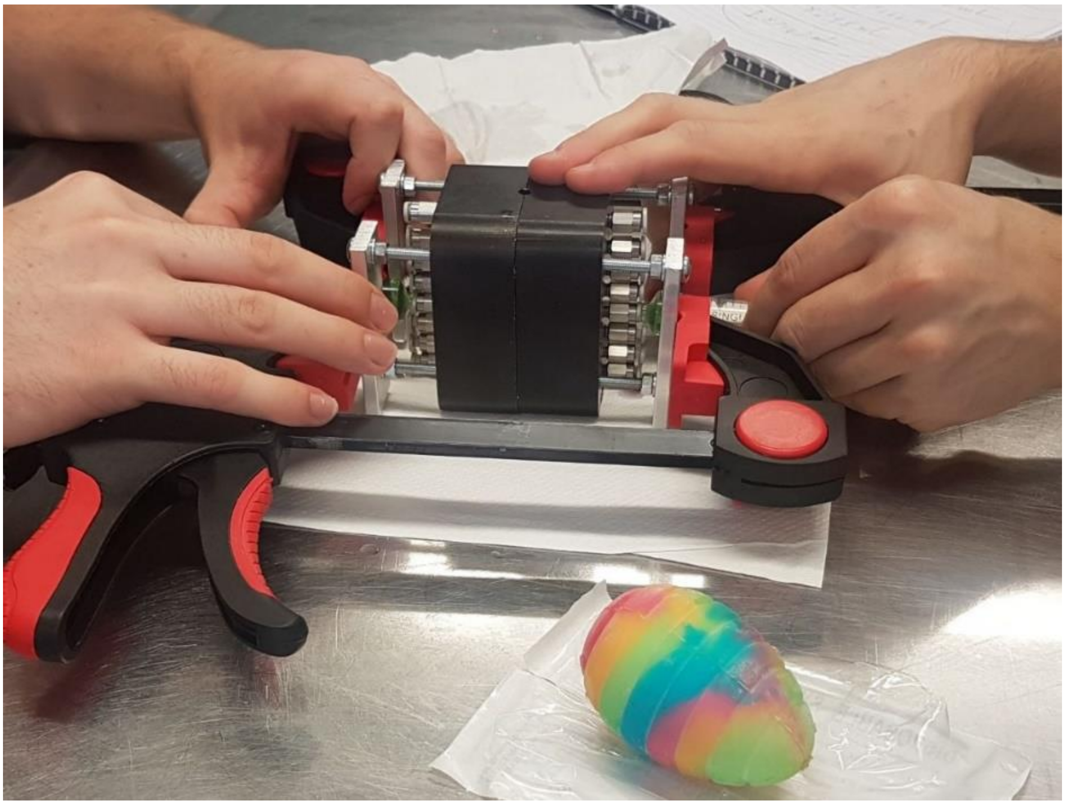

Figure 34: Mould version 2.0 with clamps.

Each colour was injected from both sides simultaneously, starting from the bottom and working to the top. The volumes for each section were determined by injecting until significant pressure was felt in the syringes. At this point, the next section would be injected until the entire mould was full. The mould was opened after cooling for 20 minutes at 4.5°C. As seen in Figure 35, although each section filled up, there was significant colour bleed between each layer. Additional attempts determined that during injection the gummy was escaping between the ribs and egg capsule to the neighbouring section because the ribs failed to totally separate each section. It is important that correct volumes of gummy are injected into each section.

Figure 35: Test egg - Lots of Colour Bleeding

Further findings from the test showed that the coconut oil had no effect as a release agent due to the melting point of coconut oil being 24°C. This means although the oil is a liquid when applied to the mould, the cooling process took the coconut oil past its solidification temperature, setting the coconut oil (see Figure 36) and failed as a release agent. Further experiments replaced coconut oil with a vegetable oil.

Figure 36: (left) Coconut oil that solidified on surface of the mould – (right) a failed trial test with no oil applied

Test 2.2 – Summary of Findings

Table 8: Parameters for Test 2.2

Mould Type	Aluminium mould with ribs coated in PTFE
Plastic Egg Capsule	3D printed ABS egg
Gummy Recipe	Modifications made in an attempt to cool gummy quicker
Release Agent Used	Yes (Vegetable Oil)
Gummy Temperature from Water bath	60°C
Mould Temperature	18°C
Gummy Colours Used	Purple, Blue, Dark Green, Light Green, Yellow, Orange, Pink, Red
Cooling Mechanism	Convection - Fridge at 4.5°C
Cooling Time	20 Minutes

Test 2.2 aimed to determine if the theoretical volumes of each cavity of gummy matched the actual volumes when injected. The volume for each section was predetermined theoretically using CAD software. Again, the test was conducted in a food safe kitchen at the Food Technology

department of Massey University, where the gummy formulation with a range of different colours were prepared ahead of time. The same egg capsule in Test 2.1 was repurposed for this test.

The same preparation process as Test 2.1 was followed, the only difference being that vegetable oil was the release agent instead of coconut oil. Each volume was precisely measured in a syringe and injected into the respective sections from bottom to top. Once the mould cooled under the same conditions as Test 2.1, it was separated and the egg removed. It was observed immediately that the separation of colour layers had improved. The front section showed the best results and no colour bleed. However, some sections around the join of the two mould halves (or the furthest point from injection) still had colour bleed, suggesting the volumes were not correct (see Figure 37).

The biggest problem with estimating the volumes was due to the accumulative colour bleeding of the initial purple colour overflowing to the blue. This meant that even if blue's volume was correct, it would overflow onto the green section and the pattern would continue to the top. An iterative test approach was necessary to achieve the specific volumes of colour. Before this process began, a new mould was developed for a more efficient method for cooling the gummy.

Figure 37: (left) front facing test egg – (right) Same egg side facing 24 hours after starch coating

4.5 Mould Version 3: Development and Testing

Following the successful testing of mould Version 2.0, a redesign of the mould was completed (see Figure 38). The main purpose of this redesign was to incorporate cooling channels to allow for more efficient cooling by dissipating heat. These channels work through the principle of conduction cooling in which water conducts heat away from the mould. Conduction cooling is more efficient compared with a convection cooling fridge as the density of the medium, water (997 kg/m^3), is much higher than air (1.225 kg/m^3) and more heat energy is dissipated in a shorter period. Further refinements were made to the mould ribs, making them slimmer to maximise gummy material around the egg capsule.

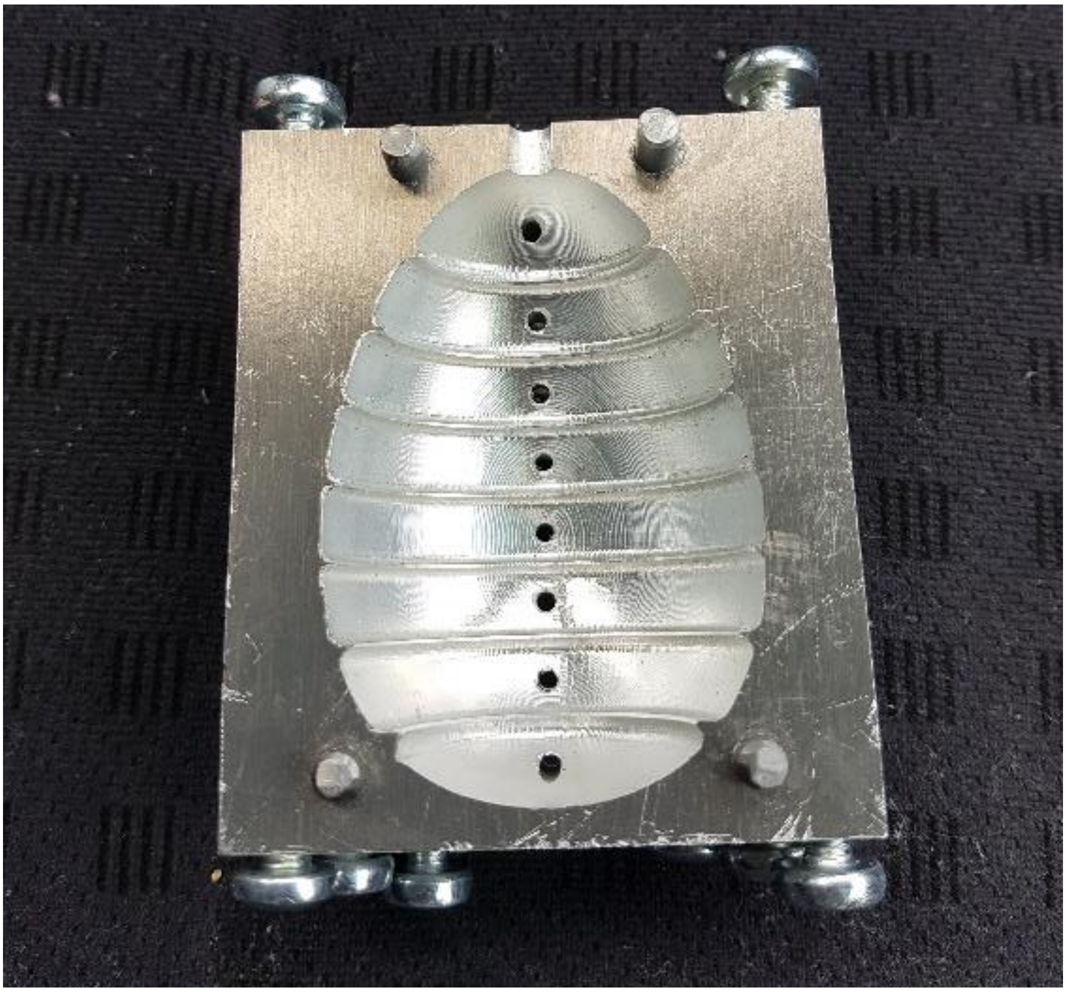

Figure 38: Mould Version 3 pre-coating of PTFE

The cooling channels were connected in a continuous loop using pneumatic straight thread-to-tube adapters and lengths of pneumatic tubing (see Figure 39). One end of the loop was fixed to a water pump which had a max flow rate of 380L/hour (6.33L/min).

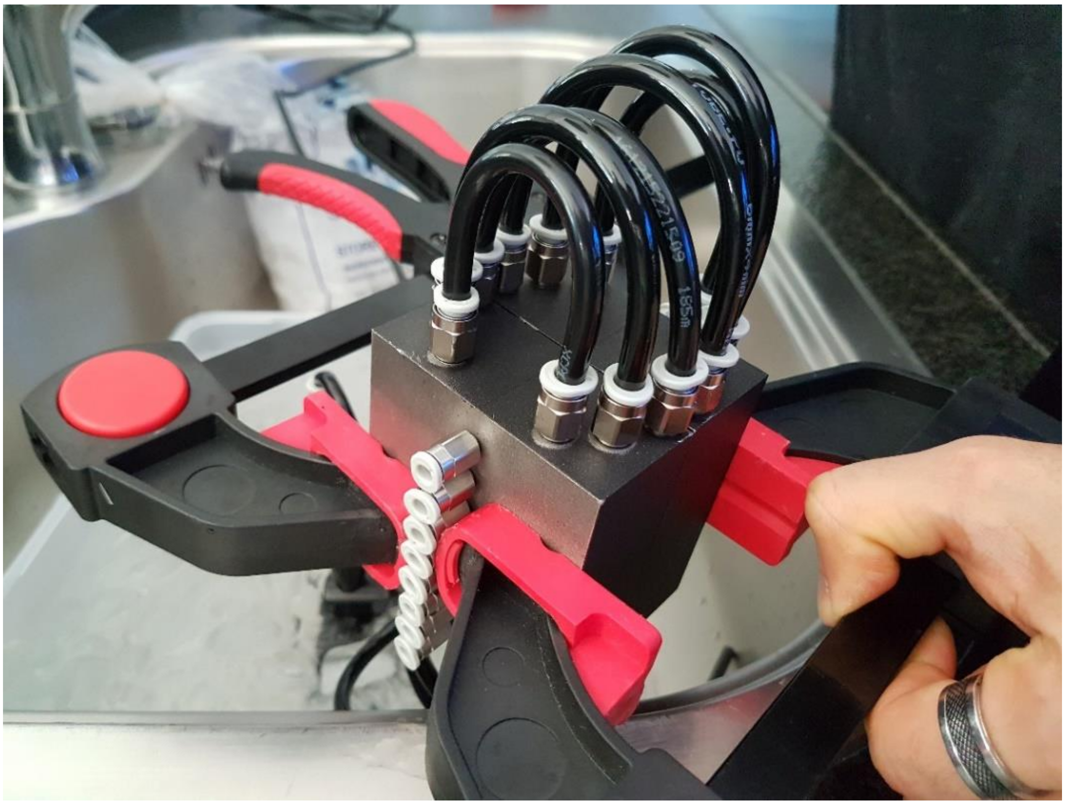

Figure 39: Cooling channels with tubing

A thermal imaging camera was used to judge the efficiency of the cooling channels. The moulds were initially placed into a water bath at a temperature of 70°C before it was connected to the pump. The pump sat in a water bath at a temperature of 15°C ± 1°C. Figures 40 and 41 show the temperature change in 90 seconds. This gave a good indication of how temperature changed over the mould as water passed through the loop. The moulds did not cool at the same rate because the loop construction meant the first half of the mould (right side of Figures 40 and 41) absorbed the heat while the second half received water at a higher temperature than directly from the water bath. The hypothesis expected one side of the mould would cool the gummy faster than the other, making one side solid and the other sticky.

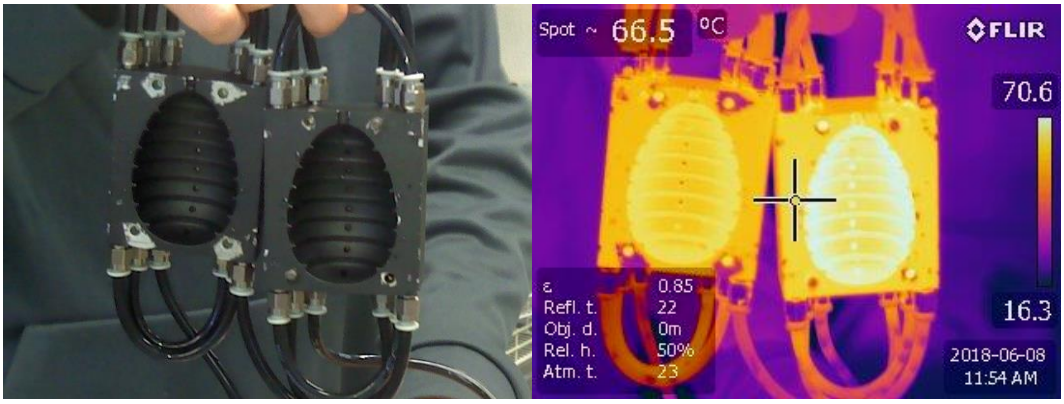

Figure 40: (left) Mould version 3 – (right) Mould under thermal camera image 1

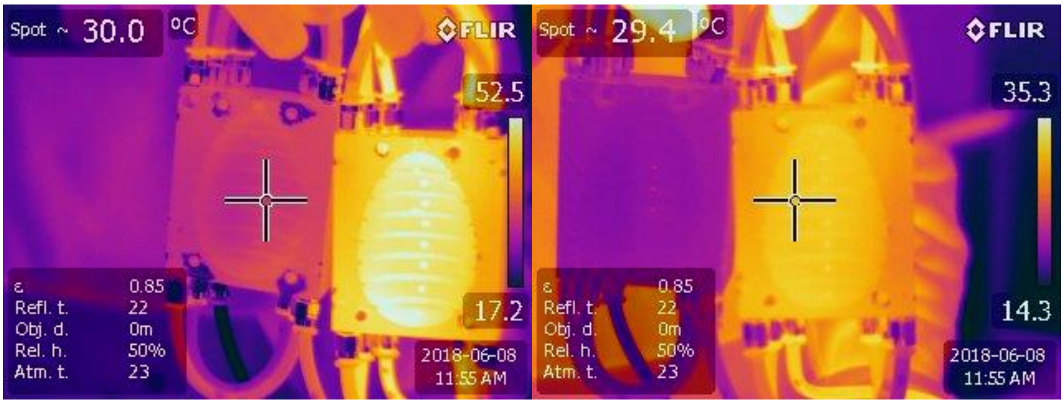

Figure 41: (left) Mould under thermal camera image 2 – (right) Mould under thermal camera image 3

Test 3.1 – Summary of Findings

Table 9: Parameters for Test 3.1

Mould Type	Aluminium mould with ribs and cooling channels, coated in PTFE
Plastic Egg Capsule	3D printed ABS egg
Gummy Recipe	Modifications made in an attempt to cool gummy quicker
Release Agent Used	Yes (Vegetable Oil)
Gummy Temperature from Water bath	60°C
Mould Temperature	18°C
Gummy Colours Used	Blue or Orange
Cooling Mechanism	Conduction – water bath at 3°C ± 1°C
Cooling Time	5 Minutes or 2 Minutes

The aim of this test was to determine if the addition of cooling channels significantly reduce the time to remove an egg from the mould. Previous tests used convection cooling in a fridge which took upwards of 20 minutes until the gummy could be released from the mould. These tests were to reduce that time to below 10 minutes. Again, the test was conducted in a food safe kitchen at the Food Technology department of Massey University, where the gummy formulation with two colours were prepared ahead of time. The same egg capsule used in Test 2.1 was repurposed for this test.

Once the gummy was injected into the mould, the pump was turned on allowing cold water to flow through the cooling channels. After five minutes, the pump was switched off and the mould halves separated revealing the gummy had solidified sufficiently to be removed from the mould (see Figure 42). This showed the cooling channels operating as anticipated meaning a much faster manufacturing time per gummy product could be achieved.

Figure 42: Gummy egg test at five minutes

Following the successful reduction in cooling time to five minutes, a test aiming for two minutes was conducted. When the two minutes had elapsed, the pump was turned off and the mould halves separated and the gummy was cool enough to be removed (see Figure 43). However, as removal began it appeared the gummy had not solidified enough and sustained some damage. This meant the fastest optimal cooling time to release an egg from a mould without damage lay between two and five minutes.

Figure 43: Gummy egg test at two minutes

Test 3.2 – Summary of Findings

Table 10: Parameters for Test 3.2

Mould Type	Aluminium mould with ribs and cooling channels, coated in PTFE
Plastic Egg Capsule	3D printed ABS egg
Gummy Recipe	Modifications made in an attempt to cool gummy quicker
Release Agent Used	Yes (Vegetable Oil)
Gummy Temperature from Water bath	60°C
Mould Temperature	18°C
Gummy Colours Used	Blue and Red
Cooling Mechanism	Conduction – water bath at 15°C ± 1°C
Cooling Time	5 Minutes

Test 3.2 was to determine if water at a higher temperature would cool the gummy as quickly as water at a 3°C. If a low water temperature was not needed then the overall project's costs would drop, making the product more feasible to mass manufacture. Again, the test was conducted in a food safe kitchen at the Food Technology department of Massey University, where the gummy formulation with two colours were prepared ahead of time. The same egg capsule used in Test 2.2 was repurposed.

Similarly, to Test 3.1, gummy was injected into the mould and a pump sitting in a bath of water at 15°C ± 1°C was turned on (Figure 44). After five minutes, the pump was turned off and the two halves separated. The gummy around the capsule had a sticky, watery texture (Figure 45) but could be removed from the mould. After testing several random temperatures, a lower cooling temperature was determined as necessary to quickly remove gummy from a mould.

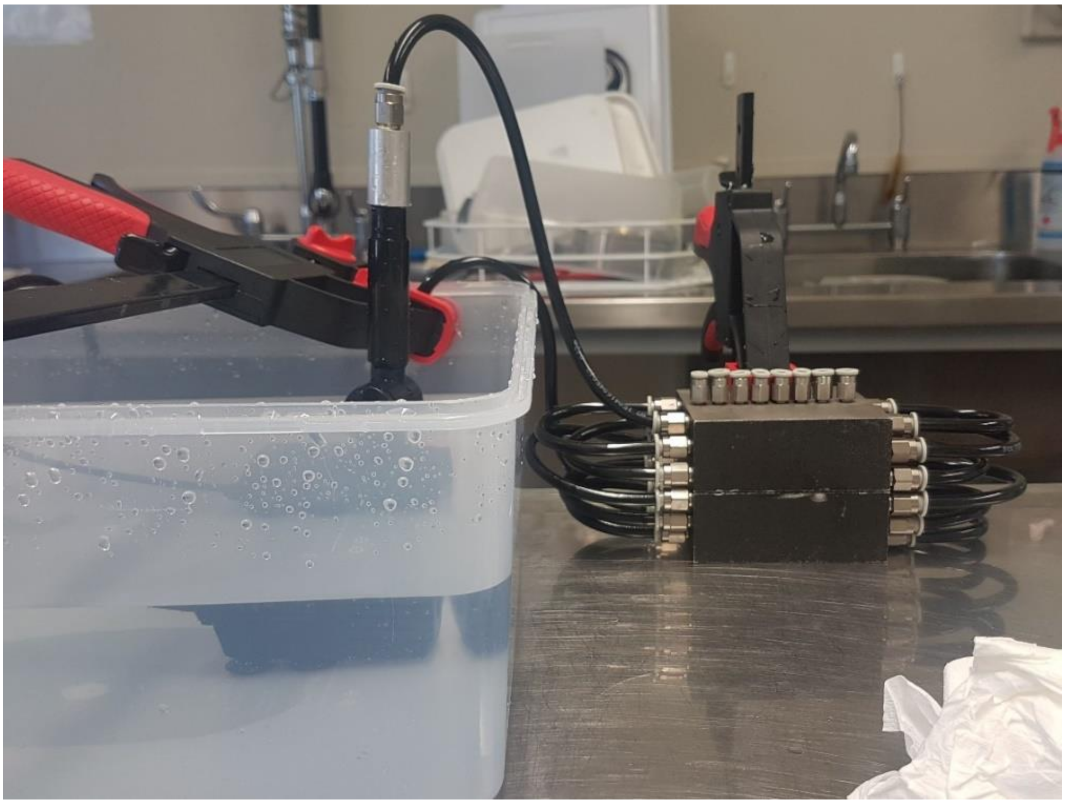

Figure 44: Test 3.2 cooling setup

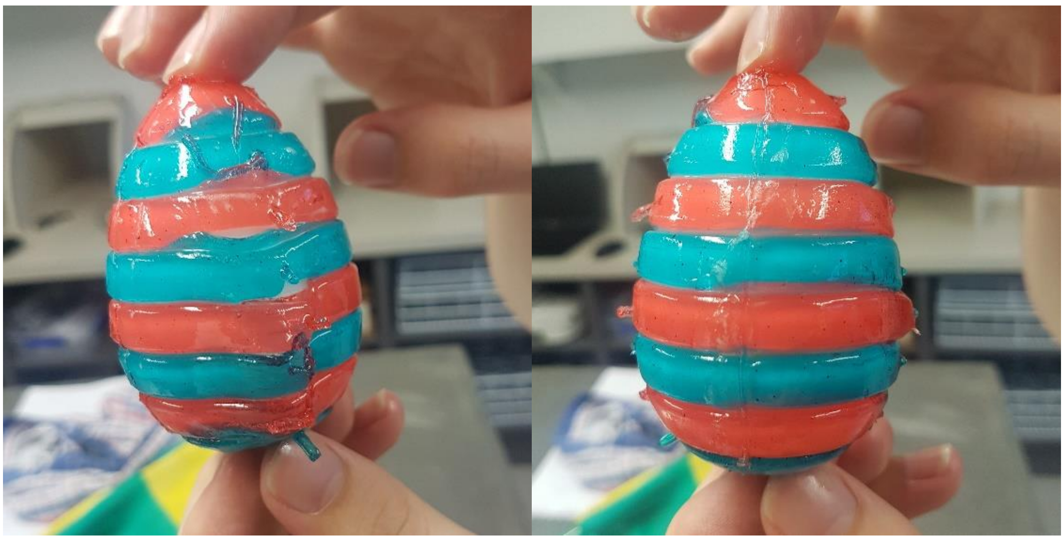

Figure 45: Gummy egg test at 15°C

4.6 Mould Version 4: Development and Testing

This section briefly discusses two moulds that were side experiments and not crucial to the final product.

During the previous testing, the client wanted to experiment with including textures on a gummy surface. The aim of the side experiments was to first explore if this could be done by making shaped cavities in the mould which, after injecting and cooling the gummy, would create protrusions on its surface. Secondly, and dependent on the success of the first aim, was to make cavities in the shape of fruit so raise the visual attractiveness of the product.

The same mould design as used in Version 3.0 was replicated as the platform for this feature. In CAD software, small imprints were made into the mould to simulate textures such as diamond shapes or small grapes. Along with the textures, a vertical rib was added on the back half of the mould to suggest to a consumer a place to start peeling each layer of gummy (see Figure 46).

Figure 46: Mould V4 with added textures

Testing was done similar to Test 3.1, following all conditions known to produce a successful gummy egg to offer the best chance of viable results. After multiple tests, the machined textures in the mould were observed to be too deep and caught on the gummy as the mould halves separated damaging the gummy and making the product look undesirable (see Figure 47).

Figure 47: Gummy eggs produced in mould V4

4.7 Chapter Summary

This chapter presented a detailed description of the development and testing of injection moulds. Each iteration was designed based on the client's needs in parallel with the unique behaviours and characteristics of gummy formulation. The first mould was a simple PTFE-coated two-part egg cavity mould with three injection holes on either half. The egg capsule was a 3D printed plastic egg with a handle to help centre the egg in the mould. The mould proved successful in two areas: that PTFE coating of the mould simplified removal of the gummy, and that the formulation could encase a plastic egg capsule showing significant promise that the product concept could be made with injection moulding techniques. However, subsequent tests found such a mould wasn't suitable as it was impossible to produce the clearly defined colour layers, which was a fixed requirement from the client.

The mould was completely redesigned with the defined colour separation of each layer as the primary focus. The design incorporated seven ribs protruding 2mm from the mould to section off the cavities and produce the client's desired eight-colour product. Multiple tests found colour separation was possible only with the correct volume of gummy. However, the process of cooling the gummy was unsustainable in a mass manufacturing context and a redesign to reduce the cooling was needed. The average cooling time per gummy egg was 20 minutes.

To reduce cooling time, the prototype was redesigned to incorporate six cooling channels running down the excess space around the injection cavity. The tests used a small pump in a bath of water at a temperature of 3.0°C which fed water through tubes fixed in a loop to dissipate heat. These tests reduced cooling time to five minutes and below.

Following the successful development and testing of the PTFE-coated rib mould with cooling channels, the client wanted to add textures to the gummy surface. The CAD model was changed to incorporate small shaped cavities into each layer of the mould which was then coated in PTFE and tested under the previous optimal conditions. The concept of adding textures to the gummy surface proved impossible as they prevented safe release from the mould.

However, the tests were an overall success and it was clear a final mould could be designed and produced. The following chapter explores the final design and testing of the mould before the development and findings were handed over to the client.

Chapter 5

Final Mould Design and Testing

5.1 Introduction

This chapter presents the design considerations during the development of the final injection mould in relation to all understandings found during previous tests and cross-compared to the client's original requirements. These sections present the mould tests conducted to evaluate the final design, including additional tests involving a plunger concept to clear the runners of gummy after injection, making it easier to remove the gummy from a mould after cooling.

Furthermore, the textured mould concept was revisited after the client requested developing the final mould concept with the addition of textures. To better evaluate the textured mould concept, findings from the previous test were implemented in the design.

The closing section of this chapter provides recommendations to the client on refining the mould design further. This section also recommends developing the peripheral machinery to create the product. Although the project was to explore appropriate manufacturing techniques, the explorations presented critical insights into possible automation machinery.

5.2 Design of Final Mould

Before developing the final mould design it was important to revisit the client's needs outlined at the beginning of the project. As presented in Chapter 4 Section 2, the client presented a graphical representation of the desired product in which eight different coloured layers of gummy loosely adhered to the surface of a plastic egg capsule containing a surprise toy. The prioritised list of requirements is repeated below, along with the concept sketch in Figure 48.

1. Defined colour layers with no bleed (Fixed)
2. Gummy loosely adhering to a plastic capsule (Fixed)
3. The gummy must have no air bubbles (Fixed)
4. Colours laid out in a continuous spiral (Flexible)

5. Eight different colours (Flexible)

Figure 48: Recreation of original concept sketch from client - Repeated

After revaluating the client's needs, some design features and considerations were made. These are listed in Table 11 along with a brief summary of how the mould should be designed.

Table 11: Final Mould Design Features

Goals and Considerations	Implementation Method
Egg shaped gummy product	Mould design machined in an egg shape, with considerations for the addition of gummy to the surface which could warp the shape
Defined colours with no bleed	2mm ribs machined on the mould against the egg capsule preventing viscous liquid from bleeding into neighbouring cavities
Gummy loosely adhering to the surface of the egg capsule	Use appropriate plastic for capsule without crevasses, indents or textures on the surface in which the gummy could set
The gummy must have no air bubbles	Use appropriate machinery to create and mix the formulation and prevent the injection system from accumulating air
Colours laid out in a continuous spiral around the egg capsule	The ribs machined on the mould would be tilted with a 15° angle mimicking a spiral aesthetic

Eight different colours	Eight sections or cavities would be divided with seven ribs on the mould
Gummy release from the mould	Achieved by coating a mould in PTFE and using a release agent (vegetable oil)
Gummy cooling quickly	Cooling channels implemented in the mould design to cycle cool water through the mould, dissipating the heat
Accurate volumes of gummy	Theoretical volumes to be found using CAD software, then cross compared with experimental volumes to ensure correct amounts are injected into each cavity
Provide a location where the customer can begin the peel of each gummy layer	A vertical rib added to the opposite side from the gummy injection, making a small indent for gummy to be peeled

This summary was used to design the final mould in CAD software with a key new feature of the spiral rib design. Although the client's initial desire was to peel the gummy in one continuous piece from the capsule (finishing with an eight-coloured snake-like 2mm strip of gummy), the constraint of defined colour layers did not allow for this due to the colour bleed at the intersection of two colours and ruining the aesthetics. To overcome this, each rib was adjusted to have an angle of 15° from the horizontal (see Figure 49). This gave the appearance that the gummy strips were a spiral and cancelled the need to connect each layer which risked colour bleed. These design changes were confirmed by the client and the mould was designed, machined and coated in PTFE, ready for testing.

Figure 49: Both halves of final mould design

5.3 Testing of Final Mould

In order to ensure the final mould design was viable, the following tests were conducted.

<u>Test 5.1 – Summary of Findings</u>

Table 12: Parameters for Test 5.1

Mould Type	Aluminium mould with spiral ribs and cooling channels, coated in PTFE
Plastic Egg Capsule	ZURU-made toy capsule
Gummy Recipe	Modifications made in an attempt to cool gummy quicker
Release Agent Used	Yes (Vegetable Oil)
Gummy Temperature from Water bath	60°C
Mould Temperature	18°C
Gummy Colours Used	Dark red, red, orange, yellow, light green, green, blue, purple
Cooling Mechanism	Conduction – water bath at 3°C ± 1°C

Cooling Time	5 Minutes

The first test was to confirm if the new spiral rib feature would detrimentally effect the features successfully tested in prior mould designs. To do this, understandings of how to produce a successful egg test were taken from previous tests, such as 3°C water for cooling, vegetable oil for release agent and injecting accurate volumes of gummy for each section (determined through CAD software). The client had also produced egg capsule samples made from PET to replace the 3D printed capsules and allow for more appropriate testing. Again, the test was conducted in a food safe kitchen at the Food Technology department of Massey University, where the gummy formulation with eight colours were prepared ahead of time.

Previously successful tests were used as guidelines for each stage of testing the final mould. The mould was first coated in oil using a brush before the egg capsule was placed into the mould. The mould was clamped together and the cooling channels connected to the water pump. Each colour was then injected from bottom to the top using syringes to ensure a precise volume. The water pump was subsequently turned on and the mould allowed to cool for five minutes. Following this, the mould was opened and an attempt was made to remove the egg.

This attempt proved successful and the egg removed with minimal resistance showing that the angled rib design had no adverse effect. The only issue arose when the gummy at the gate of injection (between the runner and the cavity) did not break away as the injection half of the mould was removed, causing the gummy to pull away slightly from the surface of the egg capsule. After multiple repeats under the same conditions, the gummy at the gate of the injection sometimes did not effect the surface of the gummy. In Figure 50, the issue can be observed on multiple layers, especially the green layer where the gate hasn't broken away during mould separation causing the green layer to peel away from the surface of the egg capsule. A solution to this issue is presented in section 5.4.

Figure 50: Gummy egg test with damaged green layer

5.4 Plunger Concept and Testing

To alleviate the issue of the set gummy at the gates of the injection, a simple plunger concept was developed which would be used post-injection and pre-cooling to clear each runner. In this way, no gummy would stay in the runners when the mould cooled ensuring that any gummy at the gates is cleared and won't damage the surface of the egg during mould separation. The plunger was simply to have eight stainless steel rods, each with a custom length and angle. These rods were fixed to an aluminium handle allowing for ease of use and for each rod position to be adjustable. The plunger concept can be viewed in Figure 51.

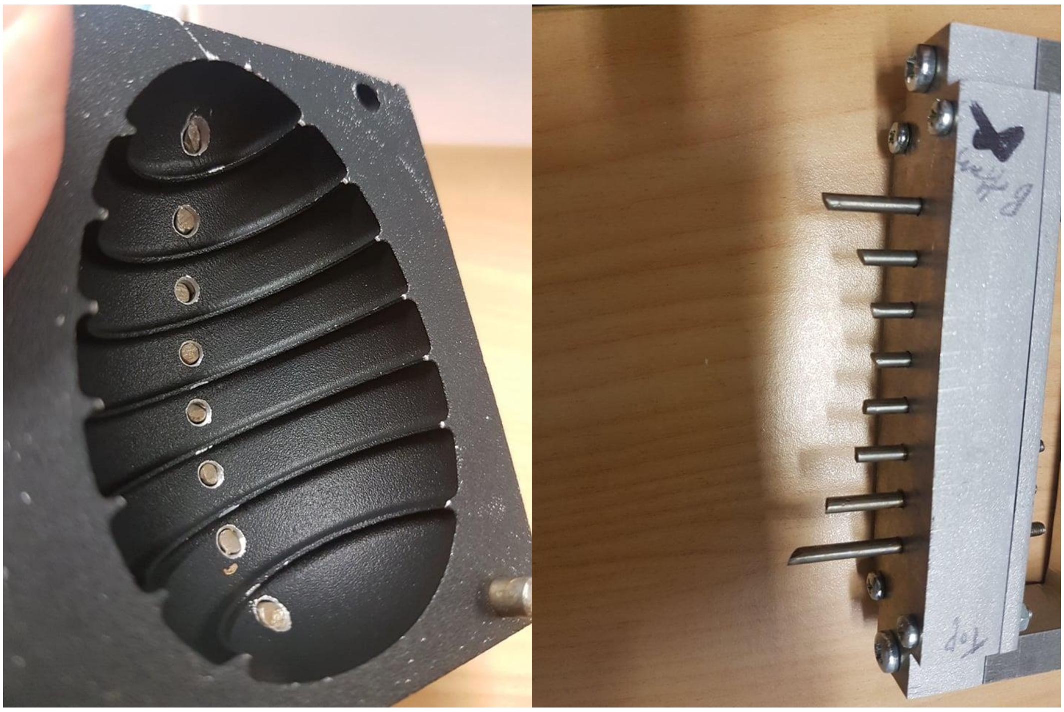

Figure 51: Mould plunger concept

Following the design and fabrication of the plunger, a repeat of the prior section test was completed to test if the gummy could be removed from the runners and subsequently the gates of the mould, alleviating the problem.

Test 5.2 – Summary of Findings

Table 13: Parameters for Test 5.2

Mould Type	Aluminium mould with spiral ribs and cooling channels, coated in PTFE with plunger concept
Plastic Egg Capsule	ZURU-made toy capsule
Gummy Recipe	Modifications made in an attempt to cool gummy quicker
Release Agent Used	Yes (Vegetable Oil)
Gummy Temperature from Water bath	60°C
Mould Temperature	18°C
Gummy Colours Used	Dark red, red, orange, yellow, light green, green, blue, purple
Cooling Mechanism	Conduction – water bath at 3°C ± 1°C

Cooling Time	5 Minutes

The aim of this test was to determine if the plunger concept alleviated the problem caused by gummy setting in the runners and at the gate of the mould, causing damaged to the surface of the gummy egg upon removal from the mould. Again, the test was conducted in a food safe kitchen at the Food Technology department of Massey University, where the gummy formulation with eight colours were prepared ahead of time.

The test procedure followed the same steps as Test 5.1 except for the plunger, which was introduced after the injection of the eight gummy layers. To determine if the plunger worked, two tests were performed which involved pushing the plunger into the mould runners and then removing it immediately before the cooling process began. The second test involved pushing the plunger into the mould but leaving it in during the cooling process. These two tests were to determine any noticeable difference with the gummy egg surface and if a future automation line required multiple plungers placed into the moulds and removed down the processing line, or if the process could be completed in one stage of the line.

Following several tests, the first observation was that the plunger concept alleviated the issue of set gummy at the gate which damaged the egg on removal. This gave us confidence that each egg produced on an automation line would be released from the mould appearing identical with only minimal surface defects, creating a high-quality visual standard. The second observation was neither removing the plunger directly after injection of the gummy (pre-cooling) or leaving it in during the cooling process made a significant difference to the quality of the egg. This meant the plunger could be flexible in its implementation, working around more vital but fixed components of the automation line. The test egg on the right in Figure 52 shows the smoothness of the surface when a plunger is used and the gummy at the injection gate is barely visible.

Figure 52: Two egg tests where the plunger was used

Further testing of the final mould proved the gummy eggs could be produced with a high consistency under previously defined successful parameters. However, two remaining problems needed additional refinement before the client could start designing the automation line. The first was excess air bubbles in the mixture due to the methods used for producing the gummy and for injecting it into the moulds (see Figure 53). After discussions with the client and food technologist, this issue was addressed through correct gummy preparation machinery at a mass manufacturing level and through an automated airtight injection system.

The second problem was the inaccuracy of volumes in each section causing colour bleed to neighbouring sections (see Figure 53). This was due to a discrepancy in volumes because the theoretical volumes calculated using CAD software are not the same as the actual volumes. The CAD software represents a 'perfect world' environment and doesn't factor in outside fabrication or production errors in the plastic capsules. For this reason, a trial and error approach was necessary in which each volume is tweaked in multiple tests. This was communicated to the client and it was decided that sufficient evidence existed from previous tests to determine that the mould could correctly produce the gummy egg product. It was decided that spending time to find the exact volumes of each section was unnecessary as the client may change the mould when producing the automation line, rendering the volumes redundant.

Figure 53: Bunch of test eggs with air bubbles and colour bleeding

5.5 Revisiting Textures on Gummy Egg

Following the successful testing of the final redesign along with the results of mould Version 4.0, the client revisited the concept of textures on the mould. Textures were added to the final mould design in CAD software and changes made to the depth of the textures, making them only slight cavities (see Figure 54). This would minimise the chances of gummy sticking in the cavities while retaining room for a visible texture on the surface of the product. Once the texture additions were made, the mould was fabricated and coated in PTFE ready for testing.

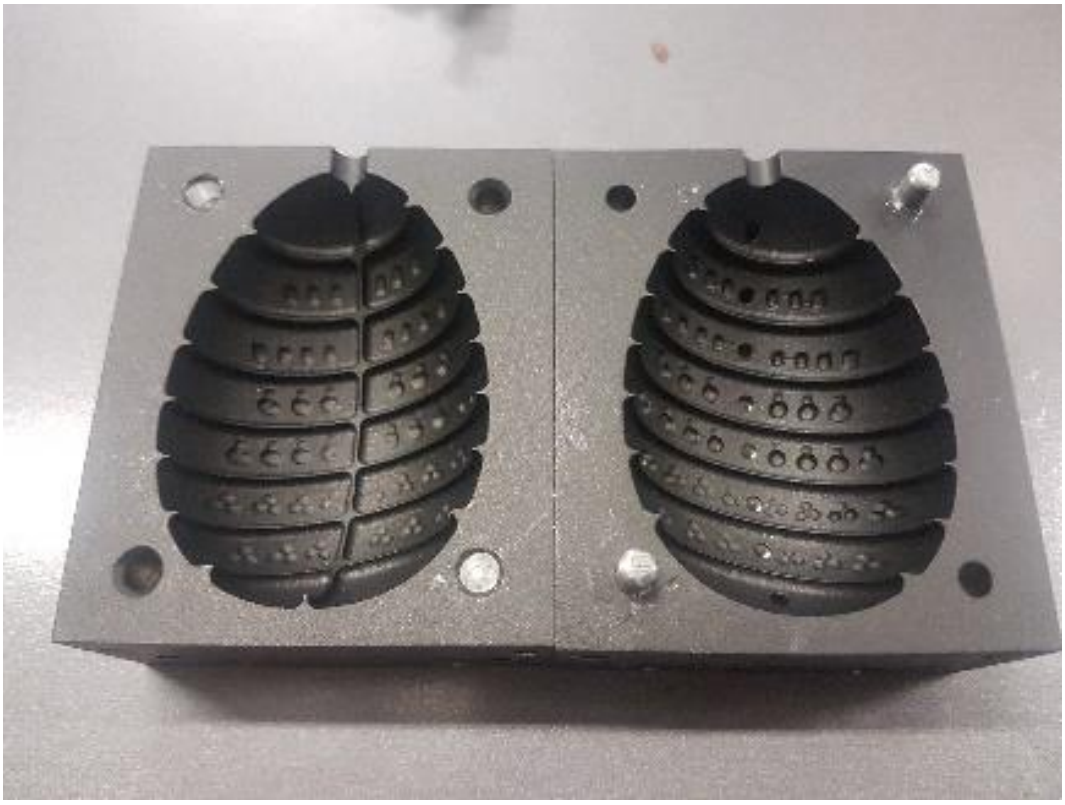

Figure 54: Final mould with textures

Test 5.3 – Summary of Findings

Table 14: Parameters for Test 5.3

Mould Type	Aluminium mould with spiral ribs, textures and cooling channels, coated in PTFE with plunger concept
Plastic Egg Capsule	ZURU-made toy capsule

Gummy Recipe	Modifications made in an attempt to cool gummy quicker
Release Agent Used	Yes (Vegetable Oil)
Gummy Temperature from Water bath	60°C
Mould Temperature	18°C
Gummy Colours Used	Blue or yellow or dark red, red, orange, yellow, light green, green, blue and purple
Cooling Mechanism	Conduction – water bath at 3°C ± 1°C
Cooling Time	5 Minutes

The aim was to revisit producing the gummy egg with textures on the surface while minimising the major problem uncovered in the prior testing when textures were machined too deep in the mould, causing the gummy to pull away from the plastic capsule. Again, the test was conducted in a food safe kitchen at the Food Technology department of Massey University, where the gummy formulation with eight colours were prepared ahead of time.

The test was conducted under identical conditions and following the same procedure as Test 5.2. The first test determined if gummy would get caught in the textures of the mould, causing it to peel prematurely from the plastic egg capsule. Testing all eight colours at the correct volumes was not important before showing the mould could produce an egg so, the first test used only blue gummy injected into each cavity (see Figure 55). After separation of the mould, the gummy did not adhere to the textures as in the previous texture test (section 4.6). To confirm this, a second test conducted using yellow gummy (see Figure 55) but again the gummy did not adhere to the mould, showing that the mould could produce the desired textured gummy egg as the client had requested.

Following this success, further testing attempted to create the eight coloured gummy egg with correct volumes. After following the identical procedure as Test 5.2 with the same volumes, a multi-coloured gummy egg with textures was produced (see Figure 55). After presenting the textured test egg to the client, it was decided that although the idea was good, in reality the textures didn’t display well on the surface, making the gummy look unpleasant and unappetising. The textured concept was finally shelved and the final mould was determined to produce the best gummy egg product for the client.

Figure 55: Final gummy egg tests with textures

5.6 Recommendations to the Client

This section documents handing over the project to the client with a list of findings, considerations and next steps for the development of the automation line. The list provides no details about how to design automation line machinery for developing the product, providing only information the client should consider when designing such machinery.

5.6.1 Considerations for Injection Mould Refinement

After completing the tests of the final mould design, further refinements to the mould design to optimise the product are recommended. These refinements will help improve cooling systems, release agents (or eliminate the need for a release agent), mould design and the efficiency of material choices.

However, three features of the mould design should not be removed. The first is the ribs, which are essential to ensure the layers of gummy suffer no colour bleed and for centring the capsule in the mould to evenly distribute gummy around the capsule. Secondly, the mould should be coated in PTFE so the gummy doesn't adhere to the mould surface during cooling. With further refinements, it may be possible to only rely on the PTFE coating for gummy release, rather than the additional vegetable oil as a release agent. Thirdly, the mould material should stay aluminium as this material is a great conductor of heat for quick mould cooling and that it is food safe. Stainless Steel was explored as an alternative material, however, it is significantly denser that aluminium and conducts heat at a much slower rate.

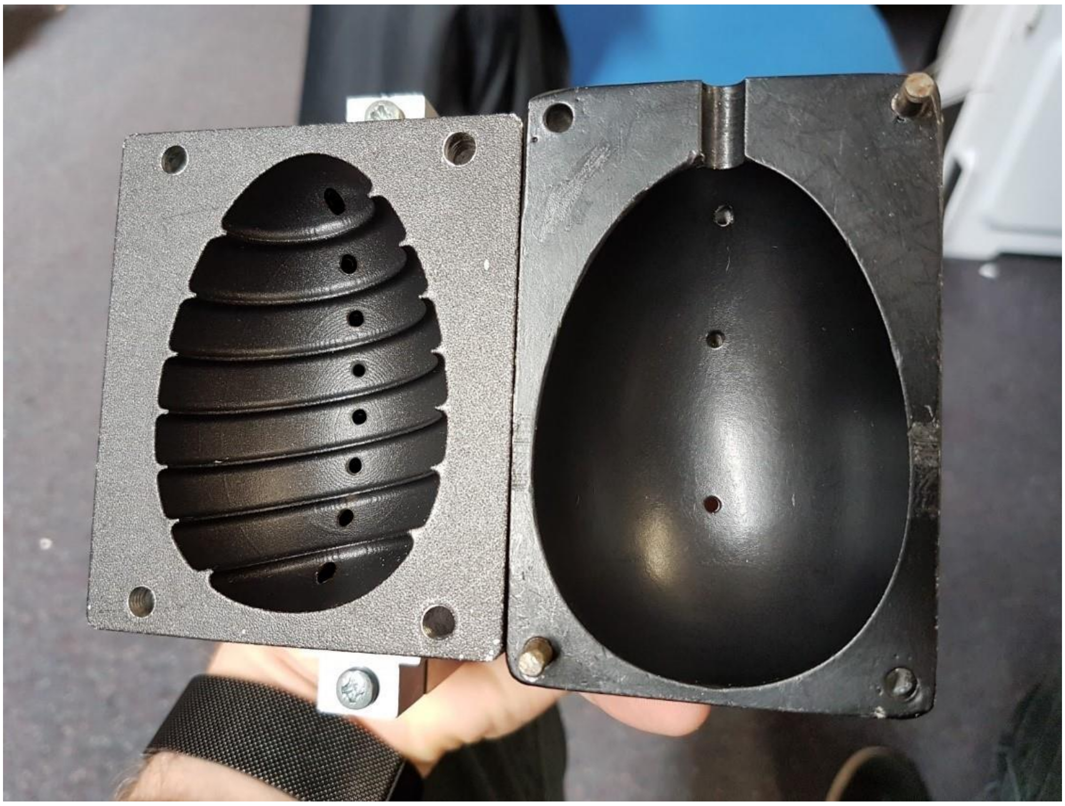

Figure 56: (left) Final Mould - (right) Mould Version 1

5.6.2 Considerations when Designing Peripheral Machinery

During the process of designing, testing and refining the injection mould, a general approach for how the product could be automated was developed. The following is a stage by stage breakdown of the overarching process.

Stage One: Mould Release Coating

It begins by coating the mould(s) with oil/release agent using either a contact or non-contact method. A contact method could be a peripheral machine applying the coating with a brush, whereas a non-contact method could apply the coating with a spray mechanism.

Stage Two: Capsule placement

Following the coating of the release agent, the egg capsule must be autonomously placed in the mould. The moulds should be positioned flat in the process so gummy can be injected from the top, which also allows for easy placement of the toy capsule. A possible mechanism could be a pneumatic suction cup or a gripper fixed to the end of a multi-axis robotic arm.

Stage Three: Injection

Before gummy injection can occur, the mould halves must be brought together under pressure. One method, used in traditional gummy manufacturing machines, is the plunger system which works by plunging a shot of gummy out of a nozzle into a cavity. This method is proven and simple to implement, however, it is difficult to inject volumes at the required precision for this product. An alternative method is a progressive cavity pump which can inject precise volumes of viscous liquid easily.

Overall, each section should be injected at the same time to ensure each colour doesn't bleed across the rib to the neighbouring section under pressure, because each section will be injecting an equal and opposite force on the neighbouring colour. This also makes the manufacturing line smaller by merging eight injection stations into one. However, this presents a logistical issue as the injection holes on the mould are close together making it difficult to place multiple plunging injection systems or progressive cavity pumps next to each other.

Stage Four: Plunging

Following injection of the gummy, the plunger should be used to clear the runners in the mould by using a peripheral machine which aligns the plunger rods to the injection holes and inserts into the mould for a small period, before being removed.

Stage Five: Cooling

Given the complexity of a continuous/revolving automation line, it is difficult to implement cooling channels into a mould with piping. A solution is to partially submerge the mould in water temporarily to cool the mould through conduction. Another solution is to transition the mould through an airconditioned tunnel to achieve cooling through convection.

Stage Six: Release

Following the cooling stage of the mould, the clamping mechanism force the two halves of the mould together must be depressurised allowing for the mould to be separated and the gummy egg to be removed. This is an important stage because the gummy is only cooled and not yet set, making the gummy surface susceptible to damage. The gummy egg must be removed with a robotic mechanism touching only a small portion of the gummy surface to minimise damage to the egg. This mechanism must then place the gummy egg on a tray or rack which can take the eggs to a drying room where they will solidify over a lengthened period of time.

Stage Seven: Cleaning

After the gummy is released, the moulds must be cleaned to remove any build-up of waste gummy and/or oil. If not cleared, the subsequent gummy egg may be produced incorrectly, slowing down the process. Furthermore, cleaning the machines after each cycle is a health and safety requirement.

Post processing

Following the removal of the cooled gummy egg from the mould, it must be allowed to solidify in a temperature- and humidity-controlled environment. This is standard process for gummy confectionery in which the product must be solidified for between 12-24 hours after removal from the mould to give the gelatine time to set, making the gummy nice and chewy.

5.7 Chapter Summary

This chapter discussed the design considerations for the final mould concept to be presented to the client. It incorporated the necessary features discovered during all previous mould iterations while introducing a new feature to give the product a spiral appearance.

Testing the final mould involved repeated tests under optimal test conditions to evaluate the design's feasibility, but also to identify further areas the client must improve. These areas were identified and presented to the client in this chapter so that, during the handover process, the client understands how to best take the lessons of this project as a guide for the design of the automation line and the subsequent manufacturing needs of the product.

Chapter 6

Conclusion

Gummy confectionery is one of the largest sectors in the global confectionery industry, growing at a rate of 4.5% in the first half of 2018 alone. [2] ZURU Inc, one of the fastest-growing toy companies in the world identified an opportunity to develop a unique gummy product which needed a new method of manufacturing that did not exist within the current gummy confectionery industry: a surprise egg capsule completely encapsulated in eight strips of gummy. These strips were to have distinctive colour layers and be peeled off the capsule in a spiral shape.

To develop a viable manufacturing solution, ZURU partnered with Massey University's Engineering and Food Technology departments to utilise their unique expertise and experience creating new automation and food technology products. Apart from a select few requirements, the client gave total freedom to explore all possible methods. After completing the literature review, it was concluded that more understanding was needed about the material behaviour of gummy confectionery manufacturing before deciding on a method. A range of interactive gummy test were conducted which showed injection moulding was the most viable given both the gummy's amorphous nature and existing manufacturing techniques used to produce gummy confectionery.

In testing this theory, the first mould was fabricated from aluminium with a smooth egg-shaped cavity and coated in a non-stick coating (PTFE). This two-part mould utilised the surprise toy capsule as the centre core with the gummy around it. After several tests, the smooth egg-shaped cavity couldn't produce the desired colour separation and even distribution of gummy around the centre core. A new mould concept was developed focusing on eight cavities within the egg-shaped mould for each injection of coloured gummy. These cavities were created by 2mm protruding ribs resting horizontally against the outside of the egg capsule. This feature meant the capsule could be centred in the mould while each colour strip was individually sectioned off to ensure no colour leaked into the neighbouring sections.

The findings from the first two successful tests were used to develop a third iteration of the mould which incorporated the rib feature and the new cooling channels that allowed for faster cooling times compared with previous air-cooling methods. These channels reduced the cooling time from over 20 minutes in a fridge to four minutes using 3°C water. Adding this to the mould design produced the final mould.

The initial product requirements were then revisited to ensure the final mould would meet the client's needs. The final mould incorporated all the successful features, however it was identified that the continuous spiral feature desired by the client was unable to be achieved with this method. To overcome this, the ribs on the mould were tilted by 15° to give the impression of a spiral on the gummy but meant it could only be peeled in eight individual strips rather than one continuous strip. After presenting this solution to the client, the final mould was designed and fabricated. Under optimal testing conditions of gummy injected at 60°C and cooling for four minutes with 3°C water, a gummy egg with eight distinctive colours was repeatedly produced showing that injection moulding is viable to create the desired product.

Upon completion of testing, the mould design and recommendations were given to the client for further refinement and implementation. ZURU's engineering team has since refined the mould and designed a complete automation line to produce the product at mass scale. The unique manufacturing technique created to produce the novel gummy product has also had a patent application filed to protect the intellectual property created by Massey University and ZURU Toys.

The product is now in extensive product development and ready for launch by ZURU.

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