UNIVERSITI PUTRA MALAYSIA

APPLICATION OF A NEW MECHANICAL COMPRESSION METHOD ON ICE CREAM

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A PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF BACHELOR OF ENGINEERING (PROCESS AND FOOD)

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ABSTRACT

Stabilizer is one of the most important ingredients in the ice cream formulation. There are many variation of percentages used of stabilizers in the ice cream formulation depends on the manufacturer. However, there was limitation in conducting mechanical test on the ice cream which cannot be performed by many researchers due to the melting rate of ice cream in room temperature. Hence, in this study, the effect of different percentages of stabilizers on the mechanical properties of ice cream were investigated using the Lego Mindstorm EV3. All the ice cream sample were produced using the same formulation and the percentages of stabilizers in each of the sample were varied by 0.1% to 0.4%. Then, the mechanical test which were compression test, stress relaxation compression test and step relaxation compression test were done. Based on the result of the mechanical analysis, the non-linear mechanical behaviour of the ice cream was studied. Based on the study, the non-linear mechanical behaviour of the sample was the viscoelastic properties of the ice cream. The viscoelastic properties was studied by referring to the stress relaxation results. Last but not least, the correct method for the sample preparation of the ice cream also being studied which the ice cream should not be melt and refreeze as it will affect the structure of the ice cream by causing the ice recrystallization of the ice cream.

ABSTRAK

Penstabil merupakan salah satu bahan yang penting dalam formulasi ais krim. Terdapat pelbagai peratusan penstabil yang digunakan dalam formulasi ais krim bergantung kepada pembuat ais krim. Walau bagaimanapun, terdapat limitasi dalam mengendalikan ujian mekanikal atas ais krim kerana kadar pencairannya pada suhu bilik. Jadi, dalam kajian ini, kesan kepelbagaian penstabil atas sifat-sifat mekanikal ais krim telah dikaji. Semua sampel ais krim telah dihasilkan menggunakan formulasi yang sama dan peratusan penstabil dalam setiap sampel dipelbagaikan dari 0.1% hingga 0.4%. Setelah itu, mekanikal analisis telah dijalankan iaitu ujian mampatan, ujian mampatan relaks, dan ujian mampatan secara langkah relaks. Berdasarkan keputusan mekanikal analisis yang telah dijalankan, sifat-sifat mekanikal bukan linear ais krim telah dapat dipelajari. Berdasarkan kajian ini, sifat-sifat bukan linear sampel ais krim adalah sifat kelikatan elastik ais krim tersebut. Sifat kelikatan ais krim tersebut dapat dilihat pada graf ujian mampatan relaks. Akhir sekali, cara yang betul untuk menyediakan ais krim juga dapat depelajari yang mana ais krim itu tidak boleh dicairkan dan dibekukan semula kerana akan memberi kesan kepada struktur ais krim tersebut dengan mengakibatkan proses pembentukan kristal kepada ais krim itu.

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NOMENCLATURES

CMC	Carboxy Methyl Cellulose
MSNF	Milk Solid Non-Fat
G	gramme
N	Newton
mm/s	millimetre per second
LTLT	low temperature long time
HTST	high temperature short time
UHT	ultra-high temperature

CHAPTER 1: INTRODUCTION

This chapter focused on the background of ice cream and the scope of the project. The scope of the project covered the whole thesis which included the literature review, methodology, discussion and conclusion. Besides, this section briefly discussed the problem statement of the project and the three main objectives of the project.

1.1 Background

Eating ice cream had become one of the people's way of spirit in their daily life and mostly serve as desserts. Ice cream can be defined as one of the frozen dairy products that loved by many because of its sweet taste, smooth and creamy texture. Furthermore, commercial ice cream in the food industry is produced using the formulations based on their own know-how in the processing. Goff and Hartel (2013) stated that the different countries had their own composition of ice cream depends on its localities and markets within each country. They further stated that the consideration must be given to legal requirements, quality of products desired, raw materials available, plant equipment and processes, trade demands, competition and also cost.

Besides, ice cream composition is comprised of a mixture of air, water, milk fat or non-dairy fats, milk solids-not-fat (MSNF), sweeteners, stabilizers, emulsifiers, and flavours (Goff & Hartel, 2013). The stabilizers used in the ice cream mixture come in different types based on the manufactures. Also, the percentages of the stabilizers can be varied based on its own range. The variety in determining the percentages of stabilizers will helps the manufacturers to produce higher quality of ice cream that fit the consumers' palatability.

Other than that, the non-linear mechanical behaviour of the ice cream formulation can be tested by performing mechanical test on the formulation such as the yield stress test. In addition, yield stress is a well-known physical and rheological properties for liquid and solid materials (Ak & Gunasekaran, 1992) .The main testing method used to study the non-linear mechanical behaviour of the ice cream formulation is the mechanical compression method. The mechanical test can be categorized into three types of compression which are the compression test, stress relaxation test and step relaxation test.

The first testing method is the compression test. The mechanical compression method is defined as the normal stress occurs when the force is directly perpendicular to a surface and can be achieved during tension or compression (Tabilo-Munizaga & Barbosa-Cánovas, 2005). The mechanical compression can also be studied based on the stress-strain curve that was obtained as results from the analysis. The second testing method is the stress relaxation test. It was defined by the materials deformation to a fixed strain and the strain is held constant. Then, the stress required to maintain the strain also decreased with time (Steffe, 1996). The third method is the step relaxation test which involved the loading and unloading actions as a function of time as the strain remain constant. The mechanical compression analysis for the ice cream can help to study the non-linear mechanical behaviour of the ice cream.

1.2 Problem statement

Most commercial ice cream contains stabilizer as one of the main ingredients. The stabilizers that commonly used were Carboxy Methyl Cellulose (CMC), guar gum, carrageenan and xanthan gum. They retard ice crystal growth and improve body, texture and melting properties (Jagdish *et al.* , 2015). A good stabilizer should be non-toxic, readily disperse in the mix, not produce excessive viscosity, separation or foam in the mix, provide ice cream with desirable meltdown, economical and not affect the flavour of the mix (Bahramparvar & Tehrani, 2011).

Besides, the study of different percentages of stabilizers in ice cream formulation was still not fully understood. This is because the amount and type of stabilizer required in ice cream depend on its properties which is mix composition, ingredients used, processing times, temperatures, pressures, storage temperature and time (Bahramparvar & Tehrani, 2011). Thus, minor changes in the formulation of ice cream will give different quality of ice cream. There were many studies have been published about ice cream stabilizers.

The stabilizer also is one of the most crucial ingredients in the ice cream mix in order to maintain the mechanical properties of ice cream. Bahramparvar and Tehrani (2011) studied that the effect of stabilizers on mechanical and stress relaxation properties of ice cream mix and sugar solutions containing hydrocolloids have also been investigated. However, there was limitation in conducting mechanical test on the ice cream which cannot be performed by many researchers due to the melting rate of ice cream in room temperature.

Thus, the aim of this research was to study the mechanical properties by conducting compression test on the ice cream with addition of different percentages of stabilizers. Data obtained and analysis may useful to study the non-linear mechanical behaviour of the ice cream in order to produce high quality ice cream.

1.3 Objectives

General aims for the study was to analyse the effect of different percentages of stabilizers on the mechanical properties and also the non-linear mechanical behaviour of ice cream. To be more specific, the three main objectives of this study were:

i. to prepare ice cream with different formulations of the ice cream mix.
ii. to study the mechanical properties of the ice cream structure with different percentages of stabilizers.
iii. to analyses non-linear mechanical properties of ice cream from the mechanical analysis of the ice cream.

1.4 Thesis organization

Chapter one comprised of an introduction which briefly discussed the background of the ice cream, the main problem and the main objectives of the project.

Chapter two, is the literature review chapter, which discussed the previous studies based on journal papers, websites that can be referred and review paper based on the current research. This chapter also comprised of introduction and overview of the ice cream. It is divided into three subtopics which are the basic ingredients in ice cream (milk fat, milk solid nonfat, sweeteners, stabilizers, water and air), ice cream processing (blending, pasteurization, homogenization, aging, freezing and hardening) , and an overview on the mechanical compression analysis of ice cream. In addition, the chapter discussed about the non-linear mechanical behavior of ice cream.

In chapter three, the methodology for the project was clearly brief. There were four stages in the methodology chapter. Stage one is the preparation for the ice cream sample based on designated formulation. In this stage, the percentage of stabilizers are varied. In stage two, detail production of ice cream including blending, pasteurized, homogenized, ageing and hardened were mentioned. As for stage three, samples that have been prepared were tested for the mechanical analysis. For the final stage, the non-linear mechanical behavior was studied based on the mechanical analysis database.

In the chapter of result and discussion which is chapter 4, graphical findings were discussed briefly based on the theory in the literature review.

Lastly, in the chapter 5, which is conclusion and recommendation, the objectives of the research had been successfully accomplished. Hence, the future recommendation regarding the research also been stated for further study in the future.

1.5 Scope of study

The scope of study is shown in Figure 1.

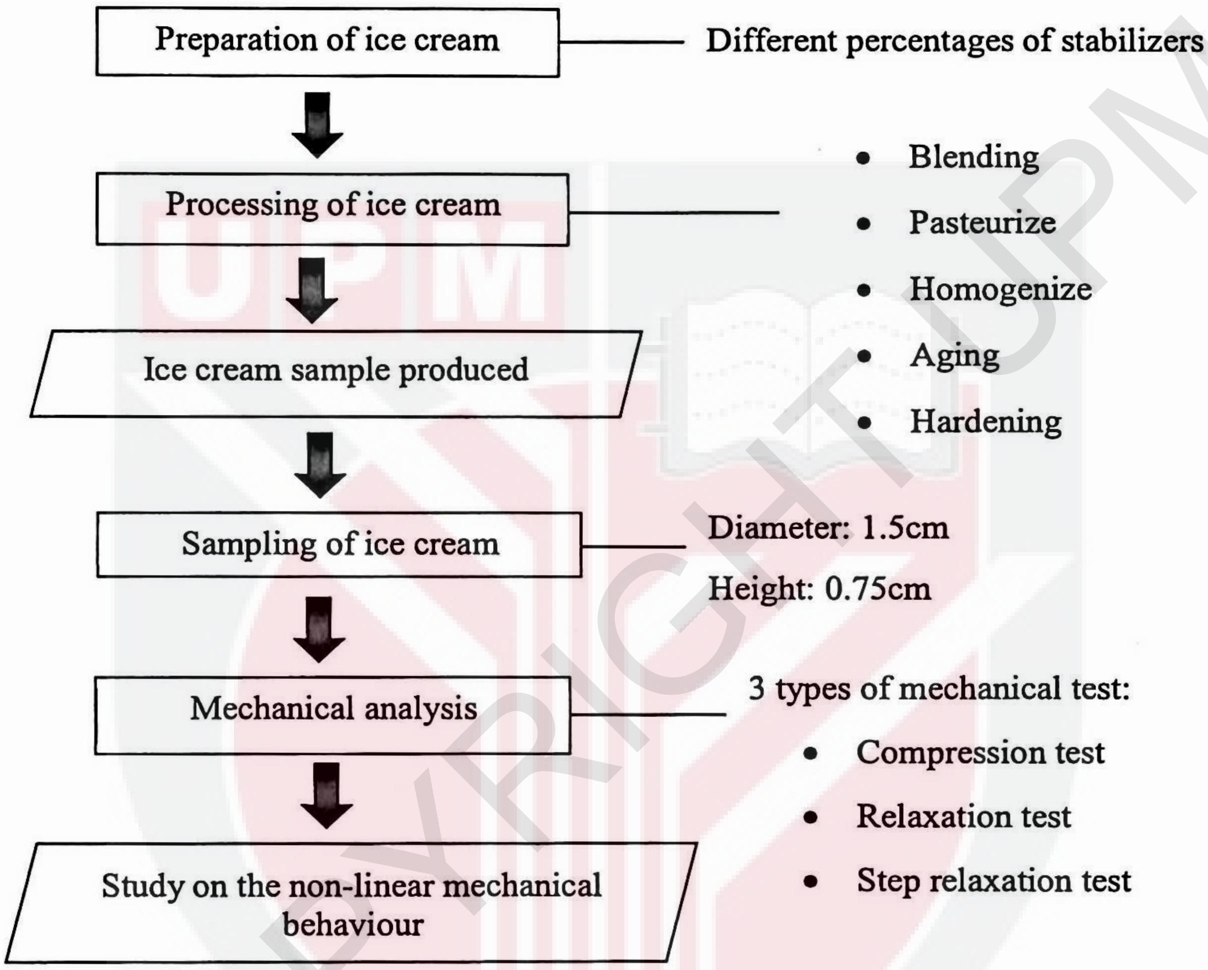


Figure 1: Scope of study

1.6 Conclusion

In conclusion, this chapter had discussed the introduction and briefly explained regarding the background of ice cream. In addition, the whole problem statement and the main objectives had been explained briefly as well.

CHAPTER 2: LITERATURE REVIEW

This chapter focused on the literature review of the ice cream based on the journals papers, review paper and also the website that can be referred. Besides, this section also briefly discussed the theoretical parts which is related to the scope of the project.

2.1 Overview of the ice cream

Basically, ice cream is a frozen dairy product which is popular across the age. Freezing and whipping processes are found to be a crucial factors in order to obtain high quality of ice cream based on its structure, texture and palatability. A typical ice cream consists of milk fat, milk solid non-fat (MSNF), sweeteners, stabilizers, colours, emulsifiers and water.

2.2 Ice cream basic ingredients

In the following subsections, the ingredients to make ice cream were explained briefly based on the literature review. The subsections consists of milk fat, milk solid nonfat, sweeteners, stabilizers, emulsifiers, water and air.

2.2.1 Milk fat

The first ingredients in the ice cream formulation is milk fat. Milk fat can be consider as one of the major ingredients in the ice cream constituents and can be refer as butterfat. Milk fat composition in ice cream is the second highest after the water composition. According to Goff (2004), the range of milk fat in the ice cream formulation is 10 percent to the 16 percent. Besides, the composition of milk fat can be varied based on the type of ice cream products manufactured (Fiol *et al.*, 2016) .The formulation of the milk fat in the ice cream should follow the legal standard in certain countries and districts. Based on Food Regulation 1985 (updated in 2014), it stated that ice cream composition should not contains less that 10 percent of milk fat or vegetable fat or combination of both of the ingredients. High content of fat in the ice cream will provide creamy texture and richer taste. However, the milk fat composition should not exceed 16 percent due to the consumer health consideration. If exceed 16 percent, the ice cream produced would be very high in calories and the production of ice cream will be costly as well.

The function of the milk fat in ice cream formulation is mainly for the structure and texture of the ice cream with the appropriate solid fat content. It also can provide the ice cream, with good melting properties and lubrication by lubricating the freezer barrel during frozen process ice cream. Milk fat can provide good melting properties due to its role in the fat destabilization.

Furthermore, McGhee *et al.*, (2015) stated that the important characteristic in the sensory quality and consumer acceptability of ice cream is the texture, and the reduction of the milk fat can cause the defects in the texture and flavour such as coarseness and iciness, crumbly body, shrinkage and flavours defect in dairy food including ice cream. Aboulfazli (2015) stated that the milk fat used in the ice cream usually is cow's milk and it cannot be eaten by the consumers who suffer from lactose intolerance. By replacing cow's milk with the vegetable milk, it would help address the nutritional issues related to the cow's milk which is lactose intolerant and high cholesterol content.

Above all, there are some limitations on milk fat constituents in the ice cream formulation. It contributed in higher manufacturing cost, hindered whipping ability, decreased on consumption because of richness and has negative effect on health due to high calories (Goff & Hartel, 2013).

2.2.2 Milk solid non fat

Milk solid non-fat (MSNF) or known as protein ingredient. It also consists of lactose, caseins, whey proteins, minerals, vitamins, and other minor components of the milk or milk products that had been derived from the certain sources (Deosarkar *et al.*, 2015) . MSNF has significant contribution to the flavour and texture of the ice cream. Besides, the common sources for the MSNF in the ice cream formulation can be obtained from fresh milk, whey proteins, buttermilk, concentrated milk and also dry milk powder. The composition of the MSNF is inversely with the fat content. Goff and Hartel (2013) revealed that as the fat and total solid content increased, concentrations of the MSNF levels, corn syrups solids, stabilizers and emulsifiers are all generally reduced to maintain the viscosity at lower level and optimize textural quality. The composition of the MSNF can be vary from 6 percent to 14 percent or more (Goff & Hartel, 2013).

Milk solid non-fat can be obtained from the fresh milk. Fresh milk contains approximately 87 percent of water, and other constituents in the fresh milk such as minor proteins, enzymes, minerals, vitamins, proteins, fat and also carbohydrate (Anynomous, 2011). Buttermilk can be one of the source of the MSNF for the ice cream formulation as well. Buttermilk can be defined as the dairy ingredient that is widely used in the food industry because of its emulsifying capacity and positive impact on flavour. In the dairy industry, buttermilk also can be used for the cheese production (Sodini *et al.*, 2006) . Skimmed milk powder can also be the source for the MSNF. Skimmed milk is widely used in the ice cream formulation because of its low cost. However, it has its own pros and cons. Based on Goff and Hartel (2013), the storability, availability and low moisture content of skim milk powder are some of the advantages, but being hygroscopic and prone to oxidize will be the downside as it must be protected well from moisture, heat and oxygen during storage.

Besides, MSNF may enhance the flavour and texture of the ice cream. Proteins in the MSNF will help to give shape and smooth texture to the ice cream, through emulsification of fat, foam formation and stability of air bubbles and viscosity enhancement in the unfrozen phase (Goff & Hartel, 2013). Viscosity of the mixture is enhanced due to the water binding capacity of proteins, which can help to produce a desired body to ice cream, increase meltdown time of ice cream and contributes to reduce iciness (Deosarkar *et al.*, 2015) .

2.2.3 Sweeteners

Other ingredient of the ice cream formulation is the sweeteners. The sweeteners is added to the ice cream to add for its sweet taste and enhance the consumer palatability. The sources of the sweeteners can be from cane and beet sugars, many types of corn sweeteners, maple sugar, honey and other types of sugar. Goff and Hartel (2013) found that the common choice of the sweetener in the ice cream mixture is the combination of 10 to 12 percent sucrose and 3 to 5 percent corn sweeteners which is derived from the corn starch.

The most common sweetening agent used is sucrose. It provides sweetness, depresses freezing point, affect freezing performance, affects body and texture, enhance flavours and contribute to the bulk or total solids and impacts on economics (Deosarkar et al., 2015). Generally, the desirable sweetness in ice cream is around 13 to 16 percent of added sucrose (Goff & Hartel, 2013).

In addition, the sweetness relies on the concentration of sweetener in the water of the mixture. Thus, decrease in the amount of water is equal to an increase in the amount of sweetness. The dissolved sweeteners will lower the freezing point of the mixture and increased the rate of melting for the ice cream. High levels of the sweeteners can also likewise lessen whip capacity, and essential for batch freezer operation. Major considerations in blending sweeteners are relative sweetness, which contributed to the total solids, and freezing point depression of the mix (Goff & Hartel, 2013).

2.2.4 Stabilizers

Other ingredients in the ice cream formulation is stabilizers. Stabilizers are a group of ingredients usually polysaccharides which is commonly used in ice cream formulations. The stabilizers must had a clean, impartial flavour, not bind to ice cream flavours, contribute to the meltdown of ice cream and provide desirable texture upon consumption (Goff & Hartel, 2013). The stabilizers also can promote the better flavour release and prevent the air bubbles from collapsing and hold flavouring compound in dispersion (Moeenfard & Tehrani, 2008) .The stabilizers structure are all very large and bulky macromolecules. They have a great ability to interact with water through hydration and swelling thus occupying a large solution volume and at sufficient concentration, entangling and interacting with each other (Goff & Hartel, 2013).

The main advantages of the stabilizers in the ice cream is that its ability to retard or reduce the ice and lactose crystal growth during storage especially during the periods of temperature fluctuation known as heat. The stabilizer also consist the disadvantages whereas the excessive in the mix viscosity will contribute to heavy, soggy body and production of undesirable melting characteristics (Goff & Hartel, 2013).

Besides, there are different stabilizers used in the ice cream formulation. The stabilizing ingredients which are mostly used in the frozen dairy foods are guar gums, CMC, sodium and propylene glycol alginates, xanthan gum, gelatin and carrageenan (Moeenfard & Tehrani, 2008) .Usually 0.2 to 0.5 percent of a stabilizers composition is used in the ice cream mix (Goff & Hartel, 2013).

The commercial stabilizers used in this project is Carboxy Methyl Cellulose (CMC). The CMC is comprised of the glucose monomers, but not digestible by humans nor is it soluble. To make it soluble and useful, cellulose is derivative by adding side group constituents such as carboxymethyl groups, which open up the backbone structure of the polymer (Goff & Hartel, 2013). The advantage of CMC is that it is easily dissolved in the mix and has a high water-holding capacity so it is considered a very good ice cream stabilizer.

2.2.5 Emulsifier

Emulsifier also one of the ingredient in the ice cream formulation. The emulsifier is defined as the substance that produce a stable suspension of two liquid that do not mix naturally, usually oil and water (Goff & Hartel, 2013). Emulsifier also play an important role in the fat destabilization process. Based on Goff and Hartel (2013), the mechanism of action in promoting the fat destabilization is that the emulsifier will lower the fat or the water interfacial tension in the mix, thus resulting in the protein displacement from the fat globule surface, hence it will reduce the stability of the fat globule which can allowing the partial coalescence during the whipping and freezing process. Goff and Jordan (1989) also state that these mechanism will lead to the formation of a structure of fat in the products that will greatly contribute to the texture and meltdown properties.

Goff and Hartel (2013) found that about 0.1 to 0.3 percent emulsifiers are typically added to ice cream mix to help destabilize the emulsion. They further state that these small molecular weight surfactants, typically mono- and di-glycerides will lower the surface tension more drastically than proteins at much lower concentration. And usually emulsifier and stabilizer will blend together but with different functions for each (Moeenfard & Tehrani ,2008).

The advantages of using stabilizers can be in many forms which are the properties in the fat destabilization will help to enhance desirable qualities in ice cream by enhancing whipping ability, increasing overrun capacity, reducing whipping time, improving resistance to meltdown, reducing ice crystal growth, increasing dryness and stiffness, imparting a smooth texture and a desirable slightly greasy mouth feel and enhancing product uniformity (Moeenfard & Tehrani, 2008).

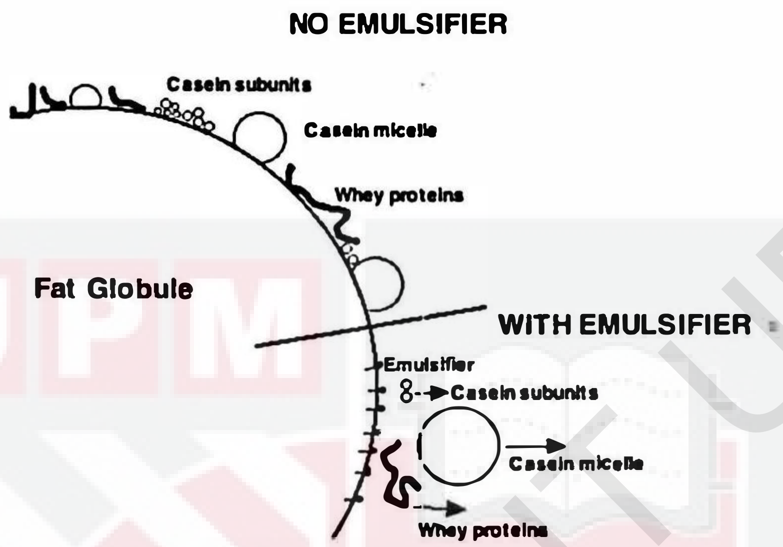


Figure 2: A schematic diagram of fat globule stabilized with and without emulsifier (Goff, 2015)

2.2.6 Water and air

Water is the highest proportion in the ice cream formulation with the percentage of 55 to 64 percent (Goff, 2015). If water is used, it must be high quality and potable, free of contamination. Water varies in pH, alkalinity, and hardness, but unless any of these parameters are extreme, water does not need to be chemically treated (Goff & Hartel, 2013). Most of the water also will be converted into ice during the freezing and hardening process.

Goff and Hartel (2013) further stated that the interface of water and air is stabilized by thin unfrozen material which consists of proteins and emulsifier and by churning of fat globules. Then, the air content in the ice cream are known as the overrun. This air is in a form of the microscopic bubble and these bubbles need to be properly formed and stabilized during manufacturing. Also, Xinyi *et al* (2010) stated that controlling the air incorporated into ice cream is critical for product quality and stability. Goff and Hartel (2013) also stated that the air is incorporated and air cells are formed simultaneously with the freezing during the freezing operations.

2.3 Ice cream processing

The ice cream processing process consists of six main steps which are blending or mixing, pasteurization, homogenization, aging, freezing and hardening. Also, the ice cream processing can be divided into two major stages which are mix processing and freezing processing.

The mix processing includes the blending of dry and wet ingredients, pasteurization, homogenization, and aging. The other stage which is freezing processing will included the freezing and hardening process. All of these steps in the ice cream processing consist their own purpose to control the quality of the ice cream that will be produced. The processing details of the ice cream production can be seen in Figure 3.

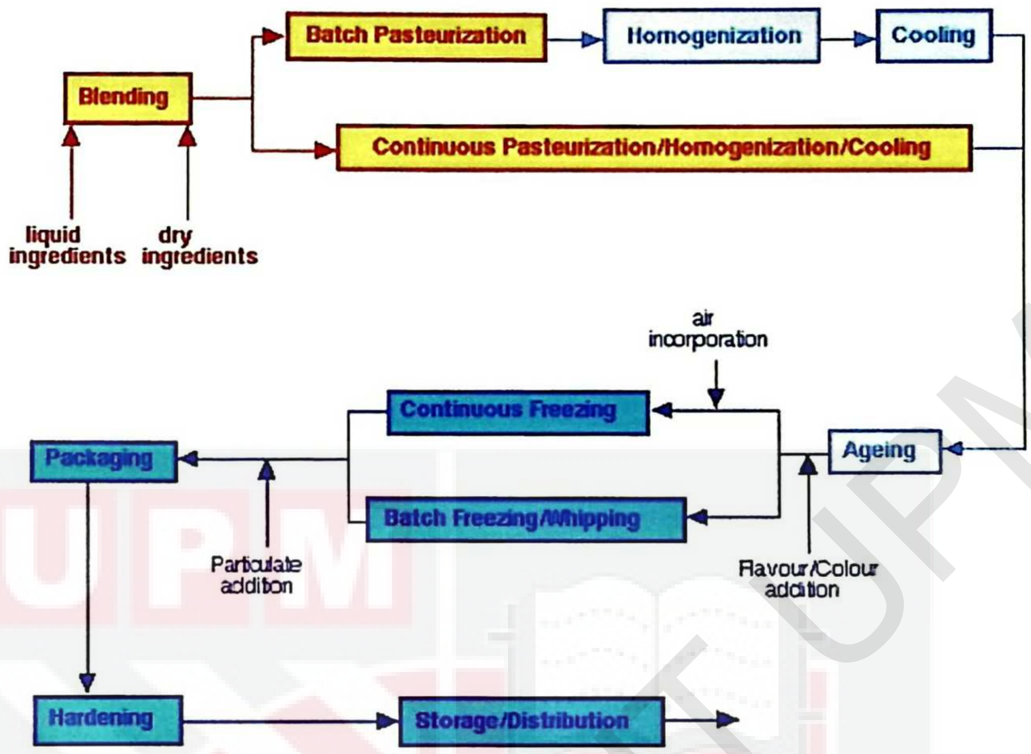


Figure 3: Schematic flow diagram of ice cream processing (Goff, 2015)

2.3.1 Blending

The purpose of the blending process is to mix the dry and wet ingredients for the production of ice cream. Then, as for the blending process, all liquid ingredients such as milk, cream, concentrated milk and syrup are placed in the vat, and the agitation and heating are started at once. Amounts of liquid ingredients can be measured with a calibrated measuring stick, pumped through a volumetric or mass flow meter, or directly added as predetermined volumes or weights (Goff & Hartel, 2013). The ingredients usually selected by the desired formulation and the calculation of the recipe from the formulation and ingredients is chosen (Goff, 2015).

Also, to facilitate the operation with a fully liquid system, it is often necessary to dissolve the dry ingredients. The dry ingredients is not liquefied first, they should be added while the liquid materials are being agitated and before the temperature reaches 50° C. The lumpiness of the dry ingredients can be avoided by mixing the dry ingredients with the part of crystalline sugar before adding slowly to the liquid or by sifting slowly into the liquid vat. Also, stabilizer is one of the ingredient that is difficult to dissolve in the mixture. Stabilizer are best dispersed into a mixture of low water activity which is 0.86 or lower such as liquid sugar or corn syrup with about 70 percent solids (Goff & Hartel, 2013).

2.3.2 Pasteurization

For the pasteurization process, it acts as the process to destroy all pathogenic bacteria and reduce the risk of microorganisms in the ice cream product. It is crucial for the safety of the ice cream product for the consumers. Goff and Hartel (2013) also state that the purpose of pasteurization are to renders the mix substantially free of vegetative microorganisms, killing all the pathogens likely to be in the ingredients, brings solids into solution, aids in blending by melting the fat and decreasing the viscosity, improves flavour of most mixes, extends keeping quality to a few weeks, and increases the uniformity of product.

Besides, pasteurizations process can be divided into two basic ways which is batch or low temperature long time (LTLT) and continuous or high temperature short time (HTST). For the first method which is the batch, the mixture of the ingredients usually compounded in the vat, which is the jacketed typically in the volume of 600-2 000 litre in size. Goff and Hartel (2013) state that the smaller tanks will typically have a paddle agitator while larger ones may need a swept wall agitator to ensure good mixing and heat transfer. They further state that during the pasteurization process, heat is applied by circulating the hot water between the double walls of the vat, while the ingredients is being added and blended. When the ingredients reach the necessary pasteurization temperature, holding time begins (Hui, 2005).

The second method which is the continuous pasteurization which can be done based on several temperature combinations such as HTST and ultra-high temperature (UHT) processes. In the HTST design, three heat exchanger sections exist which is regenerator, heating and cooling. In the HTST pasteurizer, further cooling and heating need to occur to allow the ice cream mix to achieve the target temperature (Spreer, 1998). The advantages of the HTST and the continuous pasteurization process is that the cross-contamination can be avoided due to the three sections of the heat exchanger designation.

2.3.3 Homogenization

Further processing of ice cream is the homogenization process. The homogenization process is crucial to make a stable and uniform suspension of the fat by reducing the size of the fat globules to less than 2μm (Goff & Hartel, 2013). The reason of the homogenization process mostly to produce the creamy and smooth texture of the ice cream whereas there is no cream layer of fat rise on the products.

Spreer (1998) states that the principle of homogenization is to force the liquid to flow under the high pressure though the narrow orifice, usually just slightly larger than the diameter of the particle to be homogenized. He further state that the factors that affect the overall homogenization include pressure, temperature, orifice size and design. Goff (2015) stated that the two stage homogenization usually preferred for ice cream mix. The first stage homogenization should be in the pressure of 2000-2500 psi and the 500-1000 psi for the second stage.

Also, the advantages of the homogenization process include the greater surface area of the fat globules, viscosity enhancement, and greater stability (Bodyfelt *et al.*, 1998). There is also the disadvantages of the homogenization process in which the homogenized milk fat are more sensitive to light induced oxidation and also the protein stability can be affected (Spreer, 1998).

2.3.4 Ageing

The ageing process in the ice cream processing also one of the crucial process to produce the ice cream. The aging process is needed as pasteurization and homogenization change the physical forms of the suspended solid of ice cream mixes (Goff & Hartel, 2013). The pasteurization melts all the fats in the ice cream and the homogenization reduce the fat globules diameter.

The aging process mostly take place at temperature lower than 4°C and between 4 to 24 hours. The objectives of the cooling and maintaining the cold temperature to prevent the microbial growth (Fellows, 2000).

Besides, during the aging process, there is the fat crystallization occur in the ice cream formulation. The fat start to crystallize from inside of the fat droplets. It will form the needle like structure within the droplets. Fat crystallization is important for the stabilization of the air bubbles in the ice cream. The fat crystallization generally requires up to 4 hour for complete crystallization (Goff & Hartel, 2013).

2.3.5 Freezing

The freezing process in the ice cream processing is important to produce the smooth texture of the ice cream. The freezing process mostly occur in the freezer with the temperature of -6ºC. The purpose of freezing ice cream is twofold formation of the foam structure and initiation of the freezing process (Marshall & Arbuckle, 1996).

During the freezing process, the ice crystal are formed, and both of the dispersion of the air bubbles and rearrangement of the fat globules also occur (Goff & Hartel, 2013). The process of whipping also happened during the freezing process. As the freezer is turned on, the dasher moves in a circular manner, agitating and whipping the mix and forcing the mix into contact with the cold barrel wall (Hui, 2005). The mix also contacts the barrel wall and freezes along the cold surfaces and the dasher scrape the thin layer of frozen mix from the surface of the barrel and re-suspend the frozen mix in the unfrozen mix (Marshall & Arbuckle, 1996).

And as the more mixture of the ice cream cools and freezes, the air will be incorporated and the agitation of the barrel will force air into the frozen mix that contains the small ice crystal thus producing the frozen foam known as ice cream. Goff (1999) state that the foam is formed as the fat globules destabilizes and aggregate around air bubbles, providing stability to the foam. The amount of the air whipped into the product is called as the overrun. The overrun is important to keep the texture of ice cream to be smooth and fit to the consumer palatability.

Other than that, there are several types of freezer used for the freezing process which is the batch and continuous freezer. For the continuous freezer, the mix are continuously pumps into the freezer barrel and extrudes ice cream form the barrel. For the batch freezer, Marshall & Arbuckle (1996) state that the specific quantity is added to the freezer and then the refrigerant and agitator started. Once the desired frozen products discharged, then the process is repeated with a new batch of mix. And mostly in the production of the commercial ice cream, the ice cream is frozen in the continuous freezer style as the product can be discharged at constant speed (Hui, 2005).

2.3.6 Hardening

For the hardening process, it is the continuity from the freezing process. For this reason, ice cream from the freezer is in semi-solid consistency and not stiff enough to hold its shape. Thus, the hardening process is continued in containers without agitation until temperature reaches -18ºC or lower preferably -25ºC to -30ºC (Goff & Hartel, 2013).

Most of the water in the ice cream will turn into ice during hardening. Then, about 50 percent of the water is in the form of ice at draw temperature which is −5 to −6°C, and this increases to about 80 percent when the temperature has decreased to −18°C (Goff & Hartel, 2013). Typically, ice crystal size increases by about 30 to 40 percent during hardening (Goff & Hartel, 2013).

The growth of the ice crystal in the hardening process can be minimized the stabilizer in the ice cream as it increasing the viscosity of the mixture. Also, the air cell also change during hardening which is in the whipping and freezing process, the larger air cells are broken down into small bubbles. Hence, at the draw temperature, the small air cells are not stable and can easily coalesce into larger air cells in a process similar to the ice crystal (Goff & Hartel, 2013). Chang and Hartel (2002) also state that the rapid hardening also is needed to retain the smallest air cell that change during the hardening process.

2.4 Overview of compression analysis on ice cream

For the project, there were several compression analysis that can be performed on the ice cream. The compression test included the compression test, stress relaxation test and also step relaxation test. The mechanical test are crucial in determining the non-linear mechanical behaviour of the ice cream in terms of the tensile strength and also the viscosity of the ice cream.

2.4.1 Compression test

For the first mechanical test is the compression test. Also, the compression test is suitable for the gel specimens because it is simple and eliminates the problem of premature failure arising from clamping as in the tensile tests (Forte *et al.*, 2015). The compression behaviour also can be seen as the experimental result gained which is the stress-strain curve that will show the deformation of the gels.

In the other hand, with the non-Newtonian fluids, the measured viscosity depends up on the shear rate applied because of the internal structure of the sample breaks down to a progressively increasing extent as the shear rate is increased (Sherman, 1973). Also, they further state that for the evaluation of the textural properties using the mechanical method should depend on the mechanical condition associated with the test, as it is essential that the evaluation made is using the stress-strain method. Forte *et al* (2015) state that the higher rate of viscosity in gels will enables the materials to travel higher up on the stress-strain curves before fracture as in the Figure 4 below.

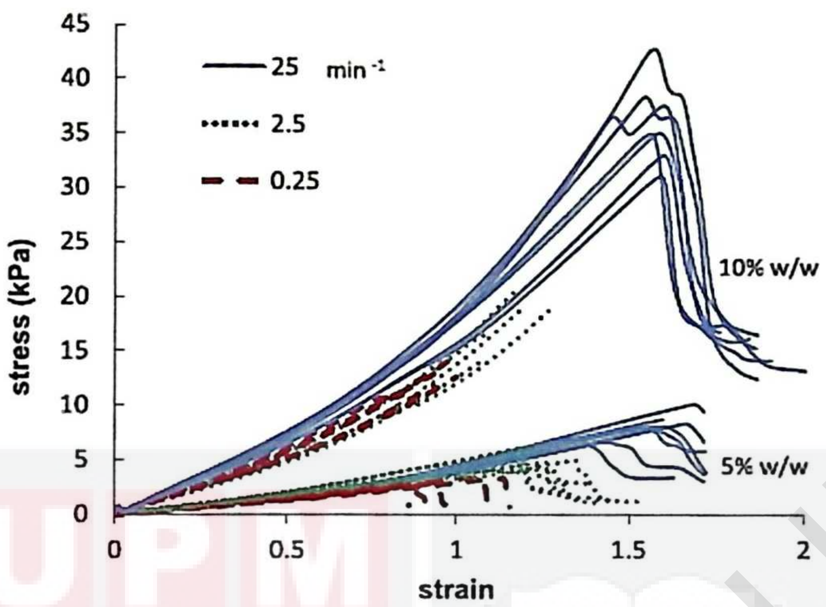


Figure 4: Stress-strain curve for different viscosity of gels (Forte *et al.*, 2015)

2.4.2 Stress relaxation test

For this stress relaxation test, the stress relaxation is defined by the materials deformation to a fixed strain and the strain is held constant. Then, the stress required to maintain the strain also decrease with time (Steffe, 1996).

Also, in this test, the stress is measured in the function of time as the material is subjected to a constant strain. This test can be conducted in shear, uniaxial tension or uniaxial compression. The Figure 5 will show the stress relaxation curved for the elastic, viscous and viscoelastic materials (Steffe, 1996).

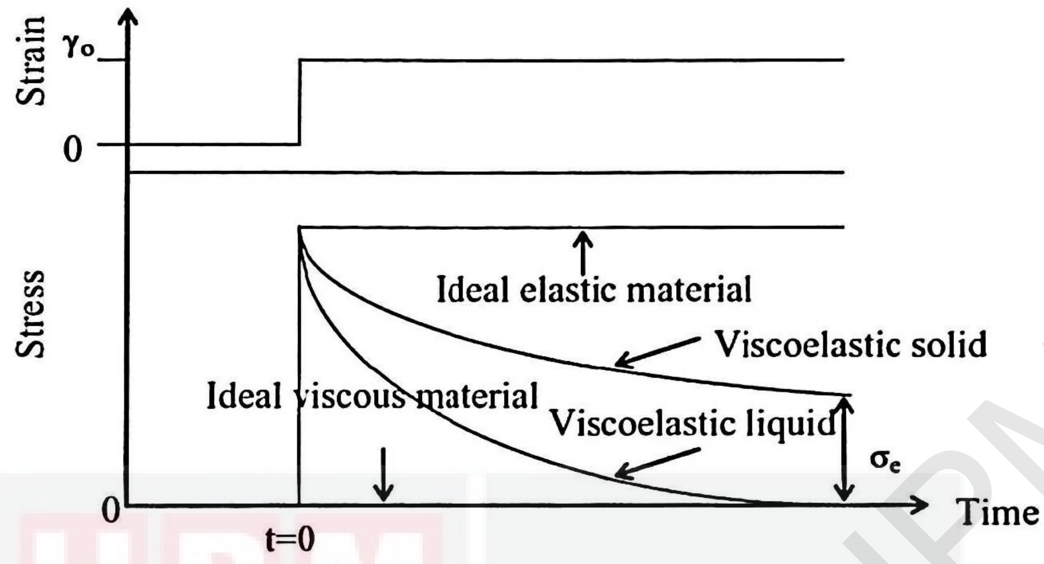


Figure 5: Stress relaxation curve for elastic, viscous and viscoelastic materials (Steffe, 1996)

Besides, this method has been primarily applied to study linear viscoelasticity of food materials, with little work done for yield stress measurements. One of the reasons is the pre-shearing required, which damages the material structure. Therefore, stress relaxation technique is suitable only for fluids whose yield stress is not dependent on shear history (Ak & Gunasekaran, 1992).

2.4.3 Step relaxation test

The other test is the step relaxation test. Step relaxation test can be defined as the experiments were conducted under constant cyclic strain range control with strain holds introduced at maximum and minimum strains (Zhan & Tong, 2007) .

Other than that, the relaxation due to cyclic loading is affected mainly by the initial magnitude and gradient of the residual stress field and degree of cold working, fatigue stress amplitude, mean stress ratio and number of cycles, and material cyclic stress–strain response and degree of cyclic work hardening and cyclic work softening (Zhuang & Halford, 2001).

And last but not least, the cyclic stress relaxation also need a better understanding of the mechanism of cyclic-dependent residual stress relaxation is needed to develop a physics-based relaxation model (Zhuang & Halford, 2001).

2.5 Non-linear mechanical properties of ice cream

As for the mechanical properties of the ice cream, the stabilizer variety in the percentages definitely give some impacts for the ice cream structure. The stabilizer can affect the mechanical and rheological properties for the ice cream formulation. Rheology is defined by the branch of physics concerned with the composition and structure of flowing and deformable materials (Bahramparvar & Tehrani, 2011). The rheological properties is like viscosity also influenced by the composition of the stabilizer.

Then, generally ice cream mixes exhibit non-Newtonian pseudo plastic behaviour, meaning that there is a nonlinear relationship between shear stress and shear rate, with the apparent viscosity decreasing with increasing shear rate (Bahramparvar & Tehrani, 2011). Also, many food materials exhibit the behaviour between the solid and liquid which can be called as the viscoelasticity. Ice cream mix usually is the viscous system where the ice cream possessed the viscoelastic properties system (Goff & Hartel, 2013).

Besides, the viscosity of the ice cream also increase as the percentages of stabilizers increase. There was significant difference in viscosity of samples with different stabilizers at different concentrations (Moeenfard & Tehrani, 2008). In terms of the overrun also, it is improving as the percentages of stabilizers increase. Moeenfard and Tehrani (2008)stated that in all samples of ice cream, the over-run increased significantly with an increase in the concentration of stabilizers. Other than that, Moeenfard and Tehrani (2008) stated that, as the sample concentration of stabilizers increased, the melting resistance also increase significantly.

2.6 Summary of the chapter

In conclusion, the chapter had briefly explained the detailed literature review regarding the scope of the project. The detailed explanation of the ice cream basic ingredients such as milk fat, milk solid nonfat, sweeteners, stabilizers, emulsifier, water and air had been discussed in the chapter. Other than that, the ice cream processing also had been discussed and referred to the journals for its detailed explanation. The processing consisted of the blending, pasteurization, homogenization, ageing, freezing and also hardening. And last but not least, the overview of the mechanical compression also had been discussed in the chapter alongside the non-linear mechanical behavior of ice cream.

CHAPTER 3: METHODOLOGY

This chapter explained the method of the project. The method consists of steps in preparing ice cream with different percentages of stabilizer. Also, the ice cream mix formulation are shown in this chapter. The analysis which are the compression test, stress relaxation test and step relaxation test were conducted and compared with each other. Data obtained from the analysis was recorded and used for the analysis of the non-linear mechanical behavior of ice cream.

3.1 Stage 1: Preparation of an ice cream mix

The preparation of the ice cream took place in the laboratory. Ice cream mix was prepared based on the formulation. The detailed formulation of the different percentages of stabilizer as shown in Table 1.

3.1.1 Ice cream mix formula

The aim of the project was to vary the percentages of stabilizer in the ice cream mix. Jagdish *et al* (2015) stated that guar gum was incorporated in the ice cream mix at four different level which are 0.1, 0.2, 0.3 and 0.4 percent.

Hence, the sample for the ice cream mix was prepared by using the formulation and of stabilizers based on the literature review. Four samples were prepared to study the mechanical properties and the non-linear mechanical behaviour of ice cream. The formulation used for the ice cream mix is shown in Table 1.

Table 1: Ice cream mix formulation

Ingredients	Sources	Weight composition (%)	Mass for each batch of 750g (g)
Water	KK Natural Mineral Water	28.9	216.75
Full cream milk	Dutch Lady Sdn Bhd, Malaysia	46.5	348.75
Creamer	Rakan, Malaysia	3.6	27.00
Whey powder	Allstarz Resources Sdn Bhd, Malaysia	3.6	27.00
Sugar	Gula Prai, Malaysia	16.3	122.25
Emulsifier	Super 88, Malaysia	0.4	3.00
Stabilizer	CMC	0.3	2.25
Vanilla Flavouring	-	0.4	3.00

The formulations for the ice cream mix with different percentages of stabilizer also can be referred in Table 2. Four samples of ice cream mix was prepared for the mechanical analysis.

Table 2: Formulation of different percentages of stabilizers

Sample	Weight composition of stabilizers (%)	Mass for each batch of 750g (g)
1	0.1	0.75
2	0.2	1.50
3	0.3	2.25
4	0.4	3.00

3.2 Stage 2: Production of Ice Cream

Stage 2 where the process to produce the sample of ice cream took place. The processing of the ice cream include the blending process of the dry and wet ingredients. Then, the process continued with the pasteurization, homogenization, ageing, freezing and hardening. Detail process was discussed briefly in the subsections below.

3.2.1 Weighing

The dry ingredients such as creamer, whey powder, sugar, emulsifier, stabilizer and vanilla powder were weighed using a weighing balance before put them together into the mixing bowl. The weighing process were done by referring to the formulation in the Table 2 that had been calculated based on the general formulation of ice cream mix.

3.2.2 Blending and mixing

The sample formulation of ice cream mix was pre-mixed and blended using the blender (Khind, Model BL1515, Malaysia) for 5 minutes. The purposed is to mix the dry ingredients and wet ingredients together.

3.2.3 Pasteurization

After blending and mixing, the sample mixture was pasteurized. The mixture was pasteurized for 10 to 15 minutes on a stove until reached a temperature of 80° C as shown in Figure 7 and until the mixture of ice cream mix simmered. The pasteurization process of ice cream is shown in the Figure 6.

Figure 6: Pasteurization of ice cream making process

Figure 7: Temperature after pasteurization process

3.2.4 Homogenization

The mixture immediately put into a beaker to undergo homogenization process. The mixture was homogenized with homogenizer (Success Technic Industries, Model WT500, Malaysia) at 12 000 rpm at first stage for 150 seconds and then reduced to 10 000 rpm at second stages for another 150 seconds. Figure 8 shows the homogenization process of the ice cream making process. It was found that the small bubbles formed on the surface of ice cream mix after the process as shown in Figure 9.

Figure 8: Homogenization process of the ice cream making process

Figure 9: Ice cream mix after homogenization process

3.2.5 Ageing

The ice cream mix was poured into small container for ageing and put inside chiller at controlled temperature of 4° C overnight. The ice cream mix ageing process is shown in Figure 10.

Figure 10: Ice cream mix for ageing process

3.2.6 Freezing and churning

On the next day, the aged ice cream mix was whipped and frozen in the ice cream freezer (Breville, Model BC1600, Australia). The freezer was run under freezing and cooling conditions until the temperature of the product was lowered to the desired draw temperature of -5° C. Figure 11 shows the ice cream processing during the freezing and churning process.

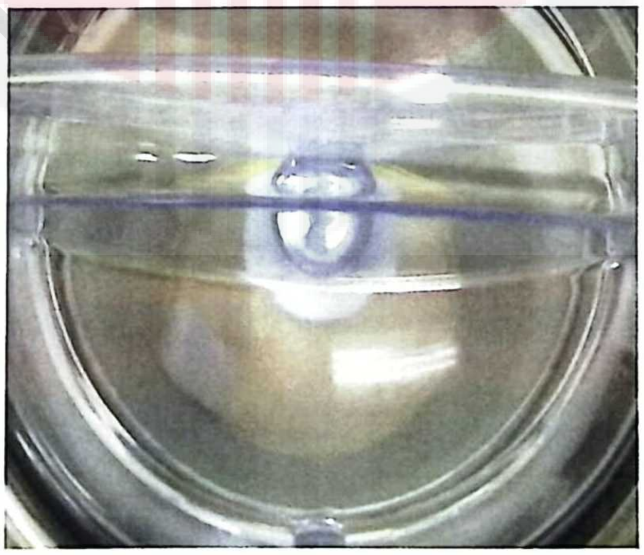


Figure 11: Ice cream churning and freezing process

3.2.7 Hardening

After the churning and freezing process, the ice cream was filled into the air-tight container and hardened in the freezer at -18° C to -25° C for at least 24 hours. Figure 12 shows the ice cream sample for the hardening process after the freezing and churning process.

Figure 12: Ice cream for hardening process

3.3 Stage 3: Mechanical analysis of ice cream

The mechanical analysis was performed on the sample of the hardened ice cream. The mechanical testing was done in the freezer at -10° C to -12° C using the Lego Mindstorm EV3 to prevent the ice cream from melting. Figure 13 shows the Lego Mindstorm EV3 for the compression test analysis.

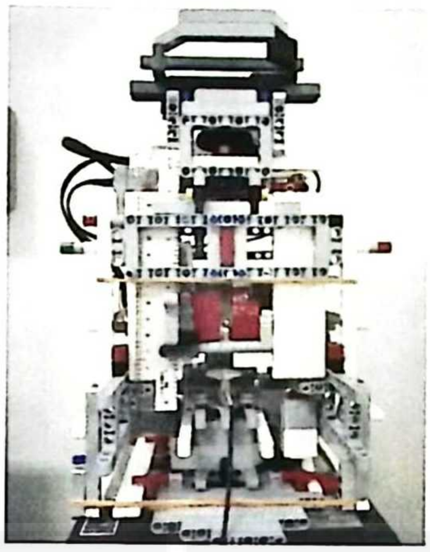


Figure 13: Lego Mindstorm EV3 for compression testing

The mechanical test performed were the compression test, stress relaxation test and step relaxation test. The detailed testing analysis method explained in the subsections above.

3.3.1 Preparation sample of ice cream

The sample of ice cream for the mechanical testing was prepared. Size of the ice cream sampling were set at the diameter of 1.5 cm and height of 0.75 cm. The small size of the ice cream sample was to fit with the small probe used for the Lego compression testing. The ice cream was melted into the semi-liquid form and put into an ice cream plastic and placed inside the freezer. Then, the ice cream sample was cut into small pieces based on diameter and height. The sample of ice cream for the mechanical testing is shown in Figure 13. The small sample that had been cut is shown in Figure 14.

Figure 14: Ice cream sample for mechanical testing

Figure 15: Ice cream sample after cut into small pieces

3.3.2 Compression test

The first test performed was the compression test. The compression test used the Matlab coding to operate the Lego. The compression test was done in three speeds which were 0.1 mm/s, 0.2 mm/s and 0.6 mm/s. The time interval used for the data gained was 0.1 s. All sample of ice cream with different percentage of stabilizers were tested using the same analysis for the compression test. Table 3 shows the detailed parameter used in the mechanical compression testing method. The analysis using the Lego shown in Figure 16 which was the process of mechanical compression test and Figure 17 shows the sample after the compression test.

Table 3: Runtime used for each speed

Speed (mm/s)	Sample of ice cream (%)	Runtime for each displacement (s)
0.1	0.1 0.2 0.3 0.4	Displaced 1mm : 10 s Displaced 3mm : 30 s Displaced 5mm : 50 s
0.2	0.1 0.2 0.3 0.4	Displaced 1mm : 5 s Displaced 3mm : 15 s Displaced 5mm : 25 s
0.6	0.1 0.2 0.3 0.4	Displaced 1mm : 1.7 s Displaced 3mm : 5 s Displaced 5mm : 8.3 s

Figure 16: Sample before the compression test

Figure 17: Sample after compression test

3.3.3 Stress relaxation test

The second test was the stress relaxation compression test. The stress relaxation compression test also used the Matlab coding to operate the Lego. The stress relaxation compression test was done in three speeds which were 0.1 mm/s, 0.2 mm/s and 0.6 mm/s. To add more, the time interval used for the data gained was 0.1 s. All sample of ice cream with different percentage of stabilizers were tested using the same analysis for the stress relaxation compression test. The Table 4 shows the detailed parameter used for the relax time used for each velocity regarding the stress relaxation compression testing method.

Table 4: Relax time for each speed

Speed (mm/s)	Sample of ice cream (%)	Runtime for each displacement (s)	Relax time (s)
0.1	0.1 0.2 0.3 0.4	Displaced 1mm : 10 s Displaced 3mm : 30 s Displaced 5mm : 50 s	30 s
0.2	0.1 0.2 0.3 0.4	Displaced 1mm : 5 s Displaced 3mm : 15 s Displaced 5mm : 25 s	60 s
0.6	0.1 0.2 0.3 0.4	Displaced 1mm : 1.7 s Displaced 3mm : 5 s Displaced 5mm : 8.3 s	60 s

3.3.4 Step relaxation test

The third test that performed was the step relaxation compression test. The step relaxation compression test also used the Matlab coding to operate the Lego. The step relaxation compression test was done in three speeds which were 0.1 mm/s, 0.2 mm/s and 0.6 mm/s. To add more, the time interval used for the data gained was 0.1 s. All sample of ice cream with different percentage of stabilizers were tested using the same analysis for the stress relaxation compression test. The Table 5 shows the detailed parameter used for the step relax time used for each velocity and the step needed in the database regarding the step relaxation compression testing method.

Table 5: Relax time and step relax for each speed

Speed (mm/s)	Sample of ice cream (%)	Runtime for each displacement (s)	Step relax time (s)	Step relax
0.1	0.1 0.2 0.3 0.4	Displaced 1mm : 10 s Displaced 3mm : 30 s Displaced 5mm : 50 s	10 s	5
0.2	0.1 0.2 0.3 0.4	Displaced 1mm : 5 s Displaced 3mm : 15 s Displaced 5mm : 25 s		
0.6	0.1 0.2 0.3 0.4	Displaced 1mm : 1.7 s Displaced 3mm : 5 s Displaced 5mm : 8.3 s		

3.4 Stage 4: Analysis on the non-linear mechanical behavior of ice cream

Stage 4 was the study of the non-linear mechanical behaviour from the mechanical properties analysis. Based on the mechanical analysis that had been performed, the viscosity and hardness of the ice cream was analysed by using the data gained which was the engineering stress-strain database. The result and the relationship for the non-linear mechanical behaviour were explained in Chapter 4.

3.5 Summary of the methodology

The ice cream sample using different percentages of stabilizer were prepared using the ice cream formulation shown in the Table 1 and Table 2. All the sample were prepared into small size to fit the probe for the Lego compression. Then, the samples were tested for their compression analysis which were compression test, stress relaxation test and step relaxation test. The results of the analysis were analyzed and the non-linear mechanical behavior were studied. The summary of the methodology is shown in Figure 18.

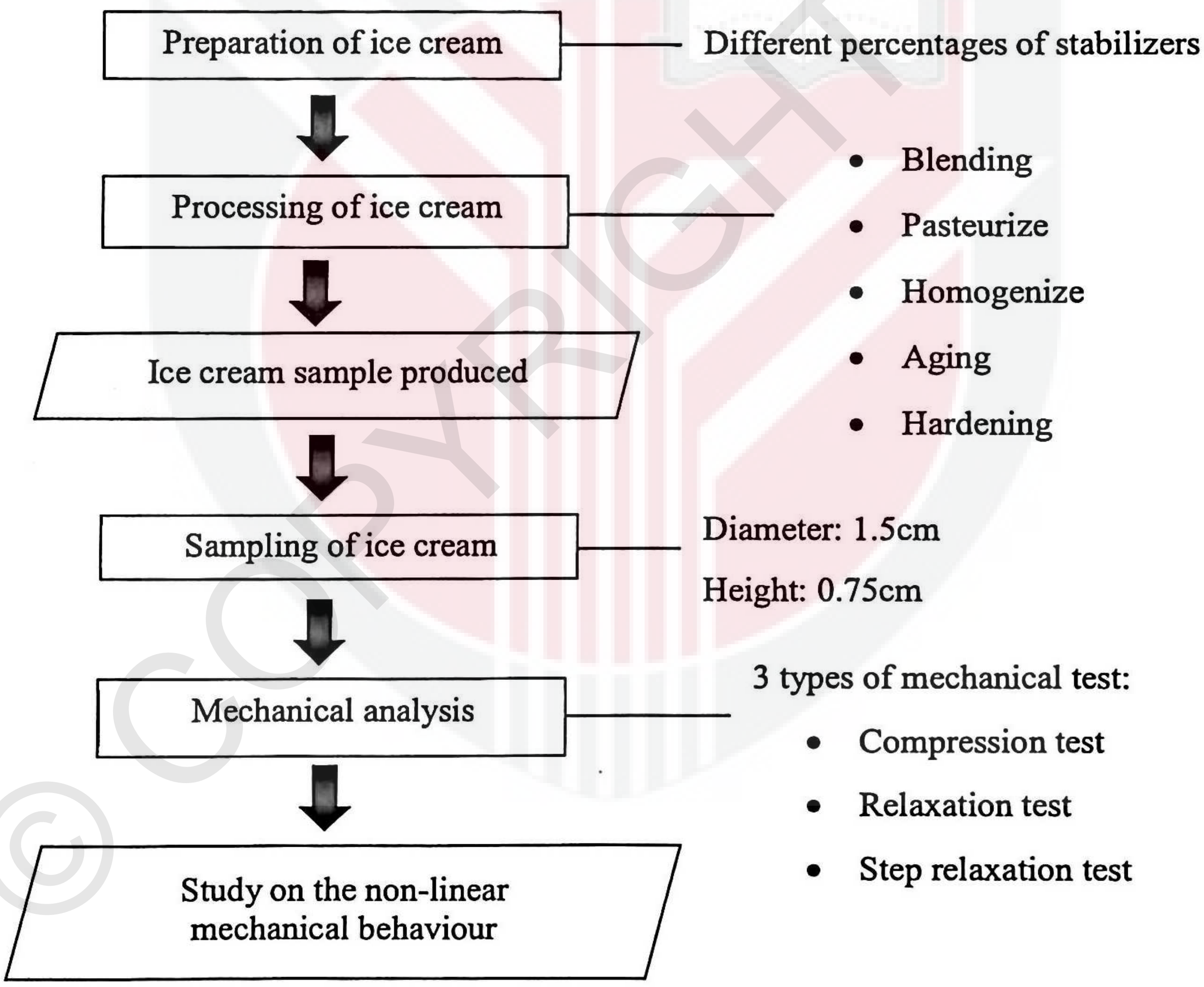


Figure 18: Flow chart of the research methods

CHAPTER 4: RESULTS AND DISCUSSION

This chapter consists of the results obtained from the analysis and experiment which was the mechanical test using the Lego. The mechanical tests consists of the compression test, stress relaxation test and step relaxation test. The results obtained will be discussed in this chapter.

4.1 Compression test

The compression test had been carried out following the research methodology. After the test were done, the graph of engineering stress and strain were plotted for different percentage of stabilizers. The graph of the engineering stress and strain showed the results of the parameter used which is the constant speed of 0.1 mm/s for each percentages of the stabilizers were plotted in Figure 19 to 21 to see the trend and peaks for those graphs.

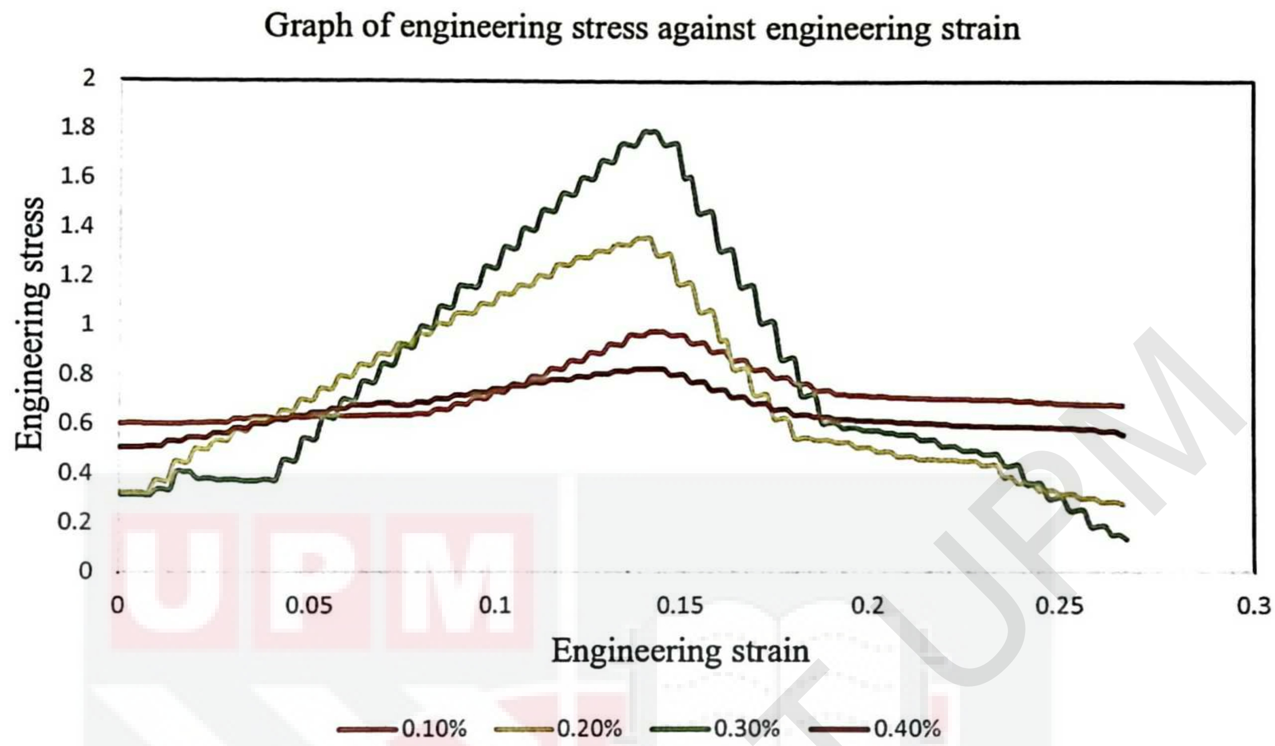


Figure 19: Engineering stress- strain curve for compression test (0.1mm/s) to displace 1mm with different percentages of stabilizers

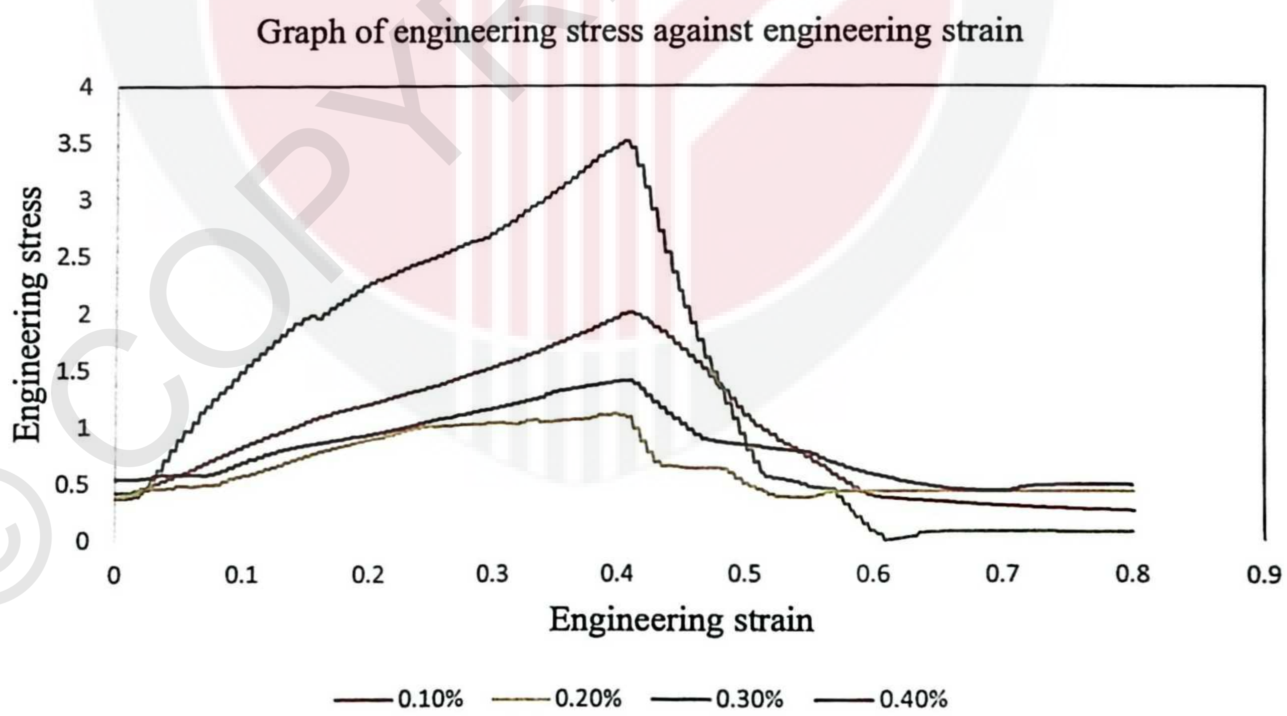


Figure 20: Engineering stress- strain curve for compression test (0.1mm/s) to displace 3mm with different percentages of stabilizers

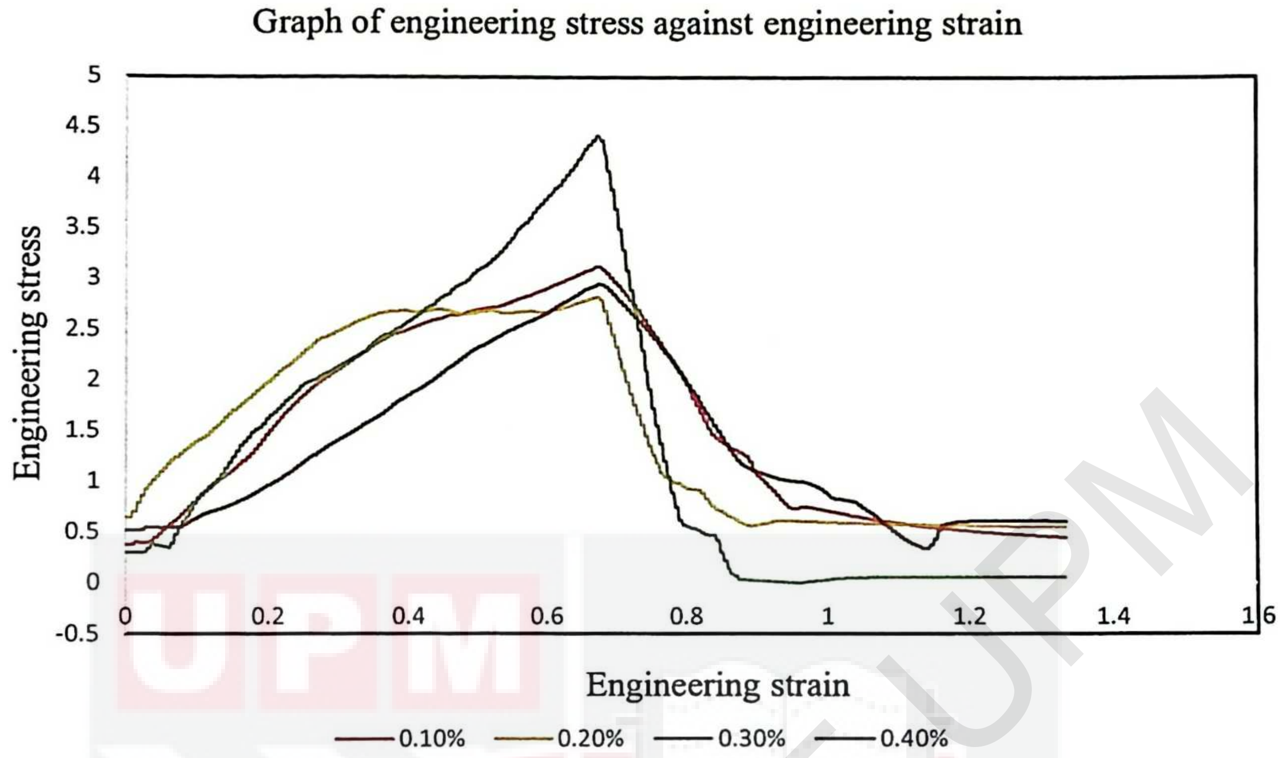


Figure 21: Engineering stress- strain curve for compression test (0.1mm/s) to displace 5mm with different percentages of stabilizers

The mechanical compression testing is important in determining the mechanical properties of the ice cream. Based on the Figure 19 to 21, the result of the different percentage of stabilizers were plotted to determine the characteristic. The speed of 0.1mm/s for the compression analysis was maintained for all three graphs. The displacement against time graph also plotted in the Appendix 5 to 16 shows the displacement of the ice cream sample linearly increased as the stress applied and held over a period of time.

Hence, the graph compared the three runtime for each of the stabilizers which were used to displace 1mm, 3mm, and 5mm of the ice cream sample. Displacement is defined as the change in position. For this test, the compression test displaced 1mm, 3mm and 5mm from the ice cream sample. Based on the results, it can be seen that in all graphs, the sample with concentration of 0.3 percent of stabilizers reached higher stress and strains before the curve fractured. The compressive strength to displace 5mm is the highest which is 4.33 N/m^2 as compared to the graph to displace 1mm and 3mm.

For this reason, the highest compressive strength might be because of the firmness of the sample with the high percentage of stabilizer compared with the other concentration which were 0.1 percent and 0.2 percent. It was reported that the an increase of the stabilizer content in the ice cream formulation will lead to an increase in the viscosity which has an important effect on the melting behaviour for the final product (Mahdian & Karazhian, 2012).

Furthermore, the other factor contributed to the higher compressive strength can be because of the hardness of the ice cream sample. Muse and Hartel (2004) stated that the hardness of ice cream can be affected by factors such as the overrun, ice crystal size, ice phase volume, and extent of fat destabilization. They further stated that both the ice crystal size and ice phase volume will contribute to the hardness of ice cream. Then, for the compression analysis to displace the 5mm of the sample, for surely it needed higher compressive stress due to the hardness and firmness of the sample. Clarke (2004) stated that high yield stress indicates strong material.

However, based on the results obtained, the graphs varied and it was perhaps inaccurate to be referred. It also can be seen that the graph dropped drastically after the fixed time for the stress applied. It was due to the mistake during the sample preparation of the ice cream. The sample prepared were melted and refreeze that affected the structure of the ice cream thus affected the results of the compression test done. Flores and Goff (1999) stated that recrystallization can affect the structure of the ice cream as its basically involve the disappearance of the small crystals in the ice cream and the growing of the large crystals in the ice cream. Hence, it will form the structure of ice crystal with the irregular shapes and also large surface area.

Hence, the structure of the ice cream also will be harder and coarse compared to the other ice cream. That was one of the reason of the varied in the results obtained and the caused the inaccuracy for the results. In addition, stabilizer also can help in the control of the ice cream recrystallization as it can prevent the crystals growth during the temperature fluctuation. However, Flores and Goff (1999) stated that migratory recrystallization is predominant mechanism in the ice cream that even stabilizer cannot prevent the crystal growth but rather delay the recrystallization process.

4.2 Stress relaxation test

The stress relaxation test had been carried out. And, the graph of engineering stress against time were plotted for different percentages of stabilizer. The graph of the engineering stress against time showed the results of the constant parameter used which was the speed of 0.6 mm/s for each percentages of the stabilizer were plotted in Figure 22 to 24 to see the trend and peaks for those graphs.

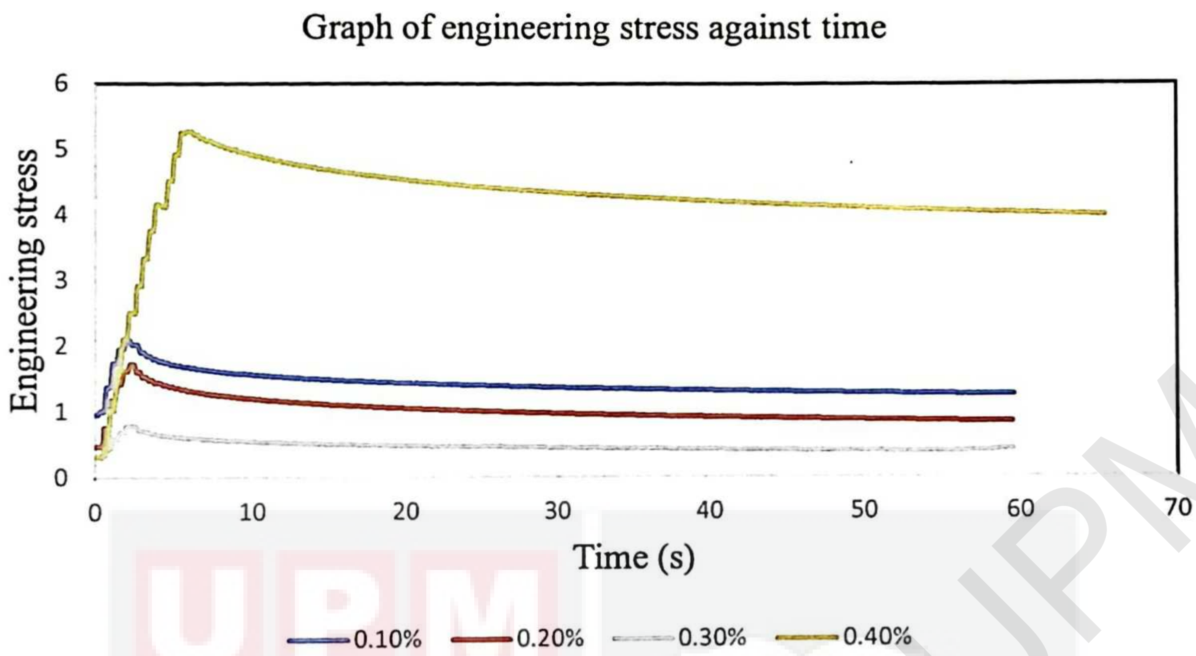


Figure 22: Engineering stress against time curve for stress relaxation compression test (0.6mm/s) to displace 1mm with different percentages of stabilizers

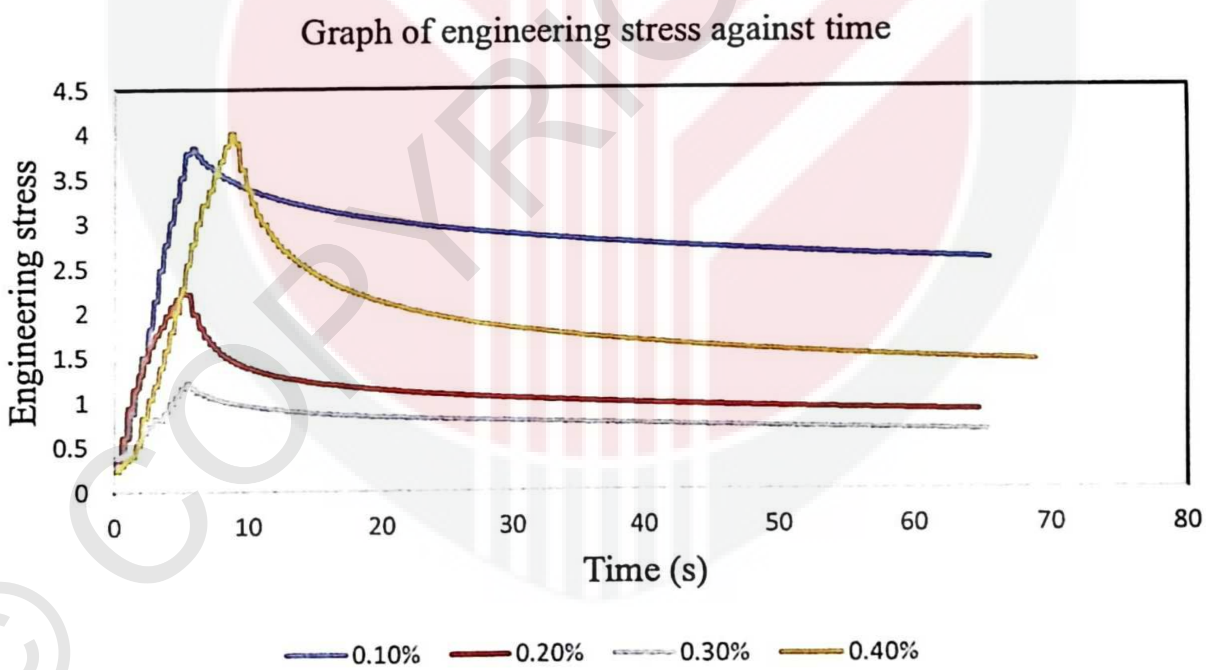


Figure 23: Engineering stress against time curve for stress relaxation compression test (0.6mm/s) to displace 3mm with different percentages of stabilizers

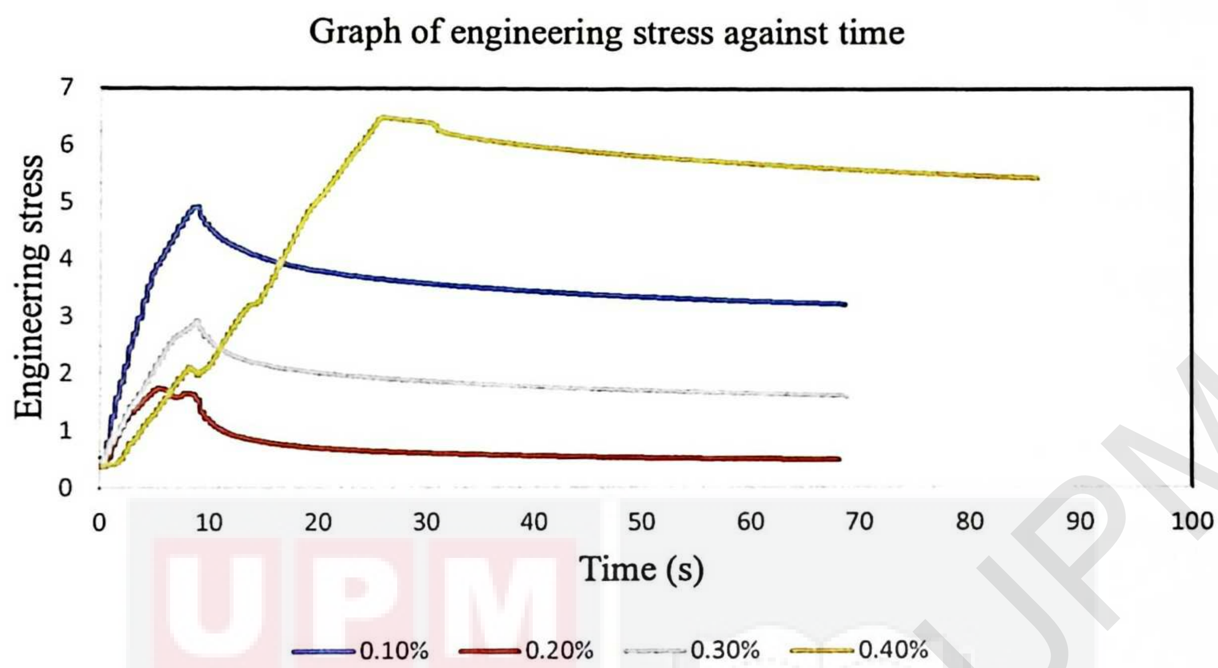


Figure 24: Engineering stress against time curve for stress relaxation compression test (0.6mm/s) to displace 5mm with different percentages of stabilizers

The stress relaxation was important to determine the mechanical properties of the ice cream sample under constant strain. Stress relaxation can be defined as the stress that is measured in the function of time as the material is subjected to a constant strain. Hence, the graph compared the three runtime for each of the stabilizers which were used to displace 1mm, 3mm, and 5mm of the sample.

Based on those graph, it can be seen that the concentration 0.4 percent of stabilizers, needed the high compressive strength to maintain the constant strain over time before it relaxed gradually and fractured compared to other concentration of stabilizers. The time taken for the relaxation also increased as the concentration of stabilizer increased.

It might be due to the molecular structure of the ice cream sample. The viscoelastic materials gradually relax and stop depending on the molecular structure of the material (Morgan & Notes, 2011). Furthermore, the higher relax time was influenced by the structure of the ice crystal as well as the ice crystal volume which affect the melting rate of the ice cream.

In the other hand, it also can be seen that the results for the graphs also varied. The graphs were inaccurate to be referred. For this reason, it might be because of the mistake in the sample preparation of the ice cream for the mechanical testing. The ice cream were melted and refreeze and it affected the structure of the ice cream sample. Also, it affect the hardness of the ice cream by altering the structure of the ice cream by recrystallization process.

The recrystallization process can be defined as the process that change the number, shape and size of the ice crystals in the ice cream. The action of melt-refreeze can greatly affect the structure of the ice cream as it lead to the complete disappearance of the smaller crystals during melting and forming the larger crystals during the cooling process (Flores & Goff, 1999). They further stated that it also can lead to the decrease in the size of the crystals during partial melting and regrowth of the existing crystals during the cooling process.

Muse and Hartel (2004) also stated that the hardness of the ice cream also can be affected by the ice crystals as it comprise a large portion of the bulk of the ice cream. They further stated that as the ice crystal size increased in the ice creams, which is mostly through the control of freezing temperature, the hardness increased. Sakurai *et al.* (1996) also found that ice creams with large ice crystals were harder than those with smaller ice crystals.

4.3 Step relaxation test

The step relaxation test had been carried out as the methodology that had been explained. And, the graph of engineering stress and time were plotted for the different percentages of stabilizers. The graph of the engineering stress and time compared the results of the speed of 0.1mm/s, 0.2 mm/s and 0.6 mm/s for each percentages of the stabilizers were plotted in Figure 25 to 27 to see the trend and peaks for those graphs.

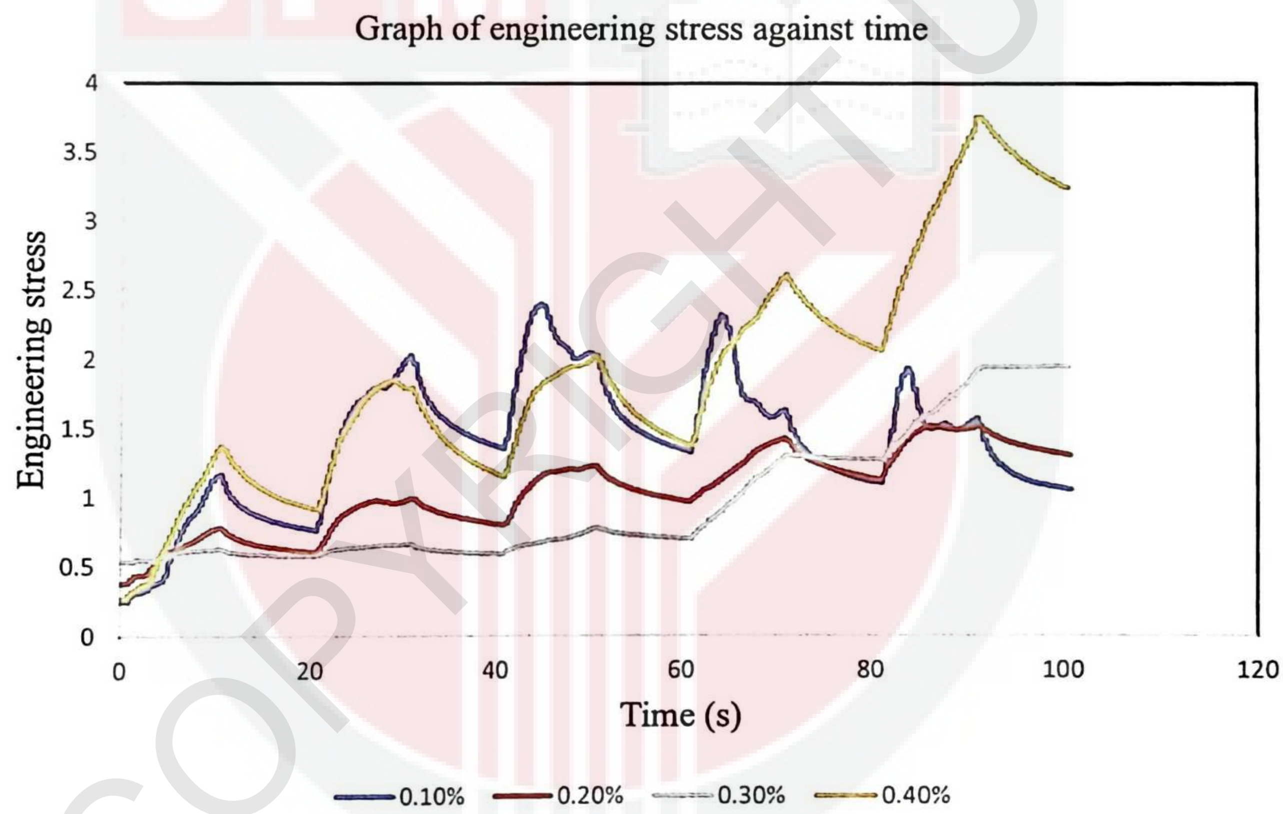


Figure 25: Engineering stress against time curve for step relaxation compression test (0.1mm/s) to displace 1mm with different percentages of stabilizers

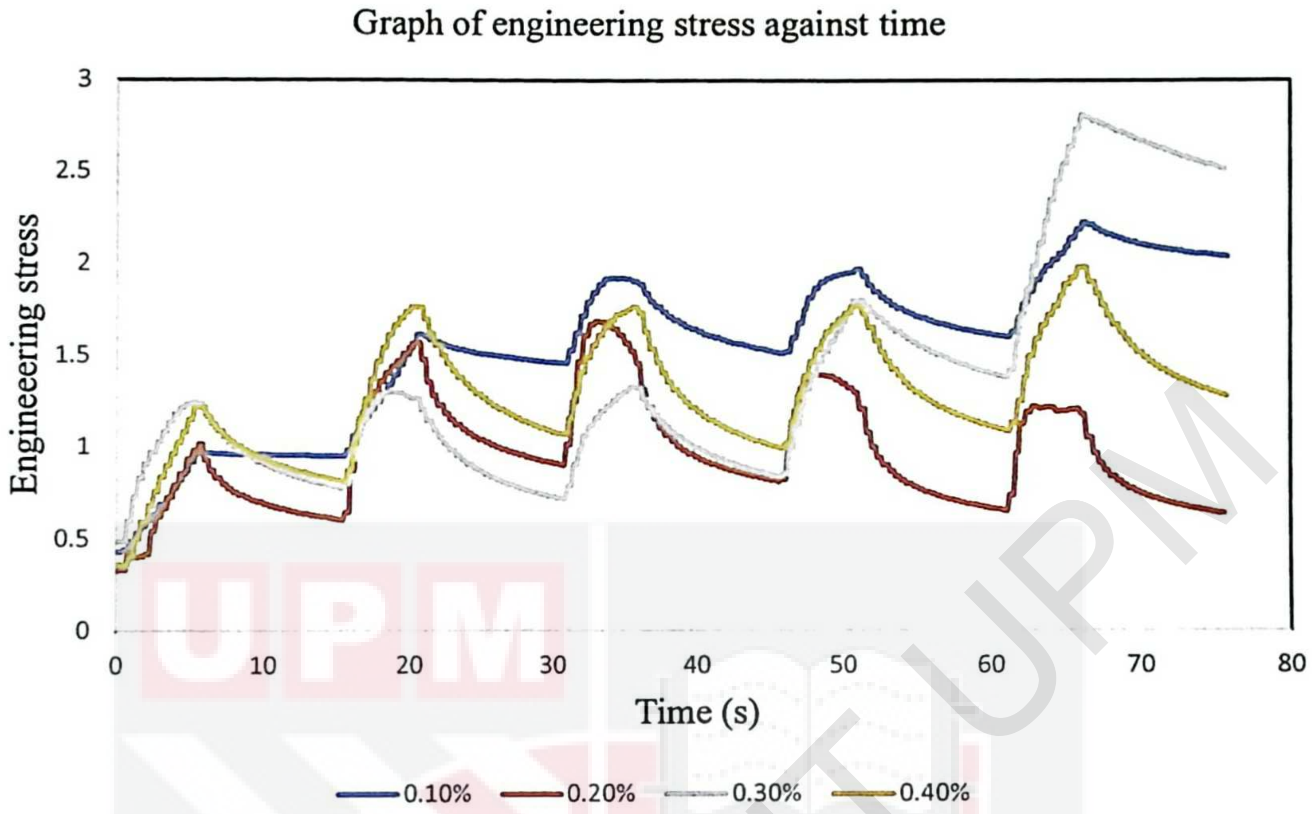


Figure 26: Engineering stress against time curve for step relaxation compression test (0.2mm/s) to displace 1mm with different percentages of stabilizers

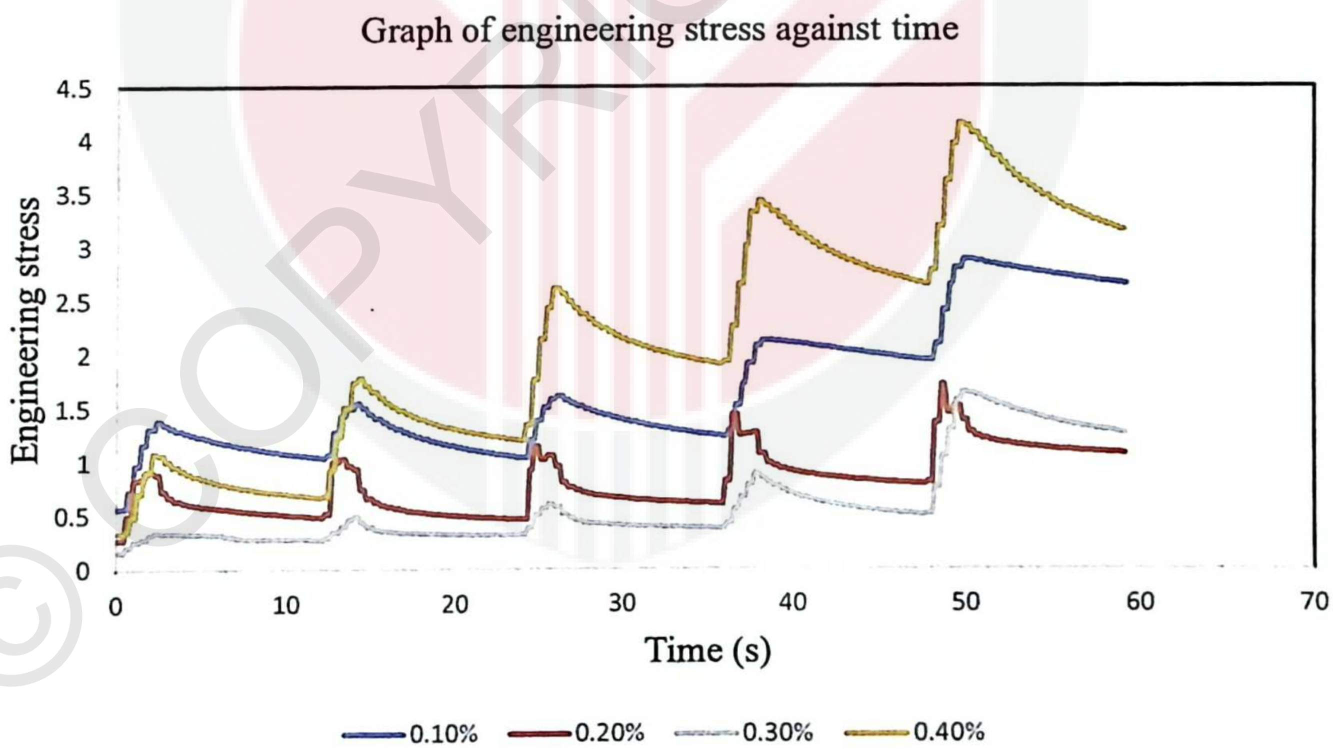


Figure 27: Engineering stress against time curve for step relaxation compression test (0.6mm/s) to displace 1mm with different percentages of stabilizers

The step relaxation was important in determining the mechanical properties of the ice cream sample under constant strain. Step relaxation also known as cyclic stress relaxation which means that the stress measured as the function of time as the stress acts in the loading and unloading actions as the material is subjected to a constant strain. Hence, the graph compared three different speeds to displace 1mm displacement of the ice cream sample.

So, based on the graph that had been compared, it can be seen that the concentration of stabilizer at 0.3 percent and 0.4 percent needed the higher compressive strength during the loading and unloading actions on the stress relaxation. For this reason, it might be due to the air content that affected the hardness of the ice cream sample. Air content also affect hardness by providing additional resistance to deformation (Goff & Hartel, 2013).

Other than that, based on the graphs, it can be seen that the results were varied and differed with each other. It might be because of the mistake in the sample preparation of the ice cream during the process of mechanical testing. It is because the step taken that can affect the structure of the ice cream which were the ice cream was melted and then refreeze again. Hence, the results obtained were inaccurate to be referred.

In the other hand, another factor of the caused the inaccuracy of the results also can be because of the nature of the serum phase with the higher viscosity may be another factor that affected the hardness of ice cream. Goff and Hartel (2013) stated that with the addition of stabilizer to the ice cream mix, both of the apparent viscosity to the mix and hardness to the finished ice cream will increase.

Other than that, it can be referred to the graph for the velocity 0.6 mm/s, where the concentration of 0.3 percent was the lowest in the value of the yield stress compared to the other three other concentrations. For this reason, it might be because of the homogeneity and the control of the ice crystal growth during the freezing process. Naresh and Merchant (2006) stated that during storage, stabilizers play a crucial role in resisting structural changes during the "heat shock" which is the fluctuation in the temperature during storage and distribution that creates ice crystal growth and other types of deterioration, which leading to structural changes.

However, the stabilizer in the ice cream composition also did not significantly prevent recrystallization in the ice cream as it incapable to control and prevent the migratory recrystallization mechanism (Flores & Goff, 1999). Then, it is also can be one of the effect of the melt-refreeze action that lead to the change in the structure of the ice cream.

4.4 Analysis of non-linear mechanical properties of the ice cream

Firstly, the relationship between the mechanical compression test, stress relaxation test and step relaxation was studied based on the results obtained. The mechanical compression analysis determined the stress that the materials can withstand until undergo deformation. The stress relaxation analysis focused on the amount of stress applied on the materials when subjected to the constant strain in the function of time. And for the step relaxation, it focused on the materials ability to withstand the stress applied during loading and unloading action when subjected to the constant strain in the function of time. Hence, the relation between the mechanical analysis was the results showed the non-linear mechanical behavior of the ice cream sample. The results showed the ice cream sample deformation under the stress applied and the ability to exhibit the non-linear mechanical behavior under the constant strain.

From the results gained by the mechanical analysis of the Lego, the analysis of the non-linear mechanical properties of for ice cream was studied. The non-linear mechanical properties of ice cream that can be studied was the viscoelastic properties of the ice cream. Viscoelastic can be defined as the property of material that exhibit the viscous and elastic characteristic under deformation. Viscous means that the characteristic where the stress applied and the materials deformed, and after the load removed, the materials kept in the deformed state. Elastic also means that the materials can deform instantaneously and return to its original state once the load are removed.

Hence, based on the results, which was the stress relaxation on the ice cream, the viscoelastic properties can be deduced. It can be seen that in the graph of the stress relaxation test, the ice cream sample is subjected to the constant strain and relaxed gradually until it deformed in the function of time. Furthermore, the viscoelastic materials subjected to the constant strain will relax under the constant strain thus the stress will gradually decrease (Papanicolaou & Zaoutsos, 2011). The viscoelastic properties also important for the quality attributes of the ice cream by determining its microstructure and also emulsion characteristics (Maria *et al*, 2015).

CHAPTER 5: CONCLUSIONS AND FUTURE WORK

This chapter summarizes the project work done. The main objectives of the project were to study the mechanical properties and analyses the non-linear mechanical behavior of the ice cream based on the mechanical analysis. The mechanical analysis that had been studied were the compression test, stress relaxation compression test and also the step relaxation compression test. Besides, the recommendation for the future work are given in this chapter also.

5.1 Conclusions

Stabilizers is one of the important ingredients to make ice cream. Although only small amount of stabilizer used in ice cream formulation, it gives significant effects that influence the quality of ice cream. Also, stabilizers can affect the viscosity of the ice cream, the hardness, the overrun of the ice cream and also meltdown rate of ice cream.

Besides, for the first objective, the preparation of the ice cream with different formulations had been studied. All the samples were produced with the same formulation but with different percentages of stabilizers. In the process of analysis, the different percentages of stabilizers are varied from 0.1 percent to 0.4 percent. The ice cream sample were analyzed after the hardening process at least 24 hours in the freezer. The results were collected, compared and analyzed in order to understand the mechanical properties and the non-linear mechanical behavior of the ice cream sample.

Furthermore, as for the second objectives, the mechanical properties of the ice cream sample with the different percentages of stabilizers was studied. In the process of analysis, the different percentages of stabilizers are varied from 0.1 percent to 0.4 percent. The four samples of the ice cream mix were made to analyze and study the properties based on the mechanical analysis which were compression test, stress relaxation compression test and the step relaxation compression test. Hence, based on the mechanical analysis, the graph of the engineering stress-strain was plotted to determine the stress that the materials can withstand before undergo deformation. The mechanical analysis also showed the non-linear mechanical behavior of the ice cream sample that can be studied.

Also, as for the third objective, the non-linear mechanical behavior had been studied based on the mechanical analysis. The non-linear mechanical behavior that possessed by the ice cream sample was the viscoelastic properties. It had been showed in the stress relaxation analysis where the viscoelastic materials will be subjected under constant strain and relax gradually until the stress decrease.

To summarize, the ice cream sample was prepared by using different percentages of stabilizer. Then, the mechanical analysis were done .to study the mechanical properties and the analysis of the non-linear mechanical behavior of the ice cream sample. The non-linear mechanical behavior that was studied by the analysis was the viscoelastic properties of the ice cream. And last but not least, the study also found that the mechanical properties and the non-linear mechanical behavior correlated with each other and the sample preparation of the ice cream can affect the structure of the ice cream.

5.2 Recommendation for future work

The analysis done were the mechanical compression test, stress relaxation compression test and also step relaxation compression test. In fact, the mechanical compression analysis already is a new thing for the ice cream. It is because the limitation to perform the mechanical analysis in the room temperature then we focused on the Lego compression analysis.

But for the further research, it is important to prepare the ice cream sample using the correct method. As for the mechanical analysis using Lego, the small size of the ice cream must be produce for the testing. Hence, the focused was on the sample preparation where the ice cream cannot be melt and refreeze. Otherwise, it will affect the structure of the ice cream sample.

Then, for the suggestion of the correct method of sample preparation, the ice cream can be put into tube and cut into small pieces. Also, other than tube, bigger size of straw also can be used for the preparation of the ice cream sample. It also can be cut into small size according to the diameter and height that had been fixed.

Besides, it is important to study the relationship between the viscosity and also hardness of the ice cream. The formulation of the ice cream can be improve by studying the correlation of the emulsifier and stabilizer in the ice cream properties.

Besides, the study done could help to study the effect of variation of stabilizers and emulsifier in the ice cream properties. Also, it can improve the mechanical properties of the ice cream.

The mechanism of the formation of ice crystal and fat destabilization also should be considered for future work in order to study the properties of ice cream. The image analysis to study the crystal distribution also should be taken into consideration to study the structure of ice cream in the liquid state and in the solid state.

REFERENCES

Aboulfazli, F. (2015). BIFIDOBACTERIUM BIFIDUM AND PHYSICO CHEMICAL PROPERTIES OF FERMENTED ICE CREAM MADE WITH COW MILK , SOYBEAN EXTRACT AND COCONUT MILK INDIVIDUALLY AND IN COMBINATION FATEMEH ABOULFAZLI THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF D.

Ak, M. M., & Gunasekaran, S. (1992). Stress-Strain Curve Analysis of Cheddar Uniaxial Compression Cheese under. *Journal of Food Science*, *57*(5).

Anynomous. (2011). Milk Facts. Retrieved from http://www.milkfacts.info/Current Events/Current News and Research.htm

Bahramparvar, M., & Tehrani, M. M. (2011). Application and functions of stabilizers in ice cream. *Food Reviews International*, *27*(4), 389–407. https://doi.org/10.1080/87559129.2011.563399

Deosarkar, S. S., Khedkar, C. D., Kalyankar, S. D., & Sarode, A. R. (2015). *Ice Cream: Uses and Method of Manufacture. Encyclopedia of Food and Health* (1st ed.). Elsevier Ltd. https://doi.org/10.1016/B978-0-12-384947-2.00384-6

Fiol, C., Prado, D., Romero, C., Laburu, N., Mora, M., & Iñaki Alava, J. (2016). Introduction of a new family of ice creams. *International Journal of Gastronomy and Food Science*, *7*(October 2015), 5–10. https://doi.org/10.1016/j.ijgfs.2016.12.001

Flores, A. A., & Goff, H. D. (1999). Recrystallization in Ice Cream After Constant and Cycling Temperature Storage Conditions as Affected by Stabilizers. *Journal of Dairy Science*, *82*(7), 1408–1415. https://doi.org/10.3168/jds.S0022-

0302(99)75367-1

Forte, A. E., D'Amico, F., Charalambides, M. N., Dini, D., & Williams, J. G. (2015). Modelling and experimental characterisation of the rate dependent fracture properties of gelatine gels. *Food Hydrocolloids*, *46*, 180–190. https://doi.org/10.1016/j.foodhyd.2014.12.028

Goff, H. D. (2004). *The Ice Cream eBook (Ice Cream History and Folklore).*

Goff, H. D., & Hartel, R. W. (2013). *Ice Cream.*

Jagdish, S., Arvind, S., & Ashok, R. (2015). Utilization of guar gum as stabilizer in ice cream. *International Journal of Microbiology and Applied Sciences*, *4*(2319–7706), 284–287.

Mahdian, E., & Karazhian, R. (2012). Effects of Fat Replacers and Stabilizers on Rheological, Physicochemical and Sensory Properties of Reduced-fat Ice Cream, *2*(2), 19–26.

Maria, T., Eleni, G., Efimia, D., & Petros, T. (2015). Modelling the effect of storage temperature on the viscoelastic properties and quality of ice cream. *Journal of Food Engineering*, *148*, 35–42. https://doi.org/10.1016/j.jfoodeng.2014.07.002

McGhee, C. E., Jones, J. O., & Park, Y. W. (2015). Evaluation of textural and sensory characteristics of three types of low-fat goat milk ice cream. *Small Ruminant Research*, *123*(2–3), 293–300. https://doi.org/10.1016/j.smallrumres.2014.12.002

Moeenfard, M., & Tehrani, M. M. (2008). Effect of Some Stabilizers on the Physicochemical and Sensory Properties of Ice Cream Type Frozen Yogurt, *4*(5), 584–589.

Morgan, S. E., & Notes, R. C. (2011). Viscoelastic Behavior.

Muse, M. R., & Hartel, R. W. (2004). Ice Cream Structural Elements that Affect Melting Rate and Hardness. *Journal of Dairy Science*, *87*(1), 1–10. https://doi.org/10.3168/jds.S0022-0302(04)73135-5

Naresh, L., & Merchant, U. S. (2006). Stabilizer Blends and their importance in Ice cream Industry – A Review.

Papanicolaou, G. C., & Zaoutsos, S. P. (2011). *Viscoelastic constitutive modeling of creep and stress relaxation in polymers and polymer matrix composites. Creep and fatigue in polymer matrix composites*. Woodhead Publishing Limited. https://doi.org/10.1533/9780857090430.1.3

Sherman, F. S. and P. (1973). EVALUATION OF SOME TEXTURAL PROPERTIES OF FOODS WITH THE INSTRON UNIVERSAL TESTING MACHINE, *4*.

Sodini, I., Morin, P., Olabi, A., & Jiménez-Flores, R. (2006). Compositional and Functional Properties of Buttermilk: A Comparison Between Sweet, Sour, and Whey Buttermilk. *Journal of Dairy Science*, *89*(2), 525–536. https://doi.org/10.3168/jds.S0022-0302(06)72115-4

Tabilo-Munizaga, G., & Barbosa-Cánovas, G. V. (2005). Rheology for the food industry. *Journal of Food Engineering*, *67*(1–2), 147–156. https://doi.org/10.1016/j.jfoodeng.2004.05.062

Y. H. Hui, F. S. (2005). Handbook of Food Science, Technology, and Engineering - 4 Volume Set. Retrieved from https://books.google.com.my/books?id=lIDOBQAAQBAJ&pg=PA154-

IA42&lpg=PA154-IA42&dq=The+storage+temperature+should+be+in+-10^0+C+to+-12^0+C+and+also+upper+limit+of+15.6+to+18.5%25+MSNF+had+been+suggested+to+prevent+the+lactose+crystallization&source=bl&ots=c2

Zhan, Z. L., & Tong, J. (2007). A study of cyclic plasticity and viscoplasticity in a new nickel-based superalloy using unified constitutive equations. Part II: Simulation of cyclic stress relaxation. *Mechanics of Materials*, *39*(1), 73–80. https://doi.org/10.1016/j.mechmat.2006.01.006

Zhuang, W. Z., & Halford, G. R. (2001). Investigation of residual stress relaxation under cyclic load. *International Journal of Fatigue*, *23*, *Supple*, 31–37. https://doi.org/http://dx.doi.org/10.1016/S0142-1123(01)00132-3

APPENDIX

```
Command Window
 Trial>> clear
 Trial>> STARTLEGO
 Please enter the type of test to
  proceed(down, up, uniaxial, relaxation, steprelaxation or cyclic)
fx
```

Appendix 1: Matlab Lego mechanical test

```
Command Window
 Trial>> clear
 Trial>> STARTLEGO
 Please enter the type of test to
  proceed(down, up, uniaxial, relaxation, steprelaxation or cyclic)
 down
 insert threshold value(kg), start with 0 first:
fx
```

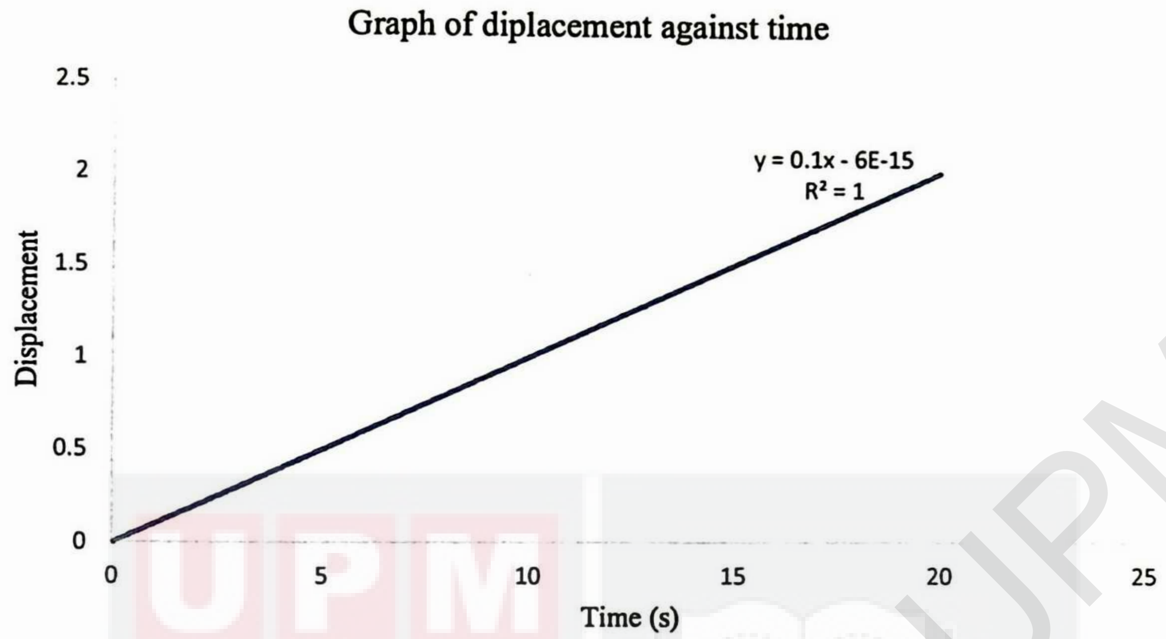
Appendix 2: Matlab Lego mechanical test

```
Command Window
 Trial>> clear
 Trial>> STARTLEGO
 Please enter the type of test to
  proceed(down, up, uniaxial, relaxation, steprelaxation or cyclic)
 down
 insert threshold value(kg), start with 0 first:
fx 0
```

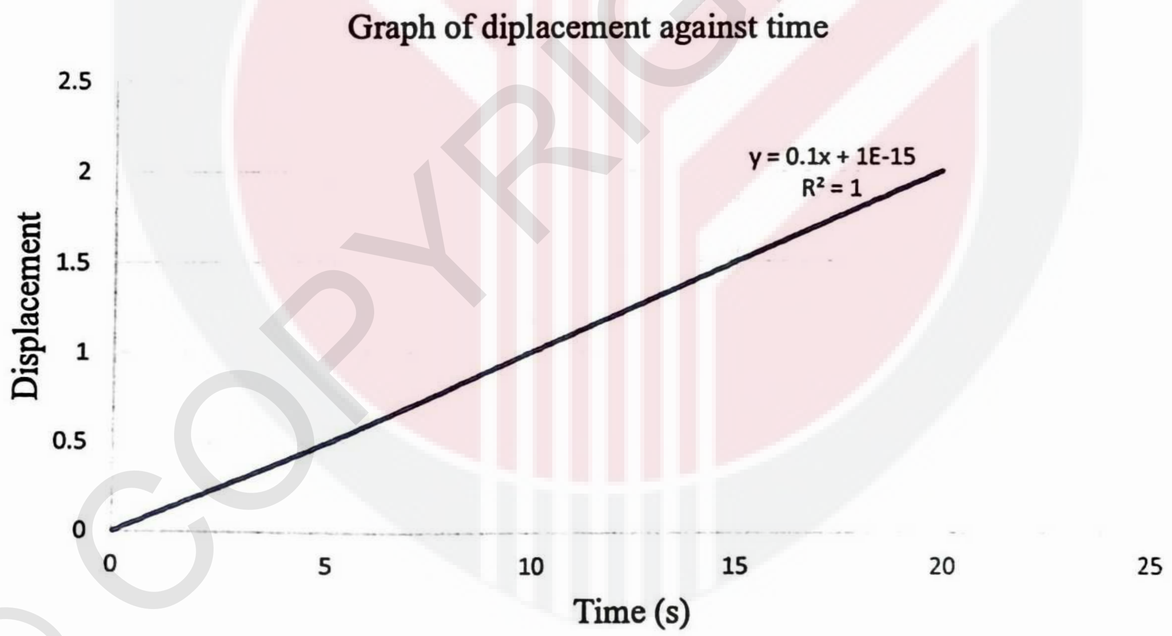
Appendix 3: Matlab Lego mechanical test

```
Command Window
 -0.0011111 kg
 -0.0011111 kg
 -0.0011111 kg
 -0.0011111 kg
 -0.0011111 kg
 0.0069687 kg
 Trial>> STARTLEGO
 Please enter the type of test to
  proceed(down, up, uniaxial, relaxation, steprelaxation or cyclic)
 uniaxial
 insert motor power(%)(0-100)
 30
 time interval of data point
 0.1
 insert runtime
 1.7
 set threshold value(kg):
fx 0
```

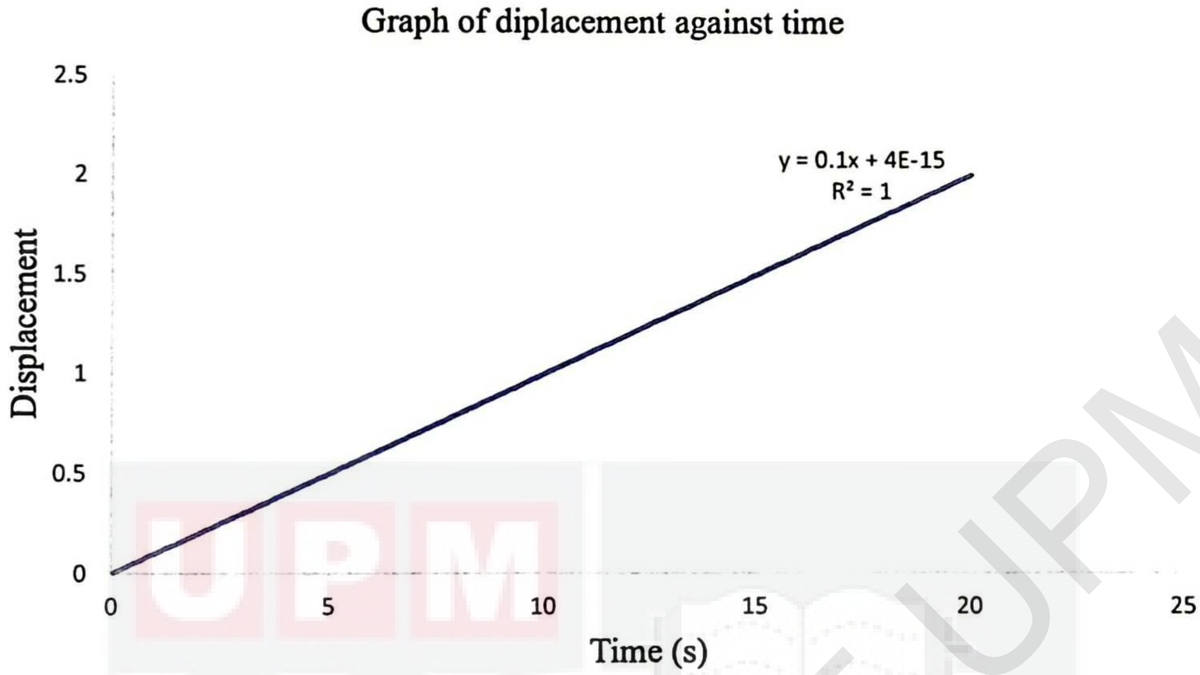
Appendix 4: Matlab Lego mechanical test



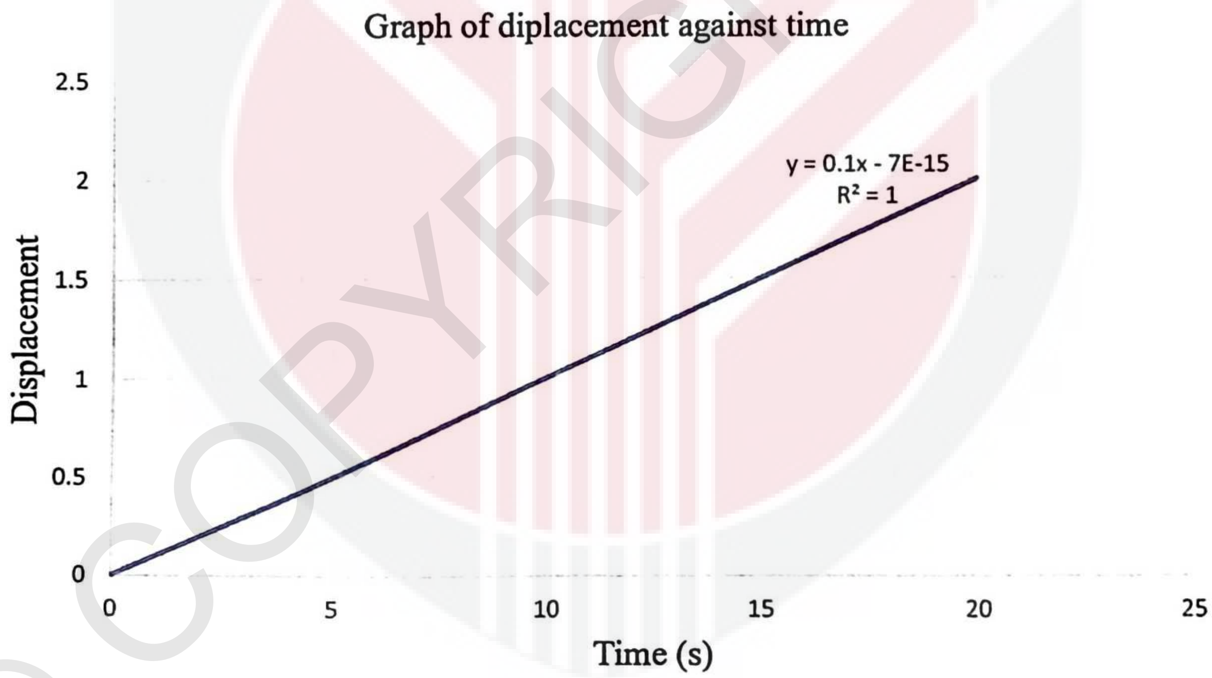
Appendix 5: Graph of displacement against time for 0.1% concentration of stabilizer with speed of 0.1mm/s to displace 1mm



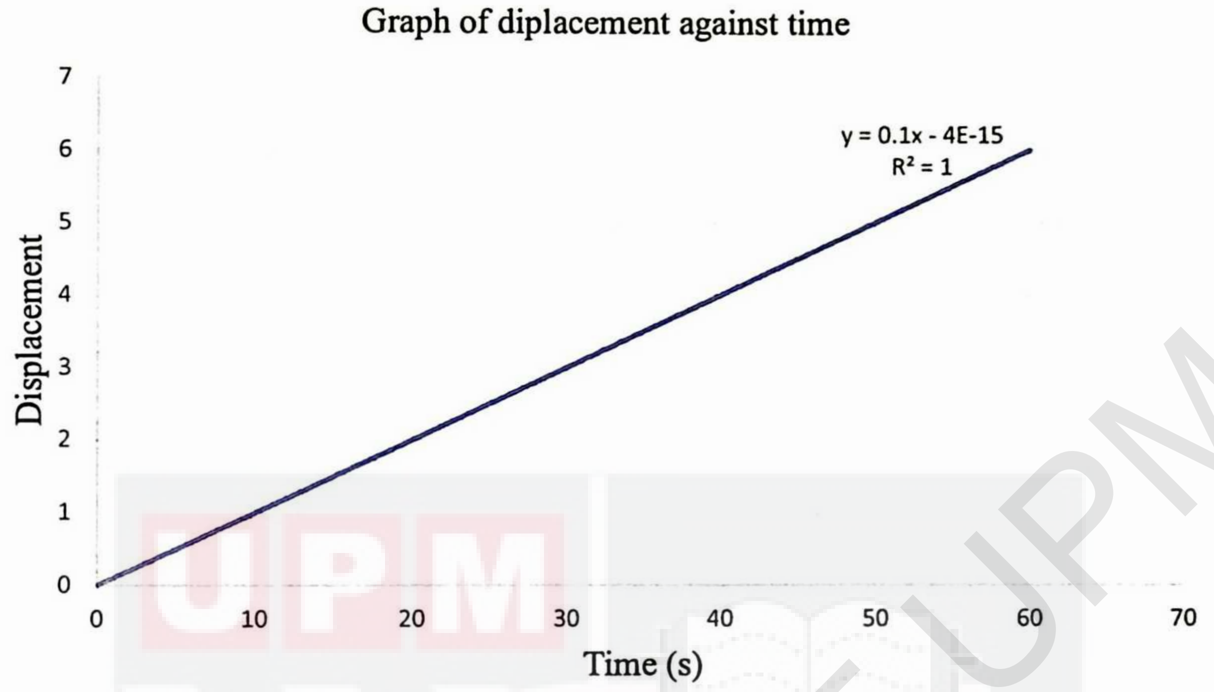
Appendix 6: Graph of displacement against time for 0.2% concentration of stabilizer with speed of 0.1mm/s to displace 1mm



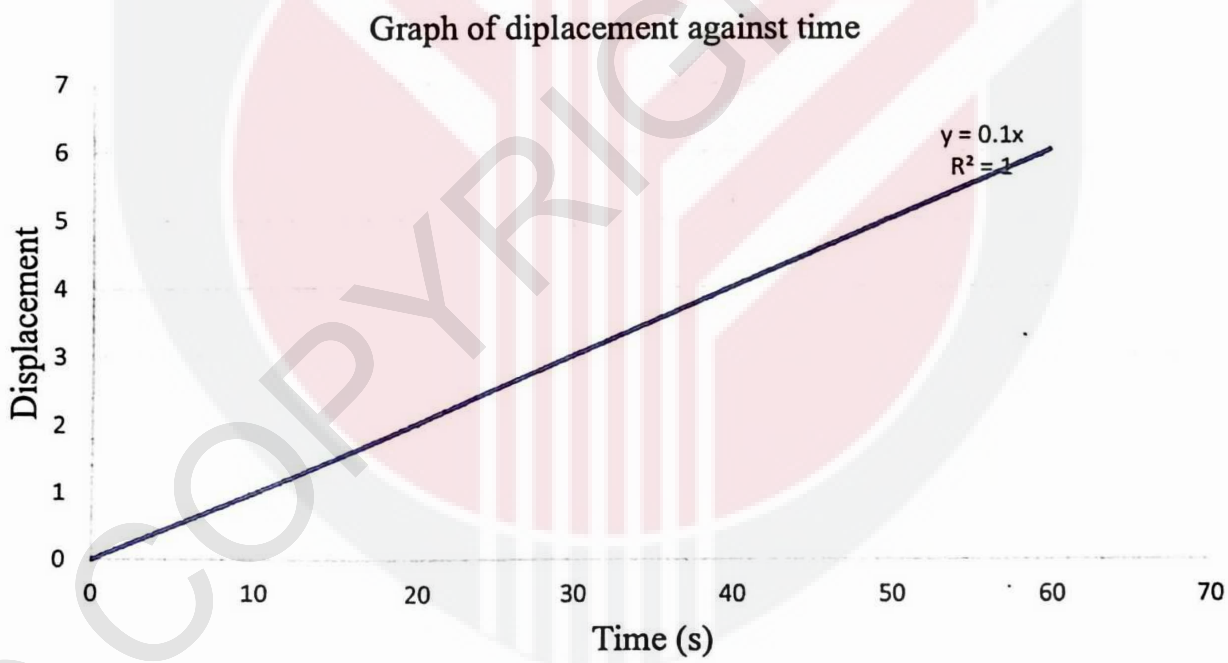
Appendix 7: Graph of displacement against time for 0.3% concentration of stabilizer with speed of 0.1mm/s to displace 1mm



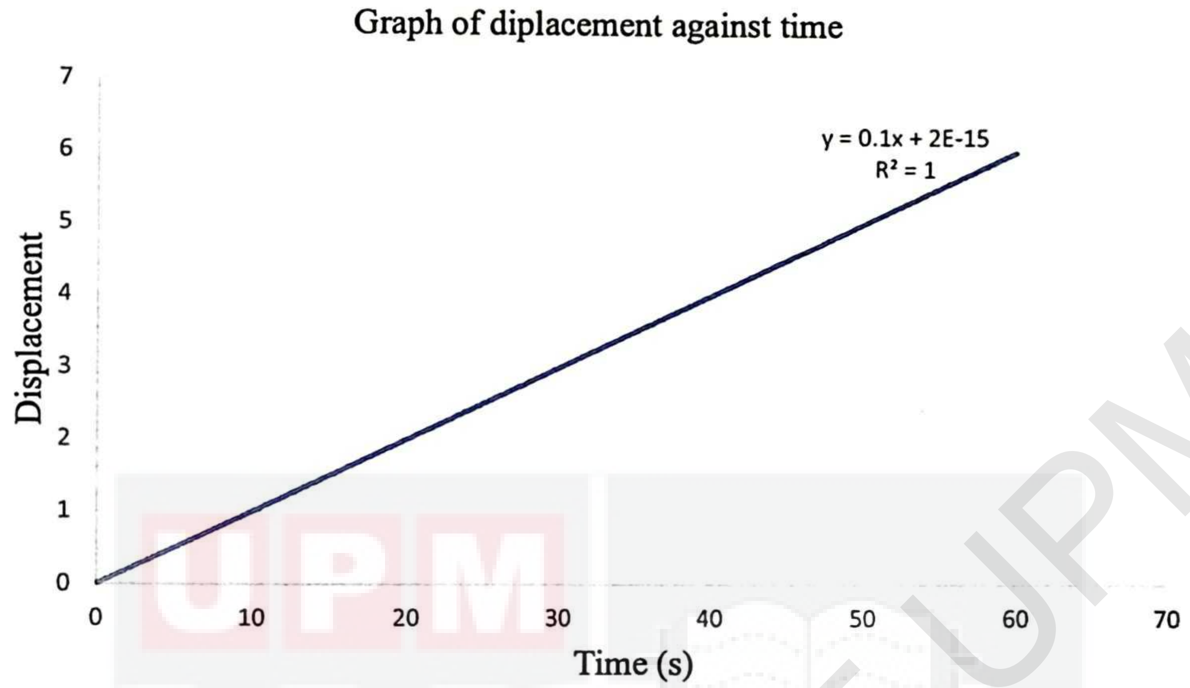
Appendix 8: Graph of displacement against time for 0.4% concentration of stabilizer with speed of 0.1mm/s to displace 1mm



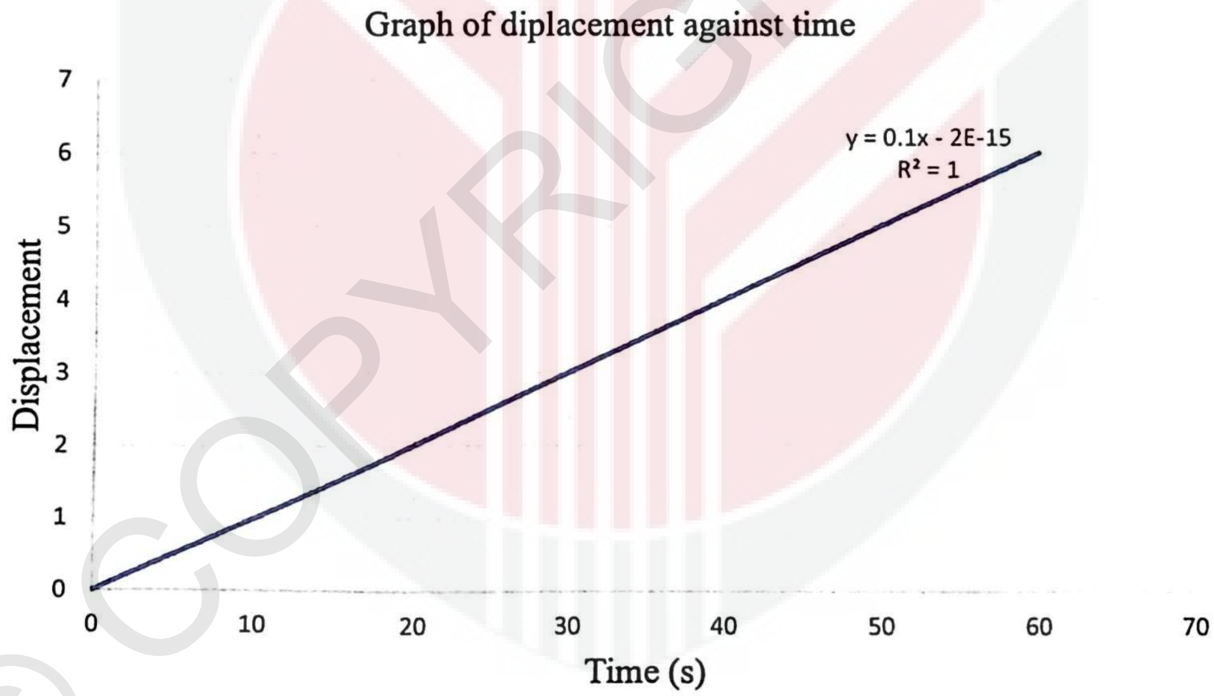
Appendix 9: Graph of displacement against time for 0.1% concentration of stabilizer with speed of 0.1mm/s to displace 3mm



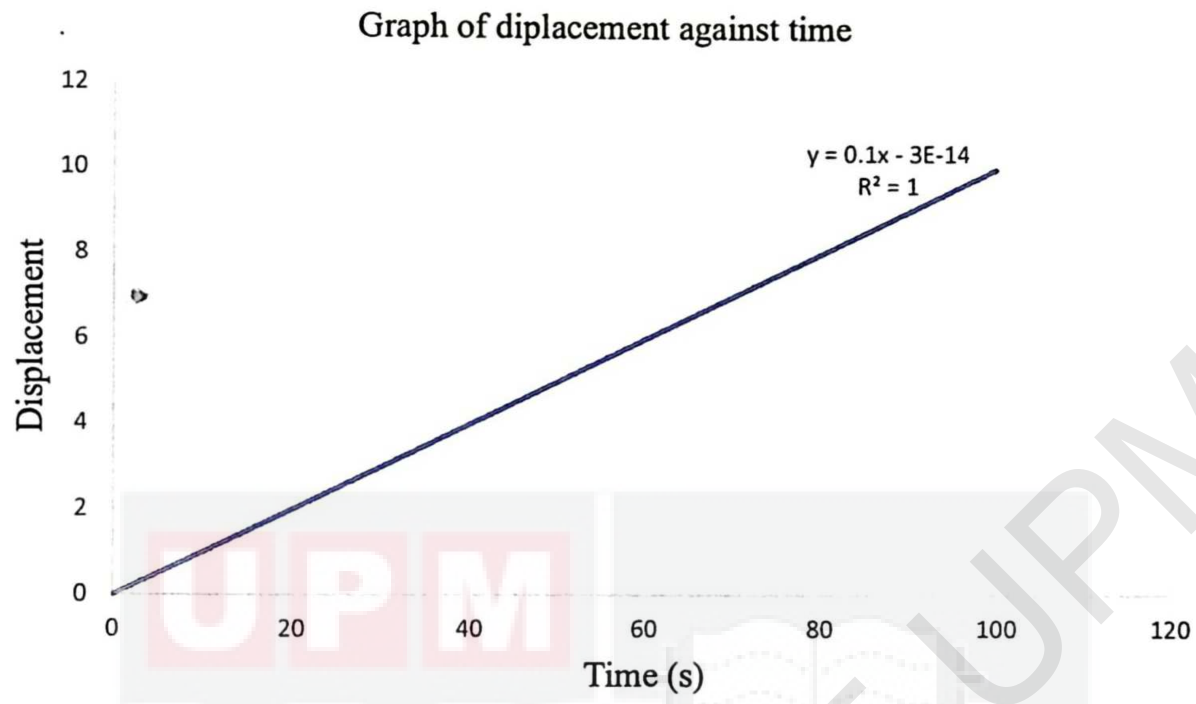
Appendix 10: Graph of displacement against time for 0.2% concentration of stabilizer with speed of 0.1mm/s to displace 3mm



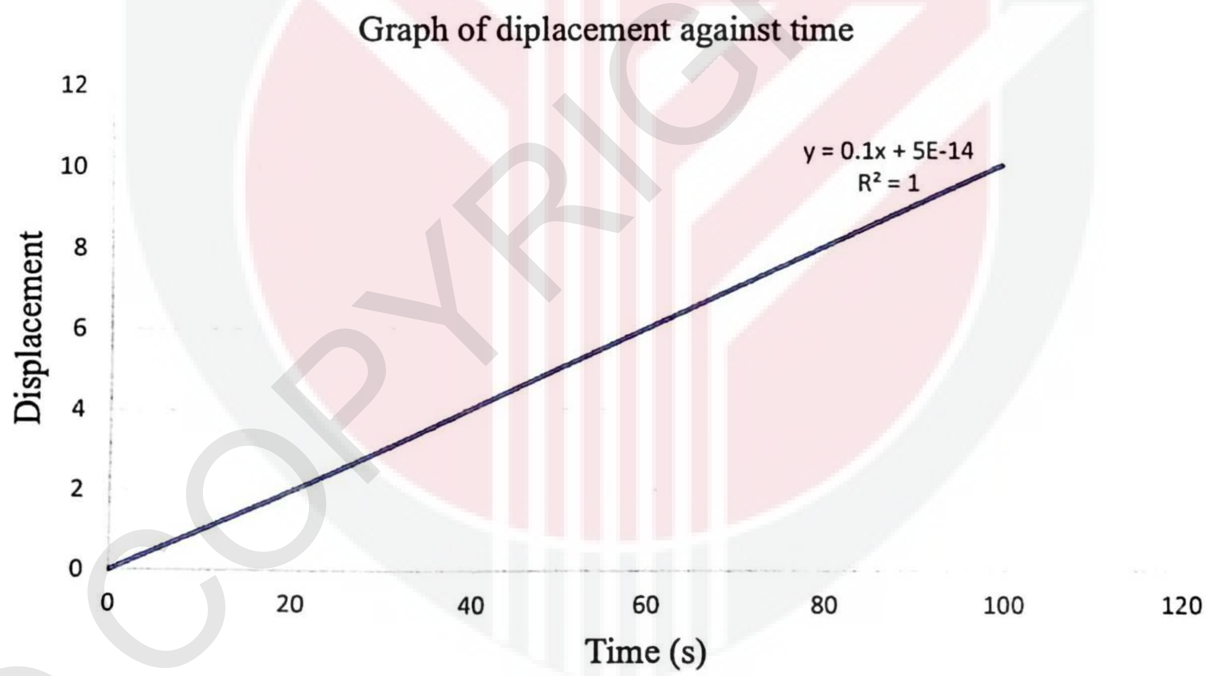
Appendix 11: Graph of displacement against time for 0.3% concentration of stabilizer with speed of 0.1mm/s to displace 3mm



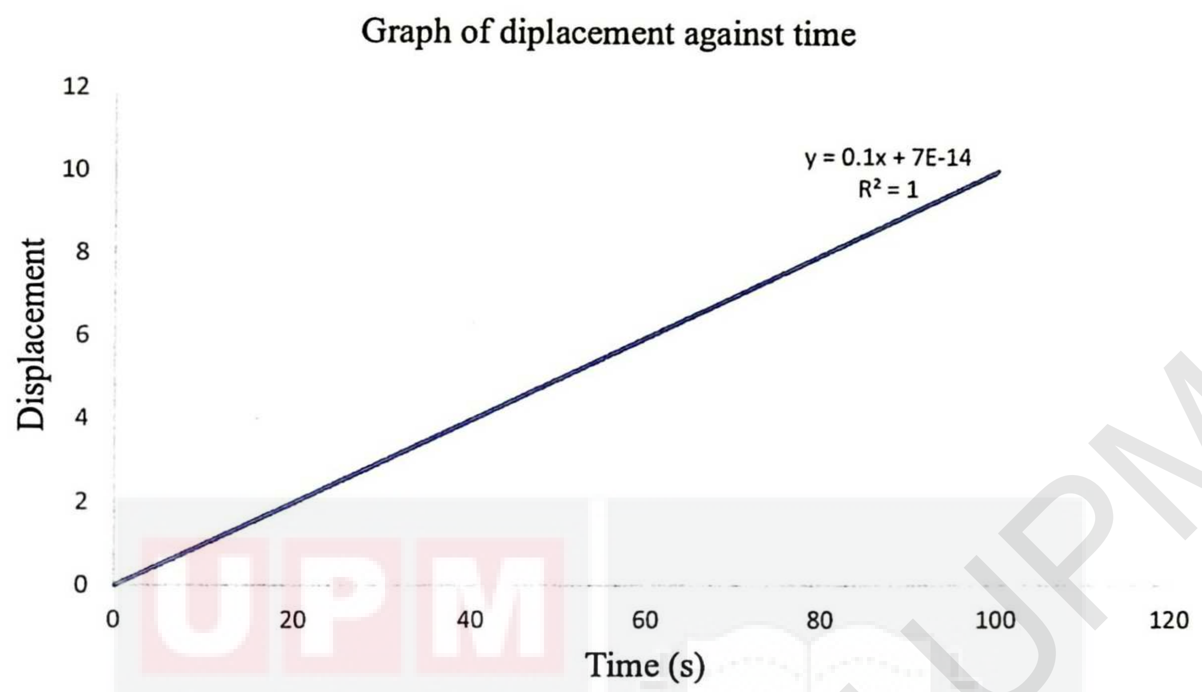
Appendix 12: Graph of displacement against time for 0.4% concentration of stabilizer with speed of 0.1mm/s to displace 3mm



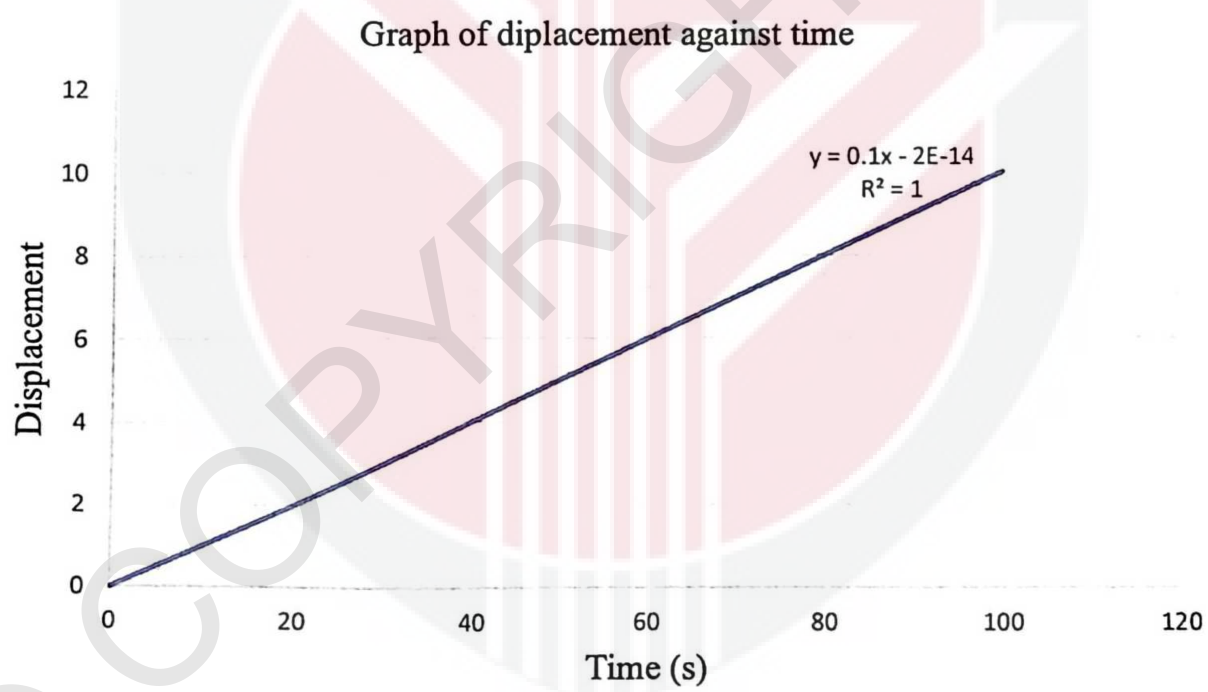
Appendix 13: Graph of displacement against time for 0.1% concentration of stabilizer with speed of 0.1mm/s to displace 5mm



Appendix 14: Graph of displacement against time for 0.2% concentration of stabilizer with speed of 0.1mm/s to displace 5mm



Appendix 15: Graph of displacement against time for 0.3% concentration of stabilizer with speed of 0.1mm/s to displace 5mm



Appendix 16: Graph of displacement against time for 0.4% concentration of stabilizer with speed of 0.1mm/s to displace 5mm