AN INVESTIGATION ON THE FUNCTIONAL PROPERTIES OF 1400 KG/M^3 FOAMED CONCRETE WITH CALCIUM STEARATE

NEO YAO YONG

UNIVERSITI TUNKU ABDUL RAHMAN

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering with Honours

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations, which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : Neo

Name : Neo Yao Yong

ID No. : 18UEB03439

Date : 19 May 2023

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"AN INVESTIGATION ON THE FUNCTIONAL PROPERTIES OF 1400 KG/M^3 FOAMED CONCRETE WITH CALCIUM STEARATE"** was prepared by **NEO YAO YONG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering with Honour.

Approved by,

Signature : ling

Supervisor : Dr. Lee Yee Ling

Date : 19 May 2023

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ABSTRACT

Lightweight foamed concrete (LFC) has become a prominent construction material for years due to its cellular structure, which provides several outstanding features. For instance, high strength-to-weight ratio, excellent thermal insulation properties, sound insulation, etc. These features make it appropriate for usage on floors, walls, and roofs. Unfortunately, LFC is not favourable in a humid environment, especially in Malaysia, characterized by a tropical climate which frequently experiences precipitation, causing high environmental humidity. LFC will tend to absorb more moisture when exposed to a humid environment. Eventually, it disrupted the performance of LFC in terms of its strength, durability, etc. Thus, a water-repellent calcium stearate (CS) is introduced to reduce water penetration and water absorption of LFC. The objectives of this study are to produce the 1400 kg/m^3 density of foamed concrete with a ± 50 kg/m^3 of acceptable deviation, to obtain the optimum water-cement ratio of LFC and to investigate the effect of CS towards compressive strength and functional properties of LFC. This study was separated into two stages. The first trial mix stage aimed to obtain the optimum water-cement ratio (w/c) for LFC between 0.5 to 0.6 with 0.02 intervals and without adding CS. It was then determined as 0.56 since it provided the highest compressive strength. For the second stage, the actual mix stage, the optimum w/c ratio of 0.56 was utilised to proceed with casting four types of LFC which contain different dosages of CS ranging from 0 % to 1 % with 0.2 % intervals and cured for 7- and 28- days before conducting the tests. The tests included compressive strength, water absorption, thermal conductivity, and sound absorption tests. LFC reached its highest compressive strength with 0.2 % CS, and LFC with 1 % CS has the lowest thermal conductivity, highest sound absorption and noise reduction coefficients. There was just a slight difference in water absorption for these LFC. In a nutshell, the optimum dosage of CS was 1% since it provides LFC with excellent thermal insulation, sound absorption, and noise reduction features. Still, its compressive strength was reduced due to the delay of the hydration process caused by excessive CS. In future, it is recommended to assess the effect of CS on LFC's pore structure and the microstructure to strengthen the dependability of the data obtained in this study.

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A	Cross-sectional area, m^2
CS	Calcium Stearate
D_E	Estimated density, kg/m^3
D_f	Density of foam, kg/m^3
D_T	Target density, kg/m^3
F_m	Mass of foam required, kg
h	Thickness of specimen, m
k	Thermal conductivity, W/mK
M_m	Mass of the total mix, kg
Q	Heat conduction, J/s
T_1	Average temperature of the hot plate, K
T_2	Average temperature of the cold plate, K
w/c	Water-Cement Ratio
W_{sat}	Weight of the saturated surface dry concrete specimen, kg
W_{dry}	Weight of the mbone-dry concrete speci$_m$en, kg
LFC	Lightweight Foamed Concrete
LFC-0%	Lightweight foamed concrete with 0 % calcium stearate
LFC-0.2%	Lightweight foamed concrete with 0.2 % calcium stearate
LFC-0.4%	Lightweight foamed concrete with 0.4 % calcium stearate
LFC-0.6%	Lightweight foamed concrete with 0.6 % calcium stearate
LFC-0.8%	Lightweight foamed concrete with 0.8 % calcium stearate
LFC-1%	Lightweight foamed concrete with 1 % calcium stearate
LFC-0.5	Lightweight foamed concrete with 0.5 water-cement ratio
LFC-0.52	Lightweight foamed concrete with 0.52 water-cement ratio
LFC-0.54	Lightweight foamed concrete with 0.54 water-cement ratio
LFC-0.56	Lightweight foamed concrete with 0.56 water-cement ratio
LFC-0.58	Lightweight foamed concrete with 0.58 water-cement ratio
LFC-0.6	Lightweight foamed concrete with 0.6 water-cement ratio
LFC-28-CS0	Lightweight foamed concrete with 0 % calcium stearate and 28 days curing age

LFC-28-CS0.2	Lightweight foamed concrete with 0.2 % calcium stearate and 28 days curing age
LFC-28-CS0.4	Lightweight foamed concrete with 0.4 % calcium stearate and 28 days curing age
LFC-28-CS0.6	Lightweight foamed concrete with 0.6 % calcium stearate and 28 days curing age
LFC-28-CS0.8	Lightweight foamed concrete with 0.8 % calcium stearate and 28 days curing age
LFC-28-CS1	Lightweight foamed concrete with 1 % calcium stearate and 28 days curing age
LFC-7-CS0	Lightweight foamed concrete with 0 % calcium stearate and 7 days curing age
LFC-7-CS0.2	Lightweight foamed concrete with 0.2 % calcium stearate and 7 days curing age
LFC-7-CS0.4	Lightweight foamed concrete with 0.4 % calcium stearate and 7 days curing age
LFC-7-CS0.6	Lightweight foamed concrete with 0.6 % calcium stearate and 7 days curing age
LFC-7-CS0.8	Lightweight foamed concrete with 0.8 % calcium stearate and 7 days curing age
LFC-7-CS1	Lightweight foamed concrete with 1 % calcium stearate and 7 days curing age
LWC	Lightweight Concrete
NRC	Noise Reduction Coefficient
OPC	Ordinary Portland Cement
PT	Potassium Trimethylsilanolate
SAC	Sound Absorption Coefficient

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Concrete is a structural component used in a building. It is made of cement, water, and aggregate, commonly including gravel and sand. There are numerous varieties of concrete, some of which have similar uses. It depends on the objective that it tends to attain. Concrete comes in various forms, including reinforced concrete, normal strength concrete, high-density concrete, lightweight concrete, etc. Building blocks and long-span bridge decking are two typical applications of lightweight concrete. It can also be used to safeguard steel buildings. This study will focus on foamed concrete, one of the lightweight concretes.

Foamed concrete has become a significant material for building use over the years. The amount of foamed concrete used and the range of applications has drastically risen. Foamed concrete is a lightweight cellular concrete that is versatile and suitable for construction work. Foamed concrete, considered self-compacting material, is made of cement mortar, including cement, water, and stable, homogeneous foam added using an appropriate foaming agent (Fu et al., 2020). Regarding air-entrained, foam concrete is distinguished from air-entrained concrete, which absorbs 3 to 8 % air. Other general terms like low-density foam concrete, lightweight cellular concrete, and so on can also be used to describe foamed concrete. In addition, it may be produced in a wide range of densities and compressive strengths and has many varied applications. It can have a variety of compressive strengths, ranging from 1 MPa to 15 MPa. Various dry densities, commonly between 1600 kg/m^3 and 400 kg/m^3, can be changed by manipulating the sand, cement, and foam when mixing them. The presence of foam will result in a decreased concrete density. This demonstrates that foamed concrete is a lightweight substance composed of cement paste and a homogeneous void structure produced by air voids that are subsequently confined within the mortar mix with foaming chemicals (Lee, et al., 2018).

Foamed concrete is used in various construction projects for structures—for instance, walls, floors, decorative panels, roof insulation screed, etc. Foamed concrete can frequently offer economical and performance advantages compared to conventional building materials. The main benefits of foamed concrete are its thermal conductivity, sound absorption, and compressive strength. The thermal and sound insulation and fire resistance give foamed concrete a considerable advantage when used as a wall in a building.

At the same time, there are limitations to foamed concrete. According to research on the subject, the properties of foamed concrete are significantly impacted by water or moisture absorption, which may lead to cracking and wastage of energy. The main factor that causes easy absorption and hygroscopicity of foamed concrete is the high amount of air void in the concrete. Other factors influencing the absorption and hygroscopicity of foamed concrete include types of foaming agents, densities, and additional mineral components (Ma and Chen, 2016). If foamed concrete is used in Malaysia, the situation will get worse. As is well known, Malaysia has a high annual average rainfall, contributing to the country's high humidity and precipitation. In that situation, the absorptivity and hygroscopicity of foamed concrete will cause it to lose strength and reduce its performance, including strength. The foamed concrete gradually cracks, as a result, losing its effectiveness.

Meanwhile, numerous studies have been published on the approach for method improvements to address the issue of water absorption in foamed concrete. Water repellents will be added to foamed concrete to reduce water absorption. Water-repellent agents can limit the water's movement inside the concrete, reducing the amount of water that the concrete absorbs. Furthermore, calcium stearate can enhance the concrete's water tightness. A hydrophobic layer, also known as a water-repellent layer, is deposited on top of the capillary pores of the concrete by calcium stearate, a waterproofing additive. In non-hydrostatic situations, this layer aids in lowering the concrete's permeability and eventually makes it water-repellent. In a recent study, calcium stearate, one of the water-repellent compounds on the market, has been extensively used to lessen the permeability of various types of concrete. Additionally, by adding more calcium stearate to concrete, corrosion attack from the aggressive ion, such as chloride ions, is prevented, improving the concrete's durability and strength (Maryoto, 2017).

1.2 Importance of the Study

Due to its high heat conductivity and dead weight, typical concrete is being replaced by other materials in the construction industry as global warming intensifies. Due to its characteristic, foamed concrete, a lightweight concrete, is highly favoured because it provides a high strength-to-weight ratio and durability. It lessens the dead weight on the structure, the production costs due to lesser material than other concrete, and the labour costs related to building and moving the structure. The foam concrete's numerous pores also lessen thermal conductivity and sound absorption, making the construction suitable for all climatic situations, especially in a country with hot weather like Malaysia (Raj, Sathyan, and Mini, 2019). Calcium Stearate also plays a vital role in foamed concrete as it helps it solve the problem of corrosion attack and the water absorption problem due to its porous structure. Hence, this study allows us to identify how the calcium stearate will affect the functional properties of the foamed concrete.

Future studies will benefit from this contribution's knowledge of a summary of water-repellent agents that could improve foamed concrete's properties in other performances, including compressive strength, cracking resistance, sorptivity, hygroscopicity, durability, etc. This study focus on compressive strength, thermal conductivity, and sound absorption.

1.3 Problem Statement

The porous structure of foamed concrete causes it to have high-water absorption and hygroscopicity, causing it to lose its performance in its properties. As a result, failure cracking of foamed concrete will also occur. Other than that, aggressive moisture and ions adversely affect the durability of concrete structures. At this moment, water-repellent agents become essential for the foamed concrete to solve these problems. The design of the mixture can include damp-proofing admixtures, such as calcium stearate, to prevent water and active ions from entering the concrete. (Nemati Chari, Naseroleslami and Shekarchi, 2019). After applying calcium stearate to the foamed concrete, the corrosion attack, high-water absorption, and hygroscopicity can be solved. As a result, it can lessen concrete's permeability in non-hydrostatic circumstances.

In addition to lowering water absorption and chloride penetration, calcium stearate, a chemical water repellent, extends the useful life of concrete construction. Eventually, it will result in indirect savings on maintenance costs, such as replacing cracked concrete. Unfortunately, adding calcium stearate into foamed concrete might bring some disadvantages to the concrete. The limitations include a sharp reduction in the fresh concrete’s workability and a reduction in the compressive strength of hardened concrete, regardless of the water-to-cement ratio.

Finding the ideal water-cement ratio for the foamed concrete would be another problem for this project. The water-to-cement ratio is a critical factor in determining the strength and durability of concrete when it has sufficiently cured. Eventually, it could also impact the foamed concrete's functional properties. Therefore, obtaining the ideal water-cement ratio will be crucial because it could influence the outcomes of upcoming experiments and tests and the foamed concrete's properties.

1.4 Aim and Objectives

This study investigates the functional properties of 1400 kg/ m^3 foamed concrete with calcium stearate. To achieve the aim, there are some objectives to be attained, and they are stated:

- To produce foamed concrete with a concrete density of 1400 kg/m^3 with a ± 50 kg/m^3 of acceptable deviation.
- To acquire the optimum water-cement ratio of lightweight foamed concrete.
- To investigate the effect/impact of calcium stearate on lightweight foamed concrete's functional properties and compressive strength.

1.5 Scope and Limitation of the Study

The functional characteristics of foamed concrete with a density of 1400 kg/m^3 and calcium stearate, a material that acts as a water-repellent, was examined in this study. The foamed concrete's compressive strength and functional characteristics, such as thermal conductivity and sound absorption, were ascertained in the study. Two main tests was conducted: the fresh properties test and the hardened test. The fresh properties test included some basic tests to identify the foamed concrete's consistency, stability, and workability—for instance, the slump test, flow table test and sieve analysis. The foamed concrete's compressive strength and other functional properties were tested as part of the hardened test, including the thermal conductivity, water absorption and sound absorption tests. Besides, the calcium stearate added to the foamed concrete was limited to 1 % of the cement weight. A 0.2 % interval of calcium stearate was added to the foamed concrete starting from 0 % to 1 %.

On the other hand, the cement to sand ratio was 1 to 1. This study was separated into Stages 1 (trial mix) and 2 (actual mix). Stage 1 was focused on the trial mix, allowing us to obtain the optimum water-cement ratio of around 0.5 to 0.6 without adding calcium stearate into the foamed concrete. Stage 2 was the actual mix, which uses the optimum w/c ratio obtained in Stage 1 to determine the effect of CS towards the compressive strength and functional properties of LFC.

There was some limitations to this study. First, in this investigation, there was only one fixed concrete density (1400 kg/m^3) of foamed concrete carried out, which means that the performance of the calcium stearate in other values of concrete density of foamed concrete was unknown as well as how it will affect the functional properties of foamed concrete in the additional value of density. Calcium stearate was the only water-repellent to assess the foamed concrete's practical qualities.

In addition, the trial mix was only be limited to 7 days of tests for compressive strength.

1.6 Contribution of the Study

The expected outcome of this study is to determine the impact of calcium stearate as a water-repellent in foamed concrete. After conducting this investigation, the uses of calcium stearate as a water repellent in foamed concrete was evaluated through some tests. It can be seen how the foamed concrete performed in the calcium stearate and through changes in its functional properties—for instance, thermal conductivity, sound absorption, water absorption and compressive strength of the concrete. Hence, if the calcium stearate improves the performance of the foamed concrete in the functional properties and compressive strength, it probably help the construction industry in better quality and efficiency of building by using foamed concrete incorporated with calcium stearate. Eventually, using high-strength mixtures does not require using them, which will lead to cost-saving and economical.

1.7 Outline of the Study

The study was separated into five chapters dealing with specific tasks for each investigation chapter.

A general introduction, the significance of the study, a problem statement, an aim and objective, and the study's scope and limitations are all included in **Chapter 1**.

Chapter 2 describes the literature review, which contains a series of studies investigating the properties of foamed concrete and the impact of the calcium stearate on the concrete.

The methodology, which outlines the method used in this study, is covered in **Chapter 3.** Basically, it shows the whole study process to achieve the investigation's final aim. For instance, some tests were conducted, such as trial mix, fresh properties test, hardened test, etc.

Chapter 4 covers the result and discussion. In short, it included the data analysis of the result after conducting the tests. This chapter discusses the effect of calcium stearate on the functional properties of foamed concrete. The properties include compressive strength, thermal conductivity, sound absorption, and water absorption.

Chapter 5 summarises the study and draw conclusions for this investigation. Furthermore, some pertinent suggestions were suggested for further investigation.

CHAPTER 2

LITERATURE REVIEW

2.1 Lightweight Concrete

With a history spanning more than two thousand years, lightweight concrete (LWC) is still undergoing scientific advancement. The use of lightweight concrete dates to the eighteenth century. As building and construction technology has advanced, and the advantages of lighter dead load concrete have been clear, so has the usage of lightweight concrete. These benefits include workability, insulating properties, sound reduction, and weight considerations. LWC has gained popularity as a building material for robust sewage systems, bridges, and load-bearing walls because of its remarkable strength and performance (TeamCivil, 2021).

While the definition of lightweight concrete is relatively straightforward— with an over-dry density range of around 300 to a maximum of 2000 kg/m^3, lightweight concrete may be created (Newman and Owen, 2003). It soon becomes clear that with technological advancements and testing new materials, not all lightweight concrete is created equal. Clay, shale, or slate with lightweight coarse aggregates are the primary materials to produce lightweight concrete. Compared to standard concrete, which has a density of 2300–4000 kg/m^3, and a portion of the aggregate, which should have a density of less than 2000 kg/m^3, lightweight concrete is classified as having a density of fewer than 2200 kg/m^3 (TeamCivil, 2021). Porous aggregates are pre-soaked in water before being added to the cement to address this problem because they take longer to dry. As a result, more water is present in lightweight concrete than in regular concrete. Because of this, many think that regular concrete is less expensive than LWC. The cost of normal concrete-built structures is increased by the requirement for additional materials for cladding, framing, and steel reinforcement.

In addition, LWC continues to be an economically efficient building material, particularly for more significant projects. Building with LWC is flexible and portable, and it doesn't require much help from other materials like steel or concrete, which makes it cost-effective, especially for larger construction projects. LWC is well-suited for safeguarding against heat-related harm due to its capacity for fire resistance and limited thermal conductivity. LWC-built structures are less dense, yet they are less susceptible to collapse. LWC is also less likely to shrink than typical concrete, demonstrating increased resistance to termite and rot infestations. LWC does have certain limits, though. It takes longer to dry since it contains more water (Merikallio, Mannonen, and Penttala, 1996). Since LWC is also quite porous, it is challenging to put the combination correctly. When LWC is mixed improperly, the cement often separates from the aggregates, which is another problem. In addition, substituting too little water for this constraint can produce a weaker mixture, while substituting too much water might form laitance layers (TeamCivil, 2021).

Additionally, there are a few distinct variations of lightweight concrete, and they can all be categorised based on how they are produced. Usually, normal-weight coarse aggregate is utilised, and fine aggregate is not included in the mixture, resulting in many interstitial spaces—it is known as no fine concrete. Large voids inside the concrete or mortar mass are a tell-tale sign of foamed concrete; these voids should be recognised from the exceedingly tiny voids brought on by air entrainment with great clarity. When lightweight porous aggregate is used, it is referred to as lightweight aggregate concrete with an apparent specific gravity of less than 2.6. These types of concrete are aerated concrete, cellular concrete, and gas concrete (Mishra, 2021).

Each kind of lightweight concrete has benefits, limitations, and specific applications. Various lightweight aggregates, including those made from pumice, foamed slag, expanded clays and shales, and other materials, can produce lightweight aggregate concrete. As a result, it might be irregular, rounded, cubical, or angular in form. The textures include uneven surfaces with large, noticeable pores and extremely smooth skins with tiny holes. Particle shape and surface roughness strongly impact concrete mixture workability, water demand, necessary cement amount, and coarse-to-fine aggregate ratio. Lightweight aggregate concrete can quickly provide a range of 2.5 to 40 MPa compression strength frequently demanded by the building sector. Such absorption is crucial because it will affect fresh concrete's density, workability, fire resistance and the hardened properties of density, freeze/thaw resistance, and thermal insulation (Newman and Owen, 2003). The stated permeability for normal-weight concrete was much higher than that of lightweight concrete, which was typically comparable to or even lower. The thermal conductivity of lightweight concrete is influenced by several factors, including its density, moisture content, pore size and distribution, the chemical composition of the solid components, and internal structure. The LWC has a lower thermal conductivity than regular concrete because of its lower density, and moisture conducts more through pores (Jogl, et al., 2021).

Conversely, no-fines concrete is lightweight concrete created by removing the fines (sand or fine particles) from regular concrete and substituting coarse aggregate, cement, and water. The mixture, which consists only of enormous voids and coarse aggregates, is transformed into no-fines concrete by removing fine particles. No-Fines concrete provides good thermal conductivity and, as a result, relatively less drying shrinkage (Mohammed and Hamad, 2014). Because of its various benefits over normal concrete, no-fines concrete is gaining popularity. The single-sized aggregates produce good no-fines concrete that is well-voided, light in weight, and has a pleasing appearance from an architectural standpoint. After that, no-fines concrete can be utilised for indoor and outdoor structures and is best suited for load-bearing walls. In almost all cases, no-fines concrete is cast on-site, particularly for load- and non-load-bearing walls, framed superstructures, and filler walls (Mishra, 2021). However, due to its ability to lessen floods and help recharge the ground water level, pervious concrete has gained substantial popularity in recent decades (Alam, Kuddus and Islam, 2014). This lightweight concrete shouldn't be used with reinforced concrete because of its reduced density and cement content. No-fines concrete is enough for many other applications and constructions up to around 20 stories high due to its strength and the decreased dead load of the structure, even though it has much less strength than normal-weight concrete (Chaipanich and Chindaprasirt, 2015).

2.1.1 Foamed Concrete

Light cellular concrete with sporadic air holes, which are produced by the foaming agent being mixed with mortar, also known as foamed concrete, with a density varying from 400 to 1850 kg/m^3, depending on the features and ratios of its component elements (Khan, et al., 2021). Foamed concrete is renowned for its outstanding thermal insulation, good workability, low cement content, and effective aggregate use. Additionally, foamed concrete is a reasonably priced choice for producing substantial lightweight building materials and components. Its simple manufacturing procedure from the manufacturing plants to the final installation of the applications—such as road embankment infill, filling grades, structural elements, and partitions—makes it popular.

The essential ingredients for making foamed concrete are a mortar made of a water mixture, sand, cement and a foaming agent that may be protein-based or synthetic. Hydrolyzed proteins exhibit superior strength performance, whereas synthetic foaming agents are more convenient to handle, less costly, require less energy, and have a longer shelf life (Mohd Sari and Mohammed Sani, 2017). The weight of the concrete will be lessened as a result. It has a high degree of workability and a low density, with as much as 75 % of its composition comprising entrapped air. For foamed concrete, both the strength-to-weight ratio and density are high. Tiny air bubbles can be pumped into the concrete mixture and typically self-levels and compacts. This situation may be accomplished by employing a batch mix that contains aluminium powder or hydrogen peroxide to create a chemical reaction that releases gas into the concrete. The chemical reaction expands the concrete as it is being poured, and high-pressure steam is used to cure the concrete after it has been placed to "set" the tiny air pockets. The second technique involves stirring a pre-mixed foam into the slurry to incorporate microscopic air spaces into the finished concrete. Foamed concrete is particularly well-suited for filling empty spaces such as decommissioned fuel tanks, sewer systems, pipelines, and culverts, particularly in cases where access is difficult. It is a recognised method for restoring transient road trenches.

Due to its distinctive features, including self-compacting concrete, low thermal conductivity, high flowability, and density reduction, foamed concrete has applications in numerous civil and structural engineering areas. It is also straightforward to create and inexpensive. Using foamed concrete saves labour costs during construction, minimises dead loads on the building's structure and base, and helps conserve energy. With the ability to be employed as a structural material, it boasts lower production and shipping costs for construction components than regular concrete. Foamed concrete is a good option for flat concrete roof insulation and sub-floor screeds due to its excellent thermal insulation qualities. Foamed concrete has gained popularity globally, particularly in areas facing housing shortages or those struck by natural disasters such as hurricanes or earthquakes. For instance, it is used yearly in Korea as a crucial part of a floor heating system. Cement-based foam has been widely employed in geotechnical applications, flowable infill, and tunnel annulus grouting in Canada.

Unfortunately, there are a few disadvantages to foamed concrete. Including water in the mixture renders foamed or lightweight concrete very sensitive. It makes wrapping up harder and extends the time needed for mixing. Flexural strength and compressive strength both decrease as density increases. Hence, water repellent will be added to foamed concrete to solve this problem. This study will determine how water-repellent affects foamed concrete. The compressive strength and functional characteristics of foamed concrete with water repellent will receive the most attention (calcium stearate).

2.2 Water Repellent

All types of water repellents have their function, different characteristics, and reactions with foamed concrete. Various water repellents include siloxane-based polymer, calcium stearate, potassium trimethylsilanolate, etc. Many researchers discuss the effects of each water repellent on the foamed concrete's properties. Water repellents help the compressive strength somewhat without reducing the foamed concrete's ability to insulate heat (Ma and Chen, 2016). Hence, this study will focus on calcium stearate, but other water repellents will also be discussed below. Silicones, paraffin latex, fatty acid metal salts, and redispersed polymers are the four primary water repellents frequently employed in the building sector.

The two most popular kinds of water repellents, siloxanes and silanes, are both derivations of the silicone molecule. Both sealants penetrate nature and enable the substrate to breathe, letting moisture vapour escape and deflect outside water. The substrates on which they are applied show little to no change in appearance, and no gloss is added to the surface. According to Medeiros and Helene's research, water under pressure and saturated concrete rendered the silane/siloxane-based water-repellent ineffective. Hence, it brings lesser impact towards the concrete. In the pores and on the surface of the substrate, silane water repellents create a hydrophobic, water-repellent resin by chemically reacting with calcium hydroxide when applied. Because silanes have smaller molecules than siloxanes, they often penetrate deeper and perform better on solid surfaces like precast and poured-in-place concrete. Siloxanes are moderately effective on surfaces up to medium porosity, such as heavyweight, smooth-faced concrete blocks, and have a significantly bigger molecular structure. Ma and Chen conducted a study investigating the impact of three different types of water repellent on foamed concrete. The results indicate the compressive strength of the concrete tends to increase as the proportion of silicone-based polymer in the mixture rises from 0 to 1.2 %. For instance, samples containing 1.0 % silicone-based polymer demonstrated compressive strengths of 1.53 MPa and 1.77 MPa after 7 and 28 days, respectively. It is challenging to find a correlation between thermal conductivity and compressive strength because the impact of silicone-based polymer concentration on thermal conductivity is erratic.

Potassium Trimethylsilanolate (PT), a basic water solution mostly made of potassium and methyl silica gel, reacts with CO2 or other airborne acid molecules to produce the active ingredient polymethyl silicic acid, which has the feature of being waterproof. It can also create surfaces that are waterproof and decrease moisture absorption. It can preserve the substrate's natural appearance while being permeable, absorbent, and able to absorb. Additionally, it can react with CO2 or other acidic compounds in the air to form a layer of insoluble mesh breathable waterproof membrane on the surface of the substrate. This membrane has excellent waterproof properties and is resistant to seepage, moisture, rust, ageing, and pollution. It also avoids a water suction base. According to Ma and Chen (2016), adding PT to foamed concrete while mixing the final product boosted the material's compressive strength. According to their findings, the strength grows virtually linearly between 7 and 28 days as the PT content increases from 0 to 1.0 %. The strength of the foamed concrete specimens with 1.0 % PT after 7 and 28 days is 1.12 MPa and 1.33 MPa, respectively. Nonetheless, the compressive strength of the foamed concrete tends to decrease somewhat when the PT content exceeds 1.0 %. It is due to the surfactant function that PT serves during the cement hydration process, which may raise the number of hydration products and enhance the density of the structure. Excessive PT concentration has a more substantial hydrophobic impact, which could reduce the water volume used in the hydration process.

The contrast specimen's thermal conductivity is 3.4 % lower than the foamed concrete specimens with 1.0 % PT. The result shows that applying PT does not significantly impact the foamed concrete's capacity for thermal insulation. Besides, the thermal conductivity often follows the trend seen in compressive strength, first increasing as the PT content increases from 0 to 1.0 %, then barely declining as the PT content increases beyond 1.0 %.

Next, similar to calcium stearate, zinc stearate is insoluble in water and white powder. It can safeguard buildings and is impervious to water's corrosive effects. Compared to mortars with silanes/siloxanes added, zinc stearates had the most significant impact on the mechanical characteristics and hydration of the binder and decreased the ability to repel water. Concrete's rate of hydration can be greatly slowed down by zinc stearate. The presence of zinc ions and the development of insoluble zinc hydroxides, which cover the surface of the cement grains and hinder their hydration, are likely to blame for the significant delay that the zinc stearates induce. Calcium hydroxyl-zincate may have formed because free zinc ions consume calcium and hydroxide ions from the solution. Free zinc ions may have contributed to the synthesis of calcium hydroxyl-zincate and a lesser (weaker) C-S-H hydrate in the case of zinc stearate.

The following water repellent that will be discussed is calcium stearate (CS). It is a kind of water-repellent made of oil that has been used for many years to manufacture concrete. Water-repellent creates hydrophobic layers on all conceivable surfaces, rendering the lightweight foamed concrete water-repellent (Lee, et al., 2018). Maryoto (2017) discovered that using calcium stearate can lessen the amount of water absorbed, the number of chloride ions introduced, and the corrosion attack. His investigation demonstrated that concrete with calcium stearate experience lesser corrosion, while concrete without calcium stearate is subject to enormous corrosion attacks. In addition, adding CS to concrete reduced corrosion due to chloride ion attacks and prevented algal fouling on cellular concrete by lowering moisture absorption by utilising water repellent.

Unfortunately, according to Lee, et al. (2018), foamed concrete without a dosage of calcium stearate performs better in compressive strength than foamed concrete with 0.2 % and 0.4 % of calcium stearate. Additionally, the compressive strength of concrete foamed with 0.4 % calcium stearate degraded with time.

On the other side, according to Maryoto, et al. (2020), adding calcium stearate to concrete maintains a relatively steady compressive strength. Concrete without calcium stearate, fly ash, or superplasticizer has a similar compressive strength to concrete with calcium stearate. Additionally, using calcium stearate will unmistakably decrease the capacity of concrete to absorb water and the infiltration of chloride ions. Finally, their research has shown that calcium stearate can lessen concrete deterioration. Consequently, calcium stearate is a strong contender to enhance concrete's mechanical and physical characteristics.

In summary, utilizing calcium stearate does not improve compressive strength but might reduce it. However, it will minimise water absorption, lessens corrosion attack, and reduces chloride ion infiltration. Concrete with more calcium stearate has less water absorption. As a result, the concrete with calcium stearate has decent water tightness. Calcium stearate can also be added to concrete to reduce corrosion on steel bars caused by chloride ion attacks. Regarding the impact of calcium stearate on the compressive strength of foamed concrete, some research shows a little discrepancy. Therefore, calcium stearate will be added to foamed concrete to assess its functional properties and compressive strength.

2.3 Properties of Foamed Concrete

After that, there are a few essential properties of foamed concrete. For instance, functional, mechanical, physical, durability and fresh state properties. In this part, the functional properties, and one of the mechanical properties, compressive strength, of foamed concrete without water repellent (calcium stearate) will be focused on and discussed.

Besides, the fresh properties test will also be done on a fresh density of 1400kg/m^3 foamed concrete. Several parameters must be considered, such as stability, consistency, workability, etc. Those parameters are deeply influenced by water content, amount and type of foaming agent added, and other primary materials. Using the air-liquid interface as an example, a foaming agent with anionic hydrophilic ends may move to the cement paste, destabilising the bubbles and resulting in their collapse (Dhasindrakrishna, et al., 2021).

Fresh foamed concrete's consistency and rheology are initially evaluated. Fresh foamed concrete's consistency and rheology are frequently evaluated to determine the performance of the combination using a flow cone and the flow marsh test. Still, in this study, a flow table test will be done. The consistency of the base mix determines stability, which is quantified by the water-solids ratio. The "consistency of foam concrete" decreases when the foam is used in the base mixture (Kunhanandan Nambiar and Ramamurthy, 2008). When the dynamic viscosity of freshly mixed concrete is restricted from 40 % to 60 % of the flowing period, foamed concrete's consistency and rheology performance are adequate. One crucial aspect that influences the rheology and consistency of freshly foamed concrete is the water concentration in the mix design. To maintain good workability, keeping the water-cement ratio as low as possible when casting foamed concrete is essential, as excessive water can cause the mixture to segregate. For standard concrete, the workability test, typically carried out by a slump test, is not relevant for the specified low-density fresh concrete. A new combination of low-strength materials should be subjected to this test by determining the spread of a sample placed inside an open-ended cylinder that is 150 mm long and 75 mm in diameter after the cylinder has been raised vertically. The workability of the fresh mix is affected by mix proportion. In other words, the workability of fresh mix will increase when the w/c ratio increases (Pranjal, et al., 2017). In fact, this may be due to more water being available for lubricating at more excellent water-cement ratios, increasing the workability. On the other side, the air gaps in the new mix due to the addition of a stable foam agent demonstrate the outstanding performance of foamed concrete's workability. The workability of foamed concrete is thus examined visually to attain the proper mix’s viscosity. However, the workability of the foamed concrete will be assessed in this study using the inverted slump test.

Functional properties, such as acoustic characteristics, including sound absorption, thermal conductivity, and other characteristics, describe the actual behaviour of lightweight foamed concrete during its lifetime. Therefore, the functional characteristics of foamed concrete will be covered in the upcoming sections despite the need for more definitive studies.

2.3.1 Compressive Strength

The most crucial criterion for assessing the application of foamed concrete in its hardened form is its mechanical qualities. Therefore, this study aims to assess the impact of calcium stearate on the compressive strength of foamed concrete. Specifically, the study will conduct 7-day and 28-day compressive strength tests using cube specimens to compare the strength of LFC with and without calcium stearate.

The water-cement ratio is the most significant element affecting compressive strength (Zhang, et al., 2018). The water-cement ratio significantly influences the distribution, size, and connectivity of pores in foamed concrete, as noted by Liu et al. (2016). In particular, when producing foamed concrete with the same density, a higher water-cement ratio can result in lower relative viscosity and a weaker ability for cement paste to maintain the integrity of air bubbles. Additionally, bubbles are more likely to merge and form larger voids, which can decrease the proportion of tiny pores, increase the average pore diameter, and create a more rounded shape of the pores. Conversely, lower dry density would enhance the proportions of tiny and big pores and extend the range of pore diameters.

One of the main factors affecting the compressive strength of the mixture is the volume/density of the foaming agent, which controls the number of air spaces in the hardened foamed concrete. Compressive strength is often influenced by factors including the kind of sand used, the rate of foam agent, the cement-to-sand ratio, the curing process, the water-to-cement ratio, and the distribution of other materials (Amran, Farzadnia and Abang Ali, 2015). Adding too much foam would not boost compressive strength, while reducing foam volume results in air gaps and reduced density.

The water dramatically impacts the compressive strength of foamed concrete to cement ratio, which is the following vital factor. The water-cement ratio in this investigation is kept between 0.5 and 0.6. High-strength foamed concrete was created at ratios of 0.19 and 0.17 between water and cement or binder. The proper quantity of water is added to the mixture to increase uniformity and stability. It also aids in reducing the formation of large foam bubbles, which boosts compressive strength. However, cement alternatives like fly ash and silica fume will gradually modify the compressive strength of the mixture. For instance, a binary mixture of fly ash and silica fume will increase compressive strength. Additionally, the utilisation of fly ash won't alter, but silica fume's strong growth will rise due to its pozzolanic behaviour.

The water-cement ratio can affect foamed concrete's strength and sand-cement ratio. For example, when using a sand/cement ratio of 1.0-2.0, the impact of the sand content on compressive strength was found to be minor. However, adding more coarse sand can decrease the strength of foamed concrete, as it changes the size of the pores in the mixture. On the other hand, using fine sand and ensuring a uniform distribution of pores within the concrete mix design matrix can enhance the foamed concrete's overall strength. In addition, the strength may be increased by adding clay, fine recycled glass aggregates, quarry dust aggregates, expanded shale aggregate, and lime.

Different amounts of water repellent will give different results. The water repellents somewhat increase the foamed concrete's compressive strength without compromising its thermal insulation ability (Ma and Chen, 2016). On the other side, some studies show that the compressive strength is severely impacted by the amount of water repellent added to the foamed concrete. It has been said that calcium stearate forms a wax-like component when it combines with cement and water. Compared to the connection created by the combination C-S-H, this one is weaker. Consequently, the concrete's wax-like components reduce compressive strength. Hence, in this study, the effects of water repellents on functional properties and the compressive strength of LFC will be figured out.

2.3.2 Thermal Conductivity

In a location with a hot temperature like Malaysia, it is crucial to employ low thermal conductivity construction materials to reduce heat input through the envelope into the structure. Foam concrete's cellular microstructure provides superior thermal insulating characteristics and low thermal conductivity. In the manufacturing process, using foaming agents causes pores to develop. Pores form due to the air bubbles produced during the foam-making process, which changes how heat is delivered. As a cementitious component, fly ash, in contrast, does little more than increase the aggregate's adherence to the air bubbles formed in the concrete matrix. However, the predominant fly ash granules would clog the pores because they work differently from the foaming agents. This situation is significant since the kind of aggregate and porosity are two elements that determine the value of heat conductivity.

Foamed concrete slabs exhibit good thermal insulation behaviour in practical applications, further complemented by decreased sorptivity and increased strength. It has been researched if foam concrete can enhance low-rise structures' thermal performance. The ground-supported slab foundation made of foam concrete has been proven to generate enough strength while being thermally efficient and having superior permeation characteristics.

This study will use fly ash and cement together as a binder. However, after research, it was found that LFC's properties can be enhanced by replacing cement with fly ash. Fly ash will react as a filler, producing a compact microstructure and a high-quality binder. The closed-cell structure was distorted due to the dense composition of the microstructure. Fly ash, defined as a pozzolan material, benefits when added since it will lessen the heat produced as the hydration process progresses. High levels of fly ash will decrease the need for cement, lowering the heat. As fly ash cools down and regulates temperature, it demonstrates that high fly ash percentages produce strong thermal conductivity. Fly ash is an additive that also minimises the number and size of pores. By acting as a filler, fly ash keeps the bubbles from fusing and ensures that the pores are distributed evenly. It will also affect the thermal characteristics of LFC.

The thermal insulation characteristic was found to reduce as the density volume grows, and the thermal conductivity interacts proportionately with the density (Amran, Farzadnia and Abang Ali, 2015). Therefore, the density will influence and decide how well-foamed concrete conducts heat. The relationship between concrete density and insulation is roughly inverse. The density, which significantly influences insulating capability, is affected by changes in the mortar/foam ratio. According to research by Mohd Sari and Mohammed Sani (2017), The thermal conductivity of foamed concrete is between 0.1 and 0.7 W/mK for dry densities between 600 and 1600 kg/m^3. Usually, foamed concrete has thermal conductivities between 5 % and 30 % lower than those found for standard-weight concrete. As densities decrease, thermal conductivities decrease as well. In this study, the water-cement ratio will be controlled from 0.5 to 0.6, and the density of foamed concrete will be fixed at ±1400kg/m^3 with around 50 kg/m^3 variance.

Besides, the temperature will also bring impact the thermal conductivity. Some reports show thermal insulation improves as the temperature drops (Laukaitis and Fiks, 2006). For example, when the temperature was dropped from 22 °C to -196 °C, there was a reported apparent reduction (down of 26 %) in the thermal conductivity of foam concrete. The decrease in high-density material was around 33.8 %. At the same time, there was an 89 per cent rise in modulus values, a 39 per cent decrease in deformation, and a 48 per cent improvement in load-bearing capacity.

Since there is no other research regarding the effect of calcium stearate on the foamed concrete's thermal conductivity, further studies will be done.

2.3.3 Sound Absorption

While thick concrete tends to deflect sound, foam concrete has a better capacity for sound absorption. The foamed concrete has a rate of sound absorption that is ten times higher than thick and foamed concrete. The level of foam inclusion, the distribution of pores, and the number, size, and homogeneity of the concrete may all influence how effectively it absorbs sound.

Furthermore, sound absorption is also affected by other factors, for instance, the density of foamed concrete. Foamed concrete's sound absorption was measured in terms of its sound absorption coefficient (Jones, et al., 2013). Compared to high densities, low-density foamed concrete was found to have a superior capability for sound absorption. This behaviour can be described by the material becoming more porous as density falls, increasing the surface area exposed to interact with sound waves and turning the sound energy into heat energy through friction. It should be noted, nevertheless, that if the porosity is excessive, sound waves may travel through the substance. Friction may also rise due to a rise in surface area in the microstructure of foamed concrete brought on by particles of unreacted fly ash. Besides, utilizing fly ash was anticipated to enhance sound insulation due to the influence of increased surface area on sound absorption properties. Thus, fly ash's ability to improve the microstructure of low-density foamed concrete while reducing extremely high porosity—which would otherwise allow sound waves to flow through easily—can be used to explain the phenomenon.

In this study, the sound absorption test will be done for the foamed concrete with and without calcium stearate. The sound absorption of the LFC with water repellent will be expected to decline after the research has been studied. Since water repellents will reduce water absorption for the foamed concrete, water repellent agents will also limit the water's movement inside the concrete, reducing the amount of water the concrete absorbs. That eventually causes the LFC to become more porous since there is less water content inside the LFC. As a result, increased porosity causes the sound absorption properties to fade. Therefore, it makes it easier for sound transmission due to the increment of porosity, causing lesser friction inside the LFC, and the sound wave can be easily transmitted through the foamed concrete. However, all the facts stated above are just in theory. In this study, the experiments for the effects of calcium stearate on sound absorption of LFC will be evaluated practically. The result will prove whether it is true.

2.4 Raw Material Used

2.4.1 Binder, Ordinary Portland Cement (OPC)

OPC is the most popular cement used worldwide as a critical element in mortar, concrete, and other materials. Grey Ordinary Portland Cement (OPC) is the most often used. OPC is produced utilising superior raw materials and a particular grinding procedure to provide a product that performs better and more consistently. OPC is mainly made up of 2 raw materials: calcareous and argillaceous. It included limestone, calcium, chalk, and so on for calcareous materials. For argillaceous materials, it included alumina, shale, slate, clay, etc. It is created by calcining clay and limestone minerals in a grinding clinker kiln and combining it with 2 to 3 % gypsum to create a fine powder. Producing cement involves crushing the raw materials combined with roughly two parts of calcareous materials to one part of argillaceous materials in ball mills, either under dry or wet conditions. The resulting dry powder or wet slurry is then heated in a revolving kiln at temperatures ranging from 1400 °C to 1500 °C.

After being burned in the kiln, the resulting clinker is cooled and ground in ball mills. Gypsum is added during the process, and the mixture is crushed to the desired fineness, depending on the product produced.

OPC has a variety of advantages. First, the outstanding binding qualities of this cement provide structural parts strength. It is less expensive than other varieties of cement, including white cement, the cement that hardens quickly, hydrophobic cement, etc. It also withstands shrinking and breaking but is less resilient to chemical assaults. On the other hand, most concrete masonry units also employ it.

Additionally, it has a significant property called sulphate resistance. It is used to treat mild sulphate resistance. Another benefit of this cement is that it is simpler to handle and set than other cement forms. These benefits make it more suitable for high-rise buildings, motorways, runways, and residential and industrial constructions. Additionally, it is advised for all RCC building types, concrete blocks, paver blocks, and more. For configuring it, no specific expertise is required.

Unfortunately, there are also disadvantages to OPC. For instance, OPC is not advised for building a mass structure because, owing to the pozzolanic effect, it has a higher heat of hydration than other types of cement like Portland Pozzolan Cement (PPC). OPC-concrete constructions are less durable than PPC-concrete ones in terms of durability. OPC is not advised for use in the construction of factories and workshops because of its lower resistance to harsh chemical assaults. In addition, PPC and many other cement forms are cheaper than OPC. At this point, the OPC is chosen due to its workability and strength performance and is more suitable for this study because just some simple foamed concrete with calcium stearate will be produced.

2.4.2 Sand

Sand comprises tiny rock fragments and mineral particles and occurs naturally. Depending on the source, its makeup varies. It is crucial to our everyday tasks and is regarded as one of the requirements for the growth of infrastructures. Hard granite stones are crushed to make sand; manufactured sand is artificial sand used in buildings as an alternative to river sand. Its size distinguishes it as finer than gravel and coarser than silt. It is the best sand ideal for construction because it is manufactured with the necessary gradation of fineness, shape, surface smoothness, texture, and consistency. It also strengthens the concrete by lowering segregation during placement, bleeding, honeycombing, voids, and capillaries.

Sand used to produce concrete is divided into three categories based on the proportion of each size of sand found in a sample: coarse, medium, and fine. Size might be the primary criterion for dividing materials into coarse and fine categories. Most of the sand's particles might be 4.75 mm or 5 mm in size. If most of the material is larger than 0.6 mm, it is considered coarse sand; otherwise, it is considered fine sand. Silt is made up of particles that are invisible to the human eye. Even though they provide considerable strength, fine sands are not advised for structural concrete since they make polishing the concrete's surface difficult. Additionally, since it is used in smaller quantities than other sands in concrete, it offers greater cohesiveness than coarse sand.

A sieve analysis (grading test) is utilised to acquire the particle size distribution of the sand material. There are additional applications for this study as well. For instance, it may assess if it complies with design, manufacturing control, and verification criteria. In addition, it requires much attention to the size distribution to understand how the material behaves when used frequently.

The sand size used for the foamed concrete will be essential at this point which will act as filler in producing the foamed concrete. By referring to research done by Lim, et al. (2014), they demonstrated the durability and roughness of lightweight foamed concrete using sand that ranged in size from 2.36 mm to 0.6 mm. When the sand gradation that produced lightweight foamed concrete became finer, its compressive strength improved (Lim, et al., 2014). Due to their greater total surface area, the microstructure was strengthened because a higher proportion of hydrated cement paste was needed to bind the finer sand particles together. Finer sand helps to reduce air void distribution and ultimately boost compressive strength. As a result, the foamed concrete's workability has been decreased, and its water-to-cement ratio has been increased for the appropriate consistency and stability. In short, the study found that specimens made with 0.6mm sand gradation had higher compressive and flexural strengths and flexural toughness compared to specimens prepared with coarser sand gradations. This was observed in both 28-day and 56-day water-cured specimens, as well as in seven-day water-cured specimens, 21-day air-cured specimens, and 49-day air-cured specimens. (Lim, et al., 2014). Hence, the sand distribution size of 0.6mm will be used for this study to produce the foamed concrete by providing better quality in consistency, stability, compressive strength and so on.

2.4.3 Water

Water plays an essential role in producing concrete. A chemical reaction occurs when water is added to the mixture and comes into contact with the cement. Most of the time, potable water is utilised to mix the concrete. The quality and usability of the concrete are put at risk when non-drinking water or water of uncertain purity is used. The structural qualities of concrete, such as strength and durability, are significantly decreased when contaminants are present in the water used to mix the concrete. Concrete strength may be a primary indicator of how water contaminants affect concrete quality compared to control specimens made with purified water. Numerous studies have demonstrated that using water or building next to a body of water with excessive salt weakens the concrete's compressive strength by 10 to 30 %. Compared to concrete made using purified water, concrete's strength has decreased. The high chloride concentration of water causes surface efflorescence, and chronic dampness, making the reinforcing steel susceptible to corrosion. The lean mix issue, which affects concrete constructions because of poor water quality, is especially severe in tropical areas.

Additionally, the properties of the concrete are unaffected if the mixing water contains suspended particles up to 0.02 per cent by weight of the total water used in the concrete. Many dispersed particles are discovered to alter the concrete's other qualities but not its strength. Additionally, the salt concentration in water negatively impacts the concrete's strength. Salts of manganese, tin, lead, copper, and zinc are among the most common salts that may be found in water. The increase in concrete strength is slowed down by zinc chloride in water.

Moreover, the pH range best for making concrete is typically between 6 and 8. It is stated that the finest water for the building is comparable to drinking water. Also, algae are seen on the aggregates' surface and in the water used for mixing. Due to the significant amounts of air entrainment caused by the algae entering the mix through the water, the strength of the concrete will be decreased.

2.4.4 Foaming Agent

A foaming agent is a crucial ingredient when making foamed concrete with prefabricated foams. Foaming agents promote foam formation, such as surfactants or blowing agents. A foaming agent creates very stable air bubbles impervious to the physical and chemical processes involved in mixing, putting, and hardening. The foam can be created by a substance made of natural or synthetic surfactants. It can be combined with the concrete or added as pre-foamed foam that has already been generated by a foaming machine (the foam is added to the mix simultaneously as it is prepared). A surfactant or blowing agent are substances that act as a foaming agent. A surfactant can lower a liquid's surface tension at tiny levels by lessening the effort required to produce foam or raise colloidal stability by preventing bubble coalescence. A blowing agent is a gas that adds to the foam's gaseous component.

Hydrolysed proteins or synthetic surfactants are the most typical materials for creating foams. The foam agents made of synthetic materials are less expensive and easy to use. They can be kept for a longer time in storage. These foams can be produced with less energy. Although expensive, the protein-based foam has a high performance and strength. Foam comes in two varieties: wet foam and dry foam. When making foamed concrete, it is not advisable to utilise wet foams with densities lower than 100 kg/m^3. They have a large, randomly formed bubble structure. The substance and water are sprayed onto a tiny mesh—bubbles in the foam created by this method range in size from 2 to 5 mm. Dry foam has a very stable physical makeup. A mixing chamber is forced with a water solution and the foaming agent through obstructions. The created foam has smaller bubbles than the wet foam. Less than 1mm make up that. These create an evenly spaced-out bubble structure.

Additionally, prefabricated foams' characteristics, cement pastes' qualities, and the interactions between foams and cement paste all played a significant role in the content, form, structure, and distribution of air pores in foam concrete. Some academics have also looked into how the foaming ingredient affects the characteristics of foamed concrete. The foam concrete was significantly influenced by the foaming agent used in density, fluidity, stability, pore structure, etc. (Hou, et al., 2021). On the other side, following Panesar (2013), the foaming agent affects foam concrete's pore size, pore size distribution, and pore connectivity, which results in variations in foam concrete's strength, water absorption, and frost resistance. According to his research, the type of foaming agent significantly impacted the mechanical properties but less so on the heat resistance and sorptivity coefficient. It is crucial since the type of foaming agent employed precisely affects the applications for which cellular concrete may be utilised. He contrasted many foaming agents, including protein-based and the CF500 and CF700 varieties of synthetic foaming agents. The kind of foaming agent employed affects the sorptivity coefficient and compressive strength. The highest sorptivity is produced by the synthetic-based foaming agent CF500, which suggests that a microstructure is made up of more capillary pores overall, a better-linked network, or both. Unfortunately, it has a lower compressive strength than the other foaming agents.

Hence, it can be concluded that different types of foaming agents might affect the properties of foamed concrete. So, only one type of foaming agent will be used throughout the study.

2.5 Summary

LFC is a lightweight material composed of Ordinary Portland Cement Paste (OPC plus a filler, often sand) and water with evenly distributed air spaces or pore structures produced by introducing air by mechanical means of a foaming agent. LFC is a lightweight, freely flowing cementitious material perfect for various building and construction-related applications. The LFC's highly porous structure has excellent water and frost resistance and offers high sound and thermal insulation. Water-repellent admixtures are therefore necessary for LFC to prevent excessive water absorption.

Additionally, research on the impact of water repellent on LFC has been analysed and evaluated. Calcium stearate will be employed in this investigation as a water-repellent. Besides, the optimum water-cement ratio will also be determined in the trial mix stage. After conducting several types of research, the compressive strength remained uncertain after adding calcium stearate when producing foamed concrete. Some researchers show that the compressive strength has increased, but some show that the compressive strength is reduced or remains unchanged. Hence, the compressive strength of foamed concrete after adding calcium stearate will be determined in this study. Lastly, since not much research is related to the functional properties of foamed concrete with calcium stearate, as shown in Table 2.1, tests would be conducted to determine the functional properties of foamed concrete, such as thermal conductivity and sound absorption. These tests are used to evaluate the effect of calcium stearate on the foamed concrete, and Table 2.1 shows the research done by other researchers.

Table 2.1: Summary of Different Types of Concrete With Several Types of Water Repellent Agents And Properties Determined In Their Study.

Author	**Type of Concrete**	**Density of Concrete (kg/m^3)**	**Type of Water Repellent**	**Properties that have been determined in the study**
Ma and Chen (2016)	Lightweight Foamed Concrete	550	Potassium trimethylsilanolate (PT), Calcium Stearate (CS), Siloxane-based polymer (SP)	Compressive strength, Thermal conductivity, Sorptivity, Hygroscopicity
Liu, et al. (2019)	Ultra-light foamed concrete	270-300	Calcium Stearate (CS), Zinc Stearate (ZS), polysiloxane (PS), Redispersible latex powder (RDL)	Water resistance properties
Lee, et al. (2018)	Lightweight Foamed Concrete	1200	Calcium Stearate (CS)	Compressive strength, water absorption, Sorptivity
Lee, et al. (2022)	Lightweight Foamed Concrete	1200	Calcium Stearate (CS)	Mechanical properties (Compressive strength, splitting tensile strength, flexural strength)
Ya, et al. (2013)	Recycled aggregate concrete	314 & 629	Silane-based	Mechanical properties and durability (Compressive strength, water absorption, chloride penetrability, durability)
Tang (2021)	Lightweight aggregate concrete (LAC), lightweight foamed concrete (LFC) and autoclaved aerated concrete	Not stated	Calcium stearate (CS), zinc stearate (ZS), sodium oleate (SO), silane and siloxane	Compressive strength and water absorption

Table 2.1 (Continued)

Maryoto (2020)	Self-compacting concrete (using Portland composite cement (PCC) and fly ash as binders)	Not stated	Calcium Stearate (CS)	Mechanical and Physical Properties (Compressive strength, water absorption, infiltration of chloride ion)
Rommel, et al. (2019)	Lightweight Foamed Concrete	1560-2000	-	Insulation properties (Compressive strength, thermal conductivity, sound absorption)

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter outlines all the steps and methods used to test the effect of calcium stearate on 1400 kg/m^3 foamed concrete. It covered the mixing procedures, the materials used, and the testing methods for various experimental inquiries. Fresh properties tests and hardened tests were all a part of the experiment that would be carried out. The optimal mix proportions were determined by studying the strength of 1400 kg/m^3 of lightweight foamed concrete that contains calcium stearate. The detailed explanation of material gathering and preparation was followed by a discussion of the mixing and testing procedures for the lightweight foamed concrete with water repellent.

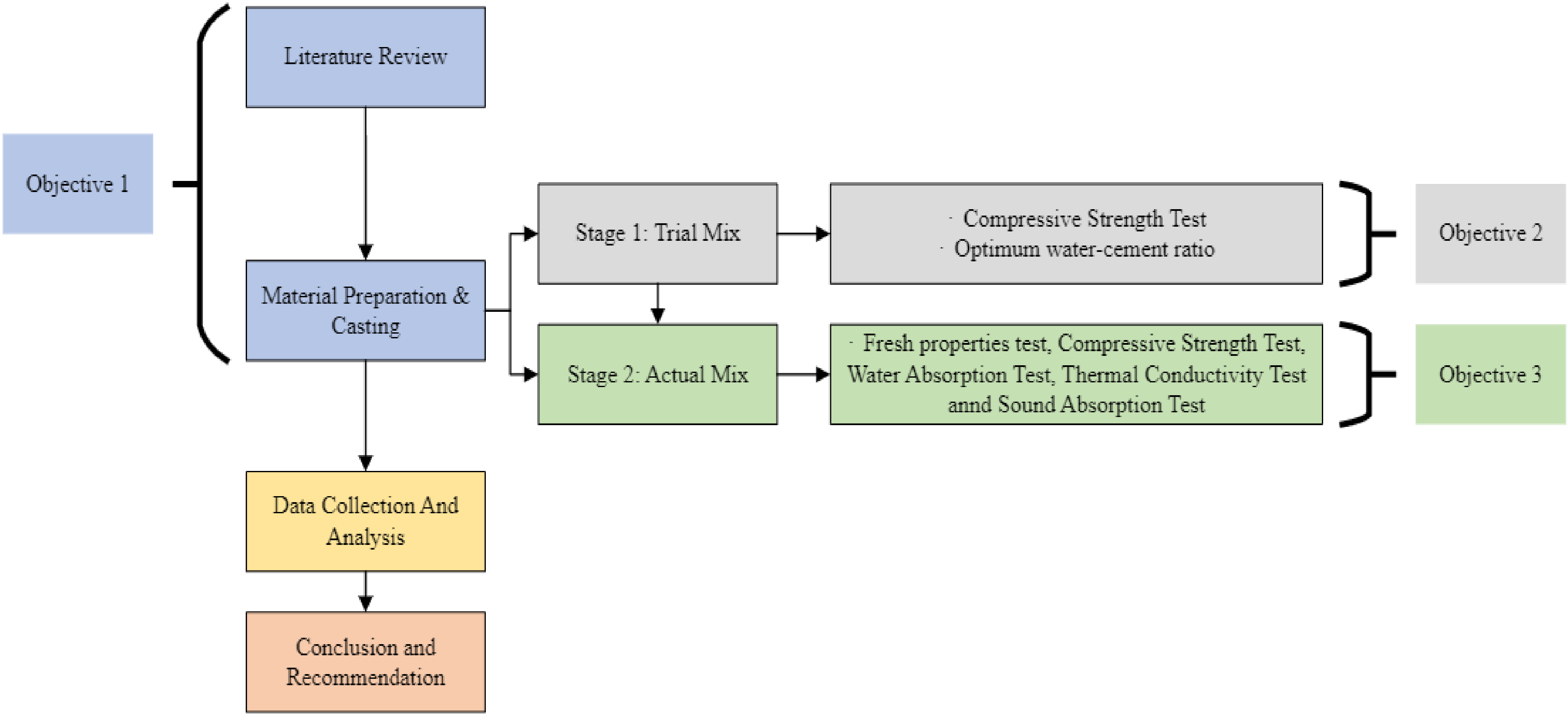


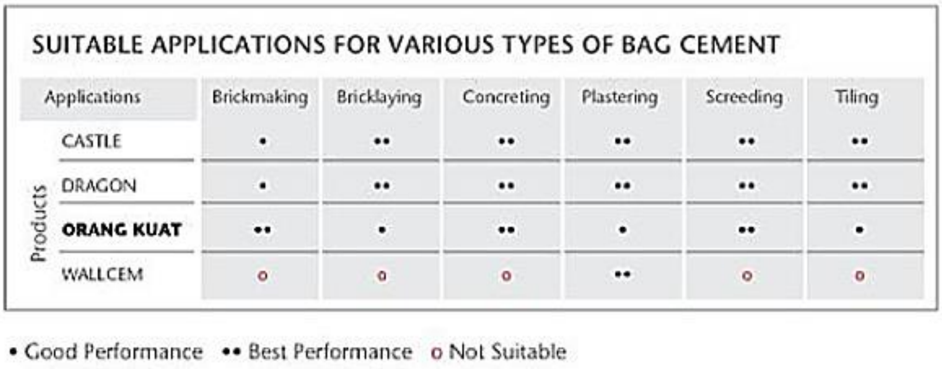
Figure 3.1: Flowchart of the overall study.

3.2 Raw Materials

Four main raw materials were used to produce foamed concrete: Ordinary Portland cement (OPC), foaming agent, water, sand and calcium stearate as water repellent. The raw materials were discussed in the following section.

3.2.1 Ordinary Portland Cement (OPC) (ASTM C150-07 2004)

The Ordinary Portland Cement (OPC), also known as "Orang Kuat OPC" from YTL, was used in this study. The YTL Orang Kuat high-strength OPC is explicitly designed for early de-moulding, handling, and usage. When time is of the essence, it is perfect for high-strength concrete applications. Moreover, this variety of OPC cement is appropriate for all general applications like structural concreting, where high strength is required to increase productivity. It was chosen by referring to Figure 3.2 because it is the most suitable choice for this study. Besides, it is made by utilising the most cutting-edge, energy-efficient cement manufacturing technology. This product was created with as little environmental impact as possible. Following ASTM C150-07 (2004), OPC needs to be sieved through a 0.3 mm sieve size and kept in an airtight container to avoid the cement powder being exposed to the air, which will cause the cement to harden. The cement is categorised as CEM I and MS EN 197-1 and fulfilled the ASTM C150-07 (2004) requirement of Type I cement. Bulk quantities of the product are offered in 50-kilogramme bags. It is produced under strict quality control, energy management, environmental management, and health and safety procedures. Lastly, the Orang Kuat OPC has a 28 days compressive strength of more than 42.5 MPa but lesser than 62.5 MPa.



SUITABLE APPLICATIONS FOR VARIOUS TYPES OF BAG CEMENT

	Applications	Brickmaking	Bricklaying	Concreting	Plastering	Screeding	Tiling
Products	CASTLE	•	••	••	••	••	••
	DRAGON	•	••	••	••	••	••
	ORANG KUAT	••	•	••	•	••	•
	WALLCEM	o	o	o	••	o	o

• Good Performance •• Best Performance o Not Suitable

Figure 3.2: Suitable Application for Various Types of Bag Cement (YTL, 2022).

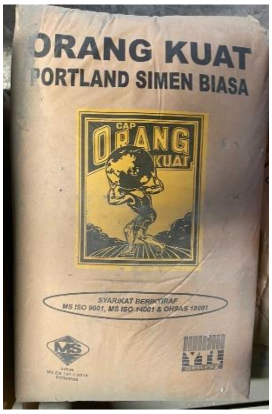
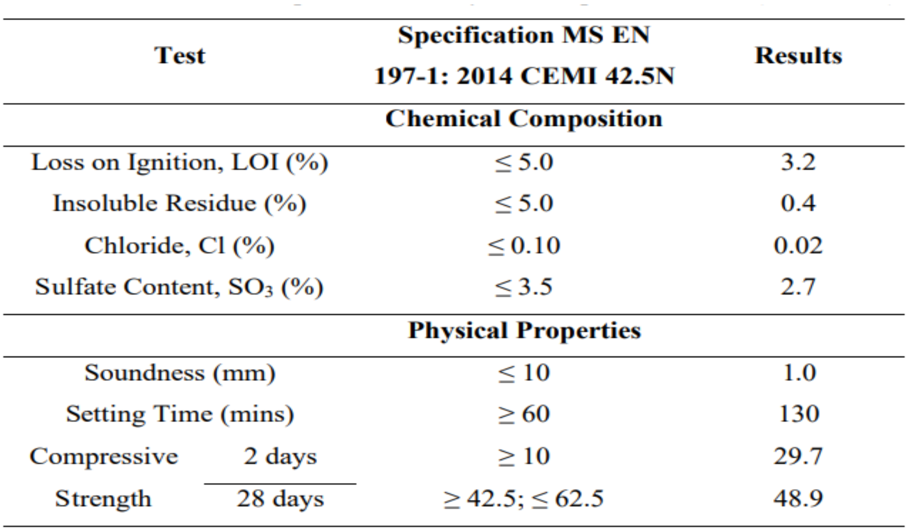


Figure 3.3: ‘Orang Kuat’ Ordinary Portland Cement.

Table 3.1: Composition and Properties of ‘Orang Kuat’ OPC (YTL, 2022).



Test		**Specification MS EN 197-1: 2014 CEMI 42.5N**	**Results**
Chemical Composition			
Loss on Ignition, LOI (%)		≤ 5.0	3.2
Insoluble Residue (%)		≤ 5.0	0.4
Chloride, Cl (%)		≤ 0.10	0.02
Sulfate Content, SO_3 (%)		≤ 3.5	2.7
Physical Properties			
Soundness (mm)		≤ 10	1.0
Setting Time (mins)		≥ 60	130
Compressive Strength	2 days	≥ 10	29.7
	28 days	≥ 42.5; ≤ 62.5	48.9

3.2.2 Sand (Find Aggregates) (ASTM C778 2004)

Fine aggregates, sometimes called fine sand, were used in this study and sieved through a 0.6 mm mesh size. The sand was used for casting LFC and two additional applications, the first of which was sieve analysis. Before sieving and casting, the sand must spend 24 hours in an oven heated to 100 and 110 °C to dry it out and remove all moisture completely. The air-dried method was rejected in favour of the oven-dried method because it was challenging to maintain the dry sand's saturation level. In addition, the inconsistent wetness of the sand in this study may be caused by variations in temperature and humidity while it is drying, utilising the air-dried approach. Therefore, it may impact the foamed concrete mixture's water-to-cement ratio. The oven-dried sand was sieved through a 0.6 mm sieve pan to maintain its fineness. Sand that passes through a sieve size of 600 µm was classified as a fine aggregate using the ASTM C778 standard specification. It was done to avoid bursting the bubble due to the coarser sand. The sand was stored in a plastic container with a cover after sieving.

3.2.3 Water (ASTM C1602 2004)

This study used tap water to produce the foamed concrete. Potable and non-potable water was utilized as the mixing water, according to ASTM C1602 standards. However, there was only low content of suspended particles in tap water because the tap water had undergone water treatment before supplying to the building. Besides, the pH value of tap water was between 6 to 8, which is acceptable and mentioned in Literature Review. Therefore, the effect of the impurities in tap water had a minor impact on the foamed concrete properties that this study determined. Hence, tap water was used for this study. The water-cement ratio was manipulated in the range of 0.5 to 0.6 with a 0.02 interval in the trial mix to find the optimum water-cement ratio by looking at the compressive strength for each different water-cement ratio of foamed concrete.

3.2.4 Foaming Agent

The foaming agent used was the Sika Aer 50/50, shown in Figure 3.4. It consisted of a blend of synthetic surfactants and polymers. It acted as a foaming agent for low-strength concrete or grout fills and lightweight pumped or poured concrete or grout used in constructions with extraordinarily high thermal and acoustic isolation levels. Depending on the water quantity, cement grade, lightweight aggregate, and sand, Sika Aer 50/50 may produce concrete with a specific weight of 800-1000 kg/m^3. Additionally, Sika® Aer 50/50 stabilizes components enabling consistently high air content maintenance during mixing and pumping. After pumping or pouring, the amount of concrete or grout was astonishingly constant due to the properties listed in Table 3.2 and its compliance with ASTM C869, the foaming agent Sika Aer 50/50 produced by Sika Kimia Sdn. Bhd was chosen to be used throughout this study.

The valve was sealed, and the compressed air valve was opened to allow compressed air to flow into the foam generator at a pressure of 0.5 MPa once all the foaming agents and water had been introduced. The foaming agent was added to the water in a 1:20 ratio to the volume added. After that, the stable foam was created and distributed through the nozzle. The density of the foam, which was created, was predicted to be 45 kg/m^3.

Table 3.2: Properties of Sika Aer 50/50 (Sika Kimia Sdn.Bhd, 2020).

Type	Sodium lauryl salt solution
Composition	A blend of synthetic surfactants and polymer
Appearance/Colour	Light straw liquid
Shelf Life	12 months from the date of production
Total Chloride Ion Content	Nil (less than 0.1 % by weight)
The Allowable Specific Weight of Concrete	800 -1000 kg/m^3 (depends on the quality of sands, aggregate, water, and cement)

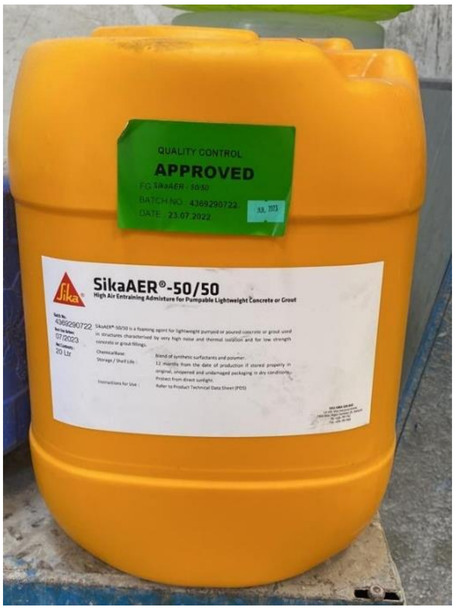


Figure 3.4: Sika Aer 50/50 Foaming Agent.

3.2.5 Calcium Stearate

Many lubricants, surfactants, and foodstuffs all have salt as a component. In the category of calcium soaps, calcium stearate is a carboxylate salt of calcium. It is a waxy, white powder, as shown in Figure 3.5. In contrast to typical sodium and potassium soaps, calcium stearate is a waxy substance that insoluble in water. Additionally, it has a low level of toxicity and is simple and inexpensive to manufacture. These features will lead to a broad application. For example, flow agents, surface conditioners, waterproofing agents, lubricants, etc. In this study, calcium stearate was used in solid powder form and can provide foamed concrete with hydrophobic features—calcium stearate from Sigma-Aldrich (M) Sdn. Bhd was utilised in this study. Table 3.3 shows the properties of calcium stearate, which refer to PubChem (2022).

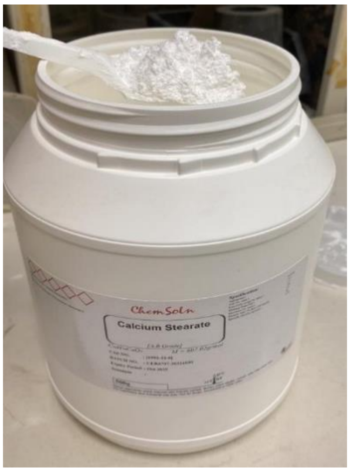


Figure 3.5: Calcium Stearate.

Table 3.3: Properties of Calcium Stearate (Sime Scientific, 2017).

Physical Characteristics	**Details**
Chemical Formula	$C_{36}H_{70}CaO_4$
Appearance	Fine White Powder
Gram/mol	607.02 g/mol
Free Fatty Acid (%)	1.0
Melting Point	150 °C
Specific Gravity (g/cm^3)	1.01
Moisture (%)	4.0

3.3 Mould

This study used a few types of mould depending on their testing method. The moulds with dimensions for each testing method are stated in Table 3.4.

Table 3.4: Types of Mould with Various Dimensions and Testing Methods.

Type of Mould	Dimension of Mould	Testing Method
Cubical	100 mm (L) x 100 mm (W) x100 mm (H)	Compressive Strength
PVC	30 mm (d) x 20 mm(H)	Sound absorption
PVC	60 mm (d) x 20 mm(H)	Sound absorption
Cuboid	300 mm (L) x 300 mm (W) x 50 mm (H)	Thermal Conductivity

Note:
L = Length, W= Width, H= Height, d= Diameter

3.4 Mix Procedure

Generally, the steps in producing foamed concrete were identical to those in creating conventional concrete. A mixing basin must first be prepared to mix the sand and cement uniformly. Next, the desired water-cement ratio was attained by pouring water into the basin. The water-cement ratio will be 0.5 to 0.6 with a 0.02 interval in the trial mix stage. Then, the foam was generated separately using a foam generator and a 1:20 ratio of a foaming agent to the water. Next, the prepared stable foam was added to the mixes to attain the acceptable density of 1400 ± 50 kg/m^3. Following the completion of the mixing process, freshly foamed concrete was poured into the various sizes of prepared moulds. After 24 hours of hardening and settling, the product underwent a curing phase that lasted between 7 and 28 days. The overall mix procedure is shown in Figure 3.6.

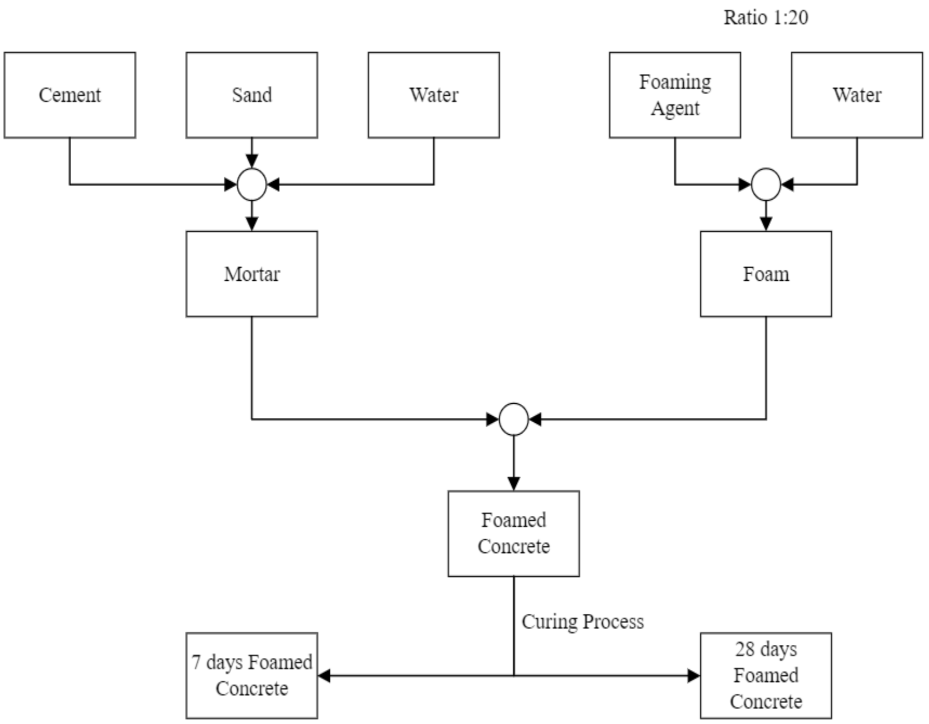


Figure 3.6: Mix Procedure.

3.5 Trial Mix

During the trial mix stage, the main aim is to achieve the most suitable water-cement ratio for the foamed concrete before incorporating calcium stearate. Therefore, six batches of foamed concrete were produced using a range of water-cement ratios from 0.5 to 0.6, with a 0.02 increment for each mix proportion. The foamed concrete specimens were subjected to a seven-day curing process before being tested for compressive strength. The compressive strength results for each mix proportion were recorded, and a graph was plotted to identify the mix proportion with the highest compressive strength. By doing that, the optimum water-cement ratio was acquired. For consistency and stability checking, the fresh density, as well as the hardened density, were recorded.

3.6 Mix Proportion

The ratio obtained for each base mix was used to compute the mix proportion of the base mix. It was assumed that all the foamed concrete had a cement-to-sand ratio of 1:1. The optimum water ratio was determined during the trial mix and applied for the actual mixes, with a 0.02 interval for the range of the water-cement ratios from 0.5 to 0.6. Equation 3.1 was used to determine the foam needed to create foamed concrete for each mixture. The proportion of foam was determined to produce foamed concrete with a density of 1400 kg/m^3 using Equation 3.1, which was used as a reference value. The actual mass of foam was calculated accordingly during the process of producing foamed concrete.

$$F_m = D_f \times M_m\left(\frac{1}{D_T} - \frac{1}{D_E}\right) \tag{3.1}$$

F_m= mass of foam required, kg,
D_f = density of foam, kg/m^3,
M_m = mass of the total mix, kg,
D_T = target density, kg/m^3, and
D_E = estimated density, kg/m^3.

Cement, sand, water, foam, and calcium stearate had densities of 3150-, 2600-, 2650-, 1000-, 45- and 1080 kg/m^3, respectively. Each base material's mass was allocated according to its ratio, using 1400 kg as the total mass for 1 m^3 of lightweight foamed concrete. The mass of materials needed to produce 1 m^3 of lightweight foamed concrete with a density of 1400 kg/m^3 was calculated and tabulated.

3.7 Sieve Analysis (ASTM C33 2013)

Sieve analysis is a necessary basic test for the aggregate and is often called the test of gradation. First, only 1000g of sand was weighted out to avoid overloading sieves because it caused inaccurate results and blinded the mesh. For a moist sample, it was dried at 105℃ in an oven. The sample was going to be put on the top sieve. The sieve was stacked with the biggest opening (1") at the top and the tiniest opening (0.6mm) at the bottom, as shown in Figure 3.7. The sieve stack was then set on the sieve-shaking apparatus. The cover plates were tightened to prevent the stack of sieves from moving away during the shaking process and prevent the dispersion of small sand particles into the air. After that, the timer was set to 15 minutes after the machine was switched on to prevent excessive sieving, which might cause sand degradation. The weight of the material retained in each sieve was determined, and from there, the percentage of the entire sample that passed through each sieve based on weight was computed. Finally, the fineness modulus and average sieve size were calculated. The fine aggregate must conform to ASTM C33 (2013) and have a fineness modulus between 2.1 and 3.1. Sand cannot be utilised for concrete casting if it does not adhere to the grading specifications.

Figure 3.7: Stack of Sieve.

3.8 Concrete Curing

The hardened foamed concretes were de-mould and labelled after 24 hours. The concrete samples were weighed to assess the hardened density before curing. Curing had a significant impact on the growth of concrete strength and durability. Besides, curing concrete involves maintaining the ideal moisture and temperature conditions for a prolonged time, both inside the concrete and close to the surface. A well-cured concrete has a sufficient amount of moisture to support continued hydration, the growth of strength, scaling, resistance to abrasion, resistance to freezing and thawing and volume stability. To maintain the temperature range of 25 °C to 30 °C, foamed concrete samples were fully submerged under the water in a water tank with a cover. Before performing the corresponding property tests, concrete samples were allowed to cure for 7 and 28 days, respectively. Figure 3.8 shows the curing process for the trial mix and the actual mix.

(a) (b)

Figure 3.8: Curing process for (a) trial mix, (b) actual mix.

3.9 Concrete Test

3.9.1 Fresh Density Test (ASTM C796, 2004)

This study's desired density for the foamed concrete is 1400 kg/m^3. A test known as the fresh density test can determine whether the foamed concrete produced falls within the acceptable limit of ±50 kg/m^3. A 1-litre volume of the empty container was filled with fresh foamed concrete. The additional filled foamed concrete was removed to assure the accuracy of the data. The foam was added and recorded accordingly when the density of the foamed concrete did not fall within 1350-1450 kg/m^3. Foamed concrete fresh density can be determined using Equation 3.2.

$$Density = \frac{Mass}{Volume} \tag{3.2}$$

3.9.2 Inverted Slump Test (ASTM C1611, 2005)

The inverted slump test was introduced as a quick and low-cost field test to determine concrete's workability. An empty inverted slump cone was placed on a pan for the inverted slump test. The inverted cone was tightly secured to the pan to prevent leakage of the foamed concrete during filling, as shown in Figure

3.9. Next, the slump cone was gently filled with freshly foamed concrete until it was full. It was done to stop the bubble from bursting. A slight and gentle shake for the slump cone is acceptable to reduce the air void in the freshly foamed concrete. Finally, the mould was raised vertically, and the spread's diameter of the slump was jotted down, as shown in Figure 3.9. Referring to ASTM C1611 (2005), the spread diameter should fall between 480 mm to 680 mm.

(a) (b)

Figure 3.9: Inverted Slump Test (a) Inverted Cone filled with concrete mix, (b) Slump.

3.9.3 Flow Table Spread Test (ASTM C230, 2004)

Concrete is subjected to a flow table test to ascertain its fluidity. It also shows the workability and consistency of the concrete. It is a standard test to check for high-fluidity concrete, which eventually collapses in a slump, particularly foamed concrete because it cannot keep its shape after removing the cone. First, the tabletop and mould were cleaned of dust, dirt, or other harsh materials before being let dry. The mould was securely maintained in the middle of the table. Next, two layers of freshly mixed concrete were carefully poured into the mould, each taking up half of the mould's capacity, as shown in Figure 3.10 (a). A tamping rod was used to tamp each layer 25 times. The extra concrete on the top layer was removed using a trowel to prevent leaks. The mould was removed immediately by lifting it vertically and steadily. The table was raised a maximum of 15 times to a height of 12.5 mm and lowered at a rate of up to 100 rounds per minute. The process for the flow table test is displayed in Figure 3.10. The average spreading width diameter and the number of drops were determined and jotted down to calculate the mean value, as shown in Figure 3.10(b).

(a) (b)

Figure 3.10: Flow Table Test (a) Cone filled with Cement Slurry, (b) Spread of Cement Slurry.

3.9.4 Compressive Strength Test (BS EN 12390, 2002)

Concrete's compressive strength was measured using a compressive machine, and the machine's settings will remain consistent throughout the study to ensure this factor does not influence the results. The previous concrete cubes with curing ages of 7 and 28 days were gone through this test. Before testing, the concrete from the curing at 7 and 28 days was dried in the oven. Before performing the compressive strength test, the specimen's dimensions were noted.

Next, the concrete was inserted into the compression machine and positioned centrally aligned with the base plate. The concrete was subjected to a constant axial load of 2 kN/s up until the point at which the specimen failed. The optimum reading was recorded from the machine. Equation 3.3 was used to calculate the compressive strength of foamed concrete by utilizing the maximum load applied at the point of failure and the cross-sectional area of the specimen. In addition, Figure 3.11 illustrates the compressive strength test carried out on the trial mix.

$$Compressive\ Strength = \frac{Maximum\ Load\ Applied}{Area} \tag{3.3}$$

Figure 3.11: Compressive Strength Test.

3.9.5 Thermal Conductivity Test

A thermal conductivity test was performed to ascertain the thermal conductivity of foamed concrete mixed with calcium stearate. Figure 3.12 shows the machinery used for the thermal conductivity test. First, the specimen was taken out of the water tank and oven dried for 24 hours at 105 °C ± 5 °C to remove any moisture since moisture accelerates heat transmission, which could substantially impact the result. Next, the specimen was removed and allowed to cool to room temperature. Next, a hot plate with a temperature of 40 °C was placed under the specimen, while a cold plate with a 25 °C temperature was placed simultaneously on top of the specimen. The hot plate, cold plate, and specimen will all transfer heat to one another. Then, every minute, the heat transfer readings were recorded. Finally, the thermal conductivity will be calculated using Equation 3.4.

$$Thermal\ Conductivity, k = \frac{Qh}{A(T_1 - T_2)} \tag{3.4}$$

where,

T_1 = Average temperature of the hot plate, K,
T_2 = Average temperature of the cold plate, K,
A = cross-sectional area, m^2,
k = thermal conductivity, W/mK,
h = thickness of specimen, m, and
Q = heat conduction, J/s.

Figure 3.12: Machinery Used for a Thermal Conductivity Test.

3.9.6 Impedance Tube Test (ASTM E1050-19, 2012)

This test, known as the "Impedance Tube Test," assessed the sound insulation properties of the foamed concrete based on the sound absorption coefficient. The concrete sample was first placed into the sample holder, and then the sample holder was tightly inserted into the impedance tube. The impedance tubes came in a total of two various internal diameters. The sound absorption test was conducted using the 30 mm and 60 mm impedance tubes. The concrete specimens were tested using a variety of frequency ranges from 200 Hz to 6300 Hz that the speaker produces to attain the maximum value for sound absorption efficiency. As soon as the test was started, a sound wave was generated, travelled down the tube, and was collected by microphones with a sound level metre. Using a programme named "VA-Lab", the sound absorption coefficient results were evaluated. The data was tabulated after being recorded. Figure 3.13 shows the setup of the apparatus for the impedance tube test.

Figure 3.13: Set up of apparatus for Impedance Tube Test.

3.9.7 Water Absorption Test

The water absorption test is a method to figure out how porous and permeable a material is. Usually, the material being tested is concrete or masonry. It entails calculating the volume of water that a material can hold after submerging it in water for a predetermined time. The percentage of water absorption that the foamed concrete specimen was identified by performing a water absorption test in accordance with ASTM C642-13 (ASTM, 2013). The results of an absorption test can be used to determine how many void spaces are present in LFC. For this test, cubic specimens with dimensions of 100 mm x 100 mm x 100 mm were utilised.

In order to attain saturated surface dry condition, the specimens were taken out of the curing tank and left indoors for 24 hours. The saturated surface dry weight was then calculated by weighing the LFC on a calibrated scale. The corresponding foamed concrete specimen was then baked in an oven for 24 hours until it was completely dry. Finally, Equation 3.5 was used to determine the concrete specimen's respective absorption based on the weight of saturated surface dry and bone-dry concrete specimens.

$$Water\ Absorption\ = \frac{W_{sat} - W_{dry}}{W_{dry}} \times 100\ \% \qquad (3.5)$$

where,

W_{sat} = weight of the saturated surface dry concrete specimen, kg,

W_{dry} = weight of the bone-dry concrete specimen, kg.

3.9.8 Stability and Consistency

The fresh, target, and hardened densities were used to evaluate the mixture's stability and consistency. The mixture was regarded as consistent when the fresh density of the foamed concrete mix was close to the target density. When the ratio of the fresh density to the hardened density is close to one, it was said that the foamed concrete mixture has excellent stability. The stability and consistency may be determined using Equations 3.5 and 3.6, and when they are close to one, it indicates that they are functioning well for the foamed concrete.

$$Consistency = \frac{Fresh\ Density}{Target\ Density} \qquad (3.5)$$

$$Stability = \frac{Fresh\ Density}{Hardened\ Density} \tag{3.6}$$

3.10 Summary

This study conducted stages 1 (trial mix) and 2 (actual mix). For stage 1, 1400 kg/m^3 of the foamed concrete was cast. The main objective is to obtain the optimum water-cement ratio from 0.5 to 0.6 with a 0.02 interval. Therefore, there will be no calcium stearate dosage at this stage. First, sieve analysis was carried out to obtain 0.06 mm of sand. Then, the sand was used with cement and water to form mortar, and foamed concrete was produced by adding foam generated from the foam generator and water. Those specimens underwent a seven-day curing process and were then used for the compressive strength test. Finally, the compressive strength graph against the water-cement ratio was plotted to assess the ideal water-cement ratio for foamed concrete.

After obtaining the optimum water-cement ratio, the foamed concrete was cast with the optimum water-cement ratio incorporated with calcium stearate, from 0 % to 1 % with a 0.2 % interval. Then, the concretes were cast in various mould sizes according to the test requirement. Before that, the fresh properties tests were done. For instance, the flow table test, inverted slump test and fresh density test were conducted to obtain the data needed. Before the hardened properties test, all specimens undergo a 7- and 28-day curing process. Then, hardened properties test, including compressive strength test, thermal conductivity test, and impedance test, were conducted, and the test result was recorded and analysed.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the sieve analysis, the data collected from tests such as fresh and hardened properties tests for trial mix and actual mix were analysed and tabulated after conducting those tests. This chapter was separated into two parts; trial mix and actual mix, and all the tests conducted were discussed after analysing and tabulating the data. For the trial mix, the optimum water-cement ratio was obtained by conducting the compressive strength test and was used to proceed to the next stage. The actual mix included several tests with various dosages of water-repellent, and calcium stearate, to determine the effect of the water-repellent towards the compressive strength and functional properties of LFC. To further investigate the impact of the water repellent towards the functional properties of LFC, a discussion on the different dosages of calcium stearate from 0 % to 1 % with 0.2 % intervals was done for several properties, including the compressive strength, thermal conductivity, sound absorption, and so on. The samples had 7 and 28 days of curing age for the compressive strength and sound absorption tests. On the other hand, for the thermal conductivity test, the samples were cured for 28 days before testing.

4.2 Sieve Analysis

After carrying out the sieve analysis, the mass of sand particles left on each sieve was recorded in Table 4.1. The total per cent passing and total per cent retained on each sieve was tabulated based on the mass of sand retained on each sieve. After tabulating the data collected from sieve analysis, the data was analysed based on the ASTM C33 (2013). By referring to ASTM C33 (2013) for fine aggregates, the result showed that the fine aggregates from the sieve analysis were within the range of the requirement. Furthermore, the fineness modulus of fine aggregate is shown in Table 4.1. Fineness modulus was used to determine the fineness of the aggregate, where a lesser number of fineness moduli often denotes a finer aggregate. The fineness modulus of fine aggregates fell within the range of 2.1 to 3.1, as specified by ASTM C33 (2013). The calculated fineness modulus from the sieve analysis was roughly 2.5, within the required range. As a result, the sand was appropriate for casting foamed concrete.

Table 4.1: Calculated Percentage Error, Fineness Modulus and Average Sieve Size for Sieve Analysis.

Percentage Error	0.04 %
Fineness Modulus	2.50
Average Sieve Size	0.45mm

Note:

$$Fineness\ Modulus = \left(\frac{Sum\ of\ Cumulative\ Percentage\ of\ Sand\ Retained\ on\ Sieve}{100}\right)$$

Table 4.2: Data Collected from Sieve Analysis with Grading Requirement.

Sieve Size (mm)	**Weight**				**Cumulative Percentage**		**Grading Requirements for Total Percent Passing by ASTM C33 (%)**
	Empty sieve (g)	**Material + sand retained on sieve (g)**	**Material retained on each sieve (g)**	**Material retained on each sieve (%)**	**Coarser (%)**	**Finer (Total Percent Passing) (%)**	
4.75	489.11	494.51	5.4	1.08	1.08	98.92	95 to 100
2.36	468.14	506.54	38.4	7.68	8.76	91.24	80 to 100
1.18	371.36	442.36	71	14.21	22.97	77.03	50 to 85
0.6	334.45	463.75	129.3	25.87	48.84	51.16	25 to 60
0.3	341	488.5	147.5	29.51	78.35	21.65	5 to 30
0.15	333.93	393.23	59.3	11.86	90.22	9.78	0 to 10
Pan	239.95	288.85	48.9	9.78	100.00	0.00	-
Total			499.8				

The graph of the percentage of passing of finer sand against the sieve size of finer aggregate was plotted in a logarithmic scale graph and shown in Figure 4.1, and there was a particle size distribution curve shown in the graph. After interpreting the particle size distribution curve shown that the fine aggregates are well-balanced and distributed among sand particle sizes. By referring to the fineness modulus and the data shown in Table 4.2, it indicated that most of the sand was retained in sieve sizes 0.3 and 0.6mm, and there were up to 51.16 % of the fine aggregates finer than 0.6mm. The average sand size and percentage error were also calculated and are shown in Table 4.2. Hence, the result demonstrated that there would be approximately 256g from a total of 500g of fine aggregates, and the average size of sand was around 0.45mm with a percentage error of 0.04 %.

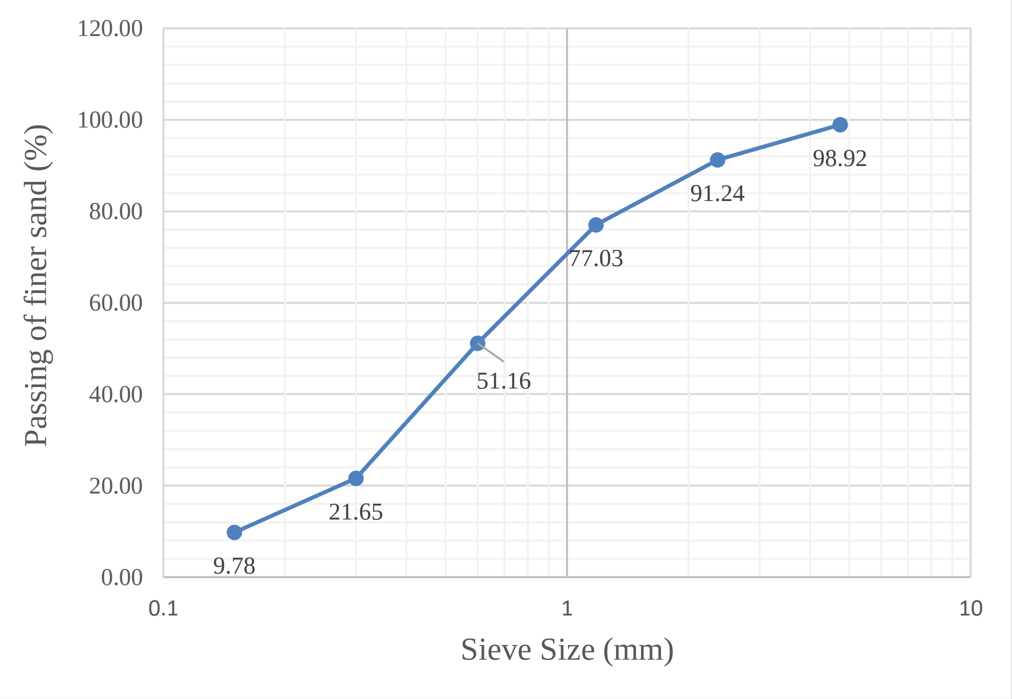


Figure 4.1: Percentage of Passing of Finer Sand against Sieve Size of Finer Aggregate.

4.3 Trial Mix

The first stage, the trial mix, was used to obtain the optimum water-cement ratio between 0.5 to 0.6 with 0.02 intervals by determining and analysing the highest compressive strength from the concrete samples without adding the water-repellent- calcium stearate. First, the concrete samples were cured for 7 days before the compressive strength test was conducted. Then, the compressive strength test data for all samples were tabulated and discussed with the trend of compressive strength when the w/c ratio increased from 0.5 to 0.6 in the following sub-section with graph and table.

4.3.1 Mix Proportion

All the concrete mixes had the same cement-sand ratio for the trial mix, which was 1 to 1. After that, four types of materials were used to produce LFC: cement, sand, water and foam in the trial mix stage. Table 4.3 states the total weight of materials used to produce LFC for each w/c cement ratio.

Table 4.3 shows that the actual foam added is way more than the calculated foam required when producing some concrete mixes, including LFC-0.5, LFC-0.54, LFC-0.56, LFC-0.58 and LFC-0.60. Table 4.3 shows that the most significant increment of foam used was around 49 %, and the lowest was 0 %. The reason that caused the additional foam to be used was the mixing method. All the concrete mixes were mixed by using bare-handed but not using any machinery to minimize the bursting of foam bubbles. Thus, the foam might burst due to excessive force acting on the bubbles during mixing.

On the other hand, the friction between the sand, cement and foam could be the key reason that causes the bursting of foam bubbles. It is due to the surface roughness of sand being way higher than the bubble, and there will be a force that resists the relative motion between the materials during the mixing process. Hence, the actual amount of foam added was higher than the calculated foam to be added.

Table 4.3: Mix Proportion of Foamed Concrete for Trial Mix in 0.0012 m^3.

Specimen	**w/c ratio**	**Material (kg)**			**Calculated Foam Required (g)**	**Actual Foam Added (g)**	**Difference between calculated foam and actual foam (%)**
		Cement	**Sand**	**Water**			
LFC-0.5	0.5	2.016	2.016	1.008	54	80.49	49.06
LFC-0.52	0.52	2	2	1.04	48.6	48.6	0.00
LFC-0.54	0.54	1.984	1.984	1.071	45.69	65.94	44.32
LFC-0.56	0.56	1.969	1.969	1.103	45.69	61.27	34.10
LFC-0.58	0.58	1.953	1.953	1.133	39.41	50.21	27.40
LFC-0.6	0.6	1.938	1.938	1.163	42.63	48.23	13.14

Note:

$$Calculated\ foam\ required = Density\ of\ foam \times Weight\ of\ total\ mix \times \left(\frac{1}{Target\ Density} - \frac{1}{Estimate\ Density}\right)$$

4.3.2 Flow Table Test

Flow table test is used to determine the fluidity of the concrete mixes and the workability of the concrete mixes in different w/c ratios. Table 4.4 shows the data collected from the flow table test, and by referring to it, the number of drops for each w/c ratio is similar, which is 25 drops. Besides, the spread values for each w/c ratio were different and increased from 19.5cm to 24cm when the w/c ratio increased. When the w/c ratio increases, the water content increases, causing the fluidity of concrete mixes to increase and spread wider in diameter. The workability of the fresh mix depends on the mix proportion, and workability will increase when the w/c ratio increases (Pranjal, et al., 2017). In fact, this may be due to more water being available for lubricating at greater water-cement ratios, increasing the workability. Thus, the workability and fluidity of fresh mixes increase when the w/c cement ratio increase.

Table 4.4: Data Collection of Flow Table Test.

w/c ratio	**Flow Table Test**	
	No. of Drops	**Spread Value (cm)**
0.5	25	19.5
0.52	25	20
0.54	25	21.5
0.56	25	22.5
0.58	25	24
0.6	25	25

Note:
Spread value = average diameter from 2 different angles.

4.3.3 Stability and Consistency for Trial Mix

The fresh state properties, stability and consistency checking for the fresh concrete were determined and tabulated in Table 4.5. The fresh and hardened densities were within the allowable density range of 1400 ± 50 kg/m^3.

Table 4.5: Consistency And Stability Checking of LFC for the Trial Mix.

w/c ratio	**Target Density (kg/m^3)**	**Fresh Density (kg/m^3)**	**Hardened density (kg/m^3)**	**Consistency**	**Stability**
0.5	1400	1411	1432	1.008	0.985
0.52		1390	1407	0.993	0.988
0.54		1438	1421	1.027	1.012
0.56		1423	1406	1.016	1.012
0.58		1421	1435	1.015	0.99
0.6		1448	1442	1.034	1.004

Note:

$$Consistency = \frac{Fresh\ Density}{Target\ Density}$$

$$Stability = \frac{Fresh\ Density}{Hardened\ Density}$$

The consistency of each w/c ratio fresh concrete was in the range of 0.993 to 1.034. The result was very close to 1, meaning it was very consistent. Besides, the result was also under the allowable consistency range between 0.934 and 1.036. Furthermore, the researchers stated that foam, water content, and other solid ingredients in the base mix would affect the stability and consistency of the foamed concrete (Kunhanandan Nambiar and Ramamurthy, 2008). When the foam was added, the basic mix's consistency significantly decreased. This decrease in the consistency of foam concrete was most likely caused by the increased cohesiveness and decreased self-weight brought on by a more extensive air content. Table 4.5 shows no significant influence of foam and w/c ratio towards the concrete. It might be due to the lack of difference in the foam added to the concrete mix during the mixing process.

The allowable range for stability checking is 0.964 to 1.036. The stability checking was conducted, and the result fell under a range of 0.985 to 1.012, within the stability range. From that, the result of stability checking shows that they are close to 1, indicating that the concrete mix produced was stable and there will have sufficient strength for the concrete mix’s matrix to retain individual aggregate particles in a homogeneous dispersion. In addition, the bursting of bubbles was also minimised under the stable concrete mix condition. The effect of w/c ratio and foam towards the stability of concrete mix does not perform any evidence and bring any obvious effect in this fresh state properties’ checking.

Since the stability and consistency for all the concrete mixes for each w/c ratio are close to 1 and within the allowable range of consistency and stability, they were considered stable and consistent.

4.3.4 Compressive Strength Test for Trial Mix

Different water-cement ratios and densities provided different compressive strengths of foamed concrete. Nevertheless, the water-cement ratio is the most significant element affecting compressive strength (Zhang, et al., 2018). The water-cement ratio affects foam concrete's pores’ connectivity, distribution, and size (Liu et al., 2016). If the water-cement ratio is higher, the relative viscosity will be lower. As a result, the cement paste will have a reduced ability to sustain bubbles at the same foamed concrete density. As a result, bubbles may combine to create larger ones more quickly as well.

Moreover, this causes a rise in the size of the foam bubbles, which weakens the compressive strength. Eventually, the w/c ratio added to the mixture will affect the bubbles' uniformity and stability and the foamed concrete's compressive strength. Besides, the w/c ratio in a range of 0.5 to 0.6 is proposed to be investigated because this range of water-cement ratio is just a little higher than the w/c ratio’s normal concrete, which is within 0.4 to 0.5. On the other hand, most of the w/c ratio concrete is between 0.4 to 0.6 (Levy, 2012). There will be cement and sand to mix with water to produce foamed concrete instead of coarse aggregate to produce normal concrete, which requires lesser water for the mixing process. Hence, in this study, the optimum water-cement ratio between 0.5 to 0.6 with 0.02 interval for 1400 ± 50 kg/m3 foamed concrete is determined by testing their compressive strength after the curing age of 7 days.

Water is a crucial reactant in cement hydration. During the mixing process, when water is added to the dry mix, which includes sand and cement, they react with each other, and the hydration process occurs. At the same time, C-S-H gel is formed, and it is the key product that provides strength for foamed concrete. The mixture, also called a binder, is produced, and the properties of the binder will impact the properties of foamed concrete. On the other hand, a low water-cement ratio will result in poor workability due to an unfavourable distribution of cement particles in the foamed concrete mix. It has been proved through the result shown in Figure 4.2. The compressive strength of foamed concrete with 0.5 w/c ratios has the lowest compressive strength. It is due to the fact of there is insufficient water to proceed with the hydration process causing lesser C-S-H gel formed and lower compressive strength.

In contrast, too much water during the mixing process does not bring any extra advantage and does not provide more compressive strength to the foamed concrete. Instead, it negatively impacts the foamed concrete by creating interconnected capillary pores in the foamed concrete and causing a decline in its strength. As a result, the optimum w/c ratio for each foamed concrete density will be different. Hence, a trial mix is a must to be conducted to obtain the optimum water-cement ratio for the desired density of the foamed concrete before carrying out further study of the research to figure out the optimum water required for foamed concrete to proceed with the hydration process and produce the maximum C-S-H gel as well as the highest compressive strength and workability of foamed concrete.

The result of the compressive strength test for the foamed concrete is plotted in Figure 4.2. Plotting the graph in Figure 4.2 is intended to create a bell-shaped curve where the compressive strength can reach its maximum in a fixed range of w/c ratio. The foamed concrete's compressive strength increased from 0.5 to 0.56 w/c ratio and started turning down until 0.6 w/c ratio. Referring to Figure 4.2, the highest compressive strength of concrete reaches a maximum of 8.343 MPa with a 0.56 w/c ratio. The foamed concrete with a w/c ratio of 0.56 yielded the highest compressive strength among all the other water-cement ratios and can be considered the optimal point. Thus, the w/c ratio of 0.56 will be used to carry out the next stage, the actual mix, for further investigation of the impact of calcium stearate towards compressive strength and functional properties of foamed concrete.

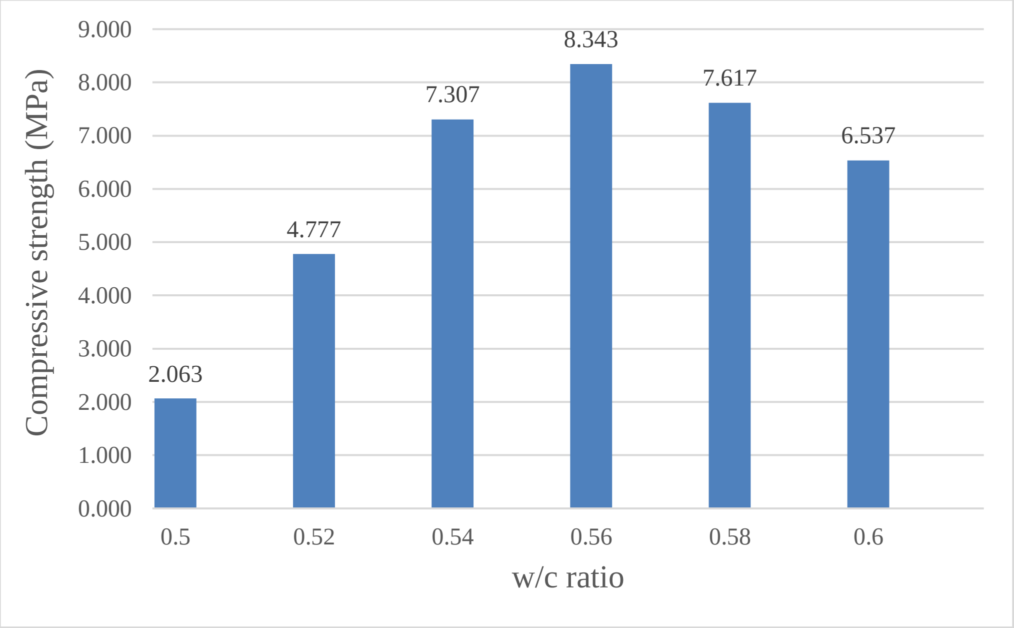


Figure 4.2: Comparison of Compressive Strength for Different w/c Ratios.

4.3.5 Summary of Trial Mix

The trial mix was completed to obtain the optimum w/c ratio of foamed concrete within the 0.5 to 0.6 w/c ratio with 0 % of calcium stearate during the mixing process. The reason for not considering including calcium stearate in the trial mix is that it had been proved that the optimum water-cement ratio would not affect the properties of LFC when the different dosage of calcium stearate is incorporated (Lee, et al., 2022). Hence, the optimum w/c ratio of 0.56 is determined and will be used to proceed with the following stage, the actual mix, to investigate the effect of calcium stearate towards the compressive strength and functional properties of foamed concrete. Table 4.6 shows the summary of the result for the trial mix.

Table 4.6: Summary of Result for the Trial Mix.

Sample name	w/c	Dimension (L x W x H) (mm)	Saturated weight (g)	Oven dry weight (g)	Actual Foam added (g)	Theoretical Foam added (g)	Fresh Density (kg/m^3)	Flow table test		Hardened Density (kg/m3)	Consistency	Stability	Compressive Strength (MPa)	Average Compressive (MPa)	Perfomance index (MPa/1000kg/m 3)	Average Perfomance index (MPa/1000kg/m3)
								Drops	Spread Value (cm)							
LFC-TM-0.5-A	0.5	100 x 100 x 99	1519.6	1188.6	80.49	54	1411	25	19.5	1447	1.008	0.985	2.91	2.063	2.011	1.438
LFC-TM-0.5-B		98 x 100 x 100	1488.3	1258.2						1425			1.50		1.053	
LFC-TM-0.5-C		99 x 99 x 100	1495.1	1191.2						1424			1.78		1.250	
LFC-TM-0.52-A	0.52	98 x 97 x 99	1479.8	1232.8	48.6	48.6	1390	25	20	1374	0.993	0.988	4.19	4.777	3.049	3.391
LFC-TM-0.52-B		100 x 99 x 100	1491	1237.8						1432			4.94		3.450	
LFC-TM-0.52-C		100 x 97 x 98	1489.3	1246.4						1415			5.20		3.675	
LFC-TM-0.54-A	0.54	100 x 99 x 100	1532.2	1289	65.94	45.69	1438	25	21.5	1445	1.027	1.012	7.53	7.307	5.211	5.141
LFC-TM-0.54-B		99x 100 x 100	1514.2	1275.4						1424			7.41		5.204	
LFC-TM-0.54-C		99 x 99 x 99	1510.8	1269.6						1394			6.98		5.007	
LFC-TM-0.56-A	0.56	98 x 99 x 99	1495.8	1244.6	61.27	45.69	1423	25	22.5	1378	1.016	1.012	6.79	8.343	4.927	5.925
LFC-TM-0.56-B		100 x 99 x 99	1551	1265.4						1433			9.12		6.364	
LFC-TM-0.56-C		99 x 100 x 97	1520.8	1294						1407			9.12		6.482	
LFC-TM-0.58-A	0.58	100 x 100 x 100	1541.4	1232.8	50.21	39.41	1421	25	24	1441	1.015	0.990	8.01	7.617	5.559	5.308
LFC-TM-0.58-B		99 x 99 x 100	1513.2	1237.8						1437			7.34		5.108	
LFC-TM-0.58-C		99 x 100 x 99	1486.8	1246.4						1427			7.501		5.256	
LFC-TM-0.6-A	0.6	100 x 100 x 100	1526.2	1138.6	48.23	42.63	1448	25	25	1443	1.034	1.004	6.01	6.537	4.165	4.532
LFC-TM-0.6-B		100 x 100 x 99	1523	1158						1446			7.32		5.062	
LFC-TM-0.6-C		99 x 99 x 100	1535.6	1121.2						1437			6.28		4.370	

4.4 Actual Mix

The optimal water-cement ratio of 0.56 obtained from the trial mix was then used for the actual mix. The primary goal of the actual mix was to investigate the impact of the calcium stearate on LFC with the optimal water-cement ratio obtained from the trial mix. For the actual mix, several tests were conducted. For example, the fresh properties test, compressive strength test, sound absorption test, and thermal conductivity test. Before the tests were conducted, the specimens were separated into two batches, which were a 7- and 28-day curing process, and all of the specimens were placed in a water tank to be cured. The tests were used to ascertain LFC’s compressive strength and functional properties, including thermal conductivity and sound absorption. After these tests, the result was tabulated and analysed by plotting graphs. The impact of calcium stearate on LFC was discussed in the following subsection.

4.4.1 Mix Proportion

Table 4.7 shows the mix proportion for LFC with 0, 0.2, 0.4, 0.6, 0.8, and 1 % of CS added into the fresh concrete to produce a total volume of 0.0115 m^3 for each batch of LFC, each percentage of LFC was considered as one batch. The optimum cement-to-water ratio, 0.56, was used to prepare all the materials, while the cement-to-sand ratio remained at 1.0. By referring to Table 4.7, the foam estimated and the foam added had different results since the foam bubbles broke during the mixing process. Moreover, the difference between the actual foam added and the calculated foam added was calculated and shown in percentage in Table 4.7, which has an increment from 0 to 44.32 %, provided that the appropriate processes were followed during mixing the LFC. The highest difference between calculated foam and actual foam had reached 44.32 %. As mentioned above in the trial mix part, it might cause by an excessive force acting on the bubbles. Before that, the mixing method was also determined and finalized by using bare hands instead of machinery to avoid friction between the bubbles and rough surfaces inside the machinery, which will cause the bubbles to burst during the mixing process. Thus, the bursting of bubbles causes the fresh density of concrete mix not to fall under the allowable range, 1400 ± 50 kg/m^3 and additional foam might need to be added to lower the fresh density to the allowable range.

Table 4.7: Mix Proportion of Foamed Concrete for Actual Mix with W/C Ratio of 0.56 in 0.0115 m^3.

Specimen	**Material (kg)**				**Calculated Foam to be added (g)**	**Actual Foam Added (g)**	**Difference between calculated foam and actual foam (%)**
	Cement	**Sand**	**Water**	**CS**			
LFC-0%	8.781	8.781	4.9174	0	240.85	289.03	20.00
LFC-0.2%	8.781	8.781	4.9174	0.018	175.76	175.76	0.00
LFC-0.4%	8.781	8.781	4.9174	0.035	203.8	294.12	44.32
LFC-0.6%	8.781	8.781	4.9174	0.053	175.76	175.76	0.00
LFC-0.8%	8.781	8.781	4.9174	0.07	190.14	190.14	0.00
LFC-1%	8.781	8.781	4.9174	0.088	190.14	238.31	25.33

Note:

$$Calculated\ foam\ required = Density\ of\ foam \times Weight\ of\ total\ mix \times \left(\frac{1}{Target\ Density} - \frac{1}{Estimate\ Density}\right)$$

4.4.2 Fresh Properties Test (flow table test, inverted slump test)

The flow table test was conducted to assess the consistency of the fresh mix before adding the foam, while the inverted slump test was carried out to evaluate the consistency of the fresh mix after adding the foam. The spread values were recorded and presented in Table 4.8. By referring to it, the flow table test shows that the fluidity of the fresh mix decreases as the spread values decrease when the dosage of CS increases. This result significantly shows that the CS lowers the fluidity of the concrete mix. When the fluidity of the fresh mix before adding foam decreases, it indicates a higher fresh density. The amount of foam needed to be added is directly related to the fresh density of the concrete mix. Therefore, a more significant amount of foam is required to reduce the fresh density of the concrete mix. The fluidity of fresh mix after adding foam will be minorly affected and should be more fluid due to the foam containing 5 % water.

However, by referring to Table 4.8, the spread values for the inverted slump test also decrease when the dosage of CS increases. Therefore, it shows that the fluidity of the fresh mix does not show any obvious effect after the foam was added.

Table 4.8: Data Collection of Flow Table Test and Inverted Slump Test for Different Dosage of CS.

Dosage of CS	**Flow Table Test**		**Inverted Slump Test**
	No. of Drops	**Spread Value (cm)**	**Spread Value (cm)**
0 %	24	24	47
0.2 %	25	23.5	45.5
0.4 %	25	21	45.5
0.6 %	25	20.5	44.5
0.8 %	25	19	43
1 %	25	17	43

Note:
Spread value = average diameter from 2 different angles.

Besides, other features of the fresh mix had been affected, including the porosity and pore structure. When CS was incorporated with LFC, it enhanced the waterproofing properties of the LFC by enclosing the capillaries, pores, voids, and air pockets present in the LFC with crystalline structure (Lee, et al., 2022). Furthermore, it showed that the porosity and pore structure had been affected instead of the fluidity of the fresh mix due to the dosage of CS into LFC.

In addition, the graph in Figure 4.3 shows the trend of water absorption of LFC at 7 and 28 days of curing age with different dosages of CS. The result shown in Figure 4.3 matches the research by Liu, et al. (2019), which stated that water absorption was higher when curing ages were longer. Besides, it shows similarities with the result from research done by Lee, et al. (2022) for 28 curing days of LFC with the dosage of CS from 0 to 0.6 %, where forming a ‘U’ shape for the graph. The water absorption of LFC decreases initially when the dosage of CS increases. Maryoto (2017) discovered that using calcium stearate can lessen the amount of water absorbed. The water absorption of LFC was reduced due to the improvement of concrete watertightness when CS was added to LFC. Waterproofing admixtures can enhance concrete watertightness and cement matrix self-sealing (Matar and Barhoun, 2020). It explained why the water absorption of LFC decreased. Hence, CS reduced the fluidity of fresh mix and water capabilities of LFC when a specific dosage of CS was added to LFC.

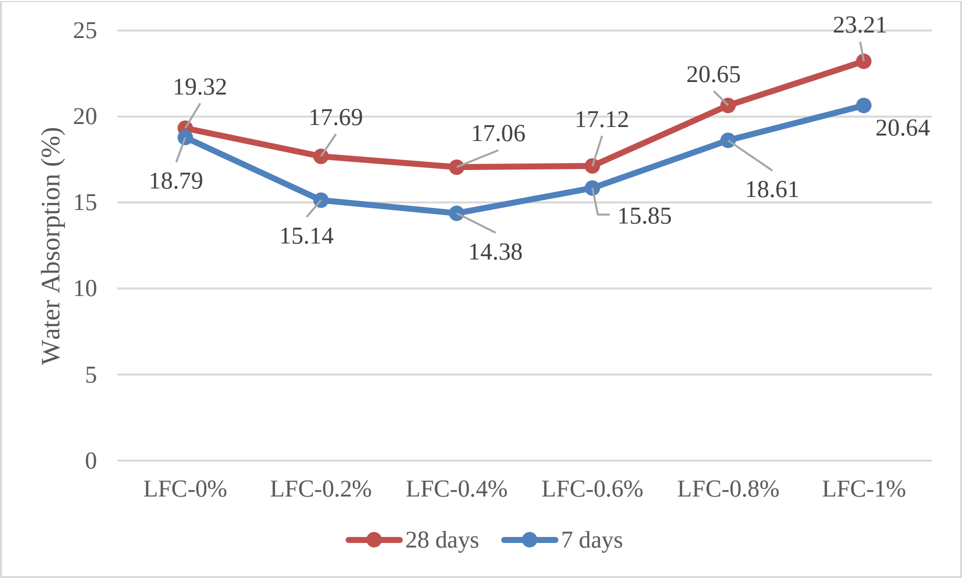


Figure 4.3: Water Absorption for 7 and 28 Curing Days of LFC with Dosage of CS.

According to Maryoto, et al. (2012), any unreacted CS compound will occupy the capillaries when fresh concrete hardens and finally be released when the hardened LFC comes into contact with water. The radius of the newly created capillaries will slightly expand; as a result, making it more straightforward for water to enter the LFC. When CS has overdosed into LFC, the water absorption may eventually rise. Nevertheless, the effectiveness of water repellents in reducing capillary absorption kinetics depends on the depth of their penetration (Namoulniara, et al., 2019). Moreover, the repellent effect has a limited duration. When water levels rise over the treated layer's limit, the absorption kinetics will turn to untreated concrete rather closely. Lee, et al. (2022) claim that the effectiveness of CS as a water repellent is reduced as CS is weak at preventing water penetration under hydrostatic pressure, and all LFC are entirely immersed throughout the curing process. It proved that the effectiveness of CS is faded when LFC is fully submerged in water, causing a slight increment in water absorption for LFC due to an overdose of CS. Hence, it can be concluded that the water absorption capability of LFC will decrease initially, and it might increase when there is an overdosage of CS into LFC and due to fully submerged LFC with longer curing ages. Besides, other features of fresh mix had been affected, which are the porosity and pore structure. Incorporating CS with LFC will enhance the waterproofing properties of the LFC by enclosing the capillaries, pores, voids, and air pockets present in the LFC with crystalline structure (Lee, et al., 2022). It shows that the porosity and pore structure had been affected instead of the fluidity of the fresh mix due to the dosage of CS into LFC.

4.4.3 Stability and Consistency for Actual Mix

The consistency and stability of the LFC for different dosages of CS and curing ages were calculated and tabulated in Table 4.9 and Table 4.10 based on fresh densities, hardened densities, and target densities. For seven days of LFC's curing age, the LFC's consistencies for different CS dosages were 0.97 to 1.03, and the stabilities were between 0.95 to 1.03. By referring to Table 4.10, for 28 days of curing age of LFC, the consistencies of LFC for different dosages of CS were in the range of 0.97 to 1.03, and the stabilities were in 0.95 to 1.01. Therefore, all of them were adequate since they are close to the value one and within the allowable range of 0.934 to 1.036. Besides, the additional material, CS, seemed like it does not affect the stability and consistency of the LFC with both 7- and 28-day curing age by referring to Table 4.9 and Table 4.10. Hence, all of the LFC was under stable and consistent conditions.

Table 4.9: Stability And Consistency Checking of LFC for Actual Mix with 7 Curing Days.

Dosage of CS (%)	Target Density (kg/m^3)	Fresh Density (kg/m^3)	Hardened density (kg/m^3)	Consistency	Stability
0 %	1400	1448	1414	1.03	1.02
0.20 %		1405	1404	1.00	1.00
0.40 %		1352	1417	0.97	0.95
0.60 %		1435	1392	1.03	1.03
0.80 %		1418	1391	1.01	1.02
1 %		1381	1415	0.99	0.98

Table 4.10: Stability and Consistency Checking of LFC for Actual Mix with 28 Curing Days.

Dosage of CS (%)	Target Density (kg/m^3)	Fresh Density (kg/m^3)	Hardened density (kg/m^3)	Consistency	Stability
0 %	1400	1448	1437	1.03	1.01
0.20 %		1405	1394	1.00	1.01
0.40 %		1352	1415	0.97	0.95
0.60 %		1435	1411	1.03	1.02
0.80 %		1418	1405	1.01	1.01
1 %		1381	1379	0.99	1.00

4.4.4 Compressive Strength Test for Actual Mix

Figure 4.4 shows the average compressive strength development trend for different dosages of calcium stearate added to LFC with 7- and 28- curing days. The summary of the compressive strength test for 7- and 28-day curing age of LFC with performance index was shown in Table 4.11. The development trend of compressive strength for both 7 and 28 curing days LFC seemed quite similar, having the same highest compressive strength when the dosage of CS was 0.2 %. All of the LFC with 28 curing days had higher compressive strength compared to 7 days curing days for each different dosage of CS. It proved that the relationship between curing age and compressive strength is directly proportional (Chen, et al., 2011).

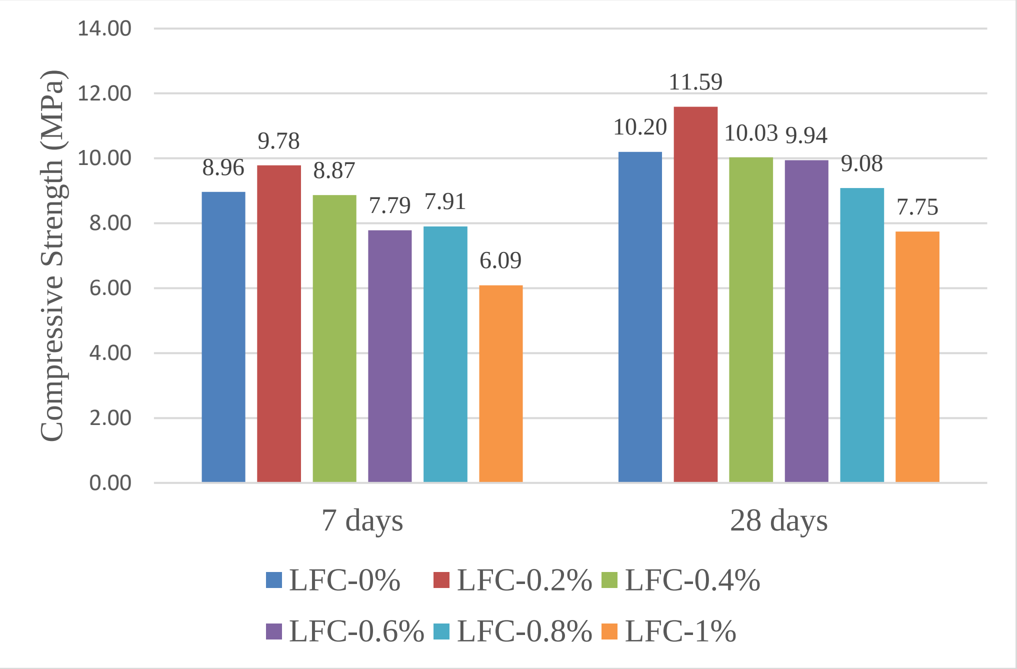


Figure 4.4: Average Compressive Strength For 7 & 28 Days of Curing Age of LFC.

Table 4.11: Summary of Compressive Strength Test for 7- And 28-Day Curing Age of LFC with Performance Index.

	7 Days					28 Days				
Dosage of CS (%)	Compressive Strength (MPa)	Average Compressive Strength (MPa)	Performance Index (MPa/1000kg/m3)	Average Performance Index (MPa/1000kg/m3)	Increment/ Decrement of Average Performance Index in Percentage (%)	Compressive Strength (MPa)	Average Compressive Strength (MPa)	Performance Index (MPa/1000kg/m3)	Average Performance Index (MPa/1000kg/m3)	Increment/ Decrement of Average Performance Index in Percentage (%)
0	8.54	8.96	5.972	6.339	-	10.37	10.20	7.252	7.103	-
	9.01		6.431			9.86		6.824		
	9.34		6.615			10.38		7.233		
0.2	10.24	9.78	7.320	6.970	9.95	11.52	11.59	8.294	8.315	17.06
	9.63		6.835			12.07		8.665		
	9.48		6.757			11.18		7.986		
0.4	8.42	8.87	5.934	6.257	-10.23	10.46	10.03	7.418	7.080	-14.85
	9.56		6.780			9.53		6.735		
	8.62		6.058			10.10		7.088		
0.6	8.19	7.79	5.879	5.595	-10.58	9.87	9.94	7.030	7.047	-0.47
	7.64		5.453			10.06		7.125		
	7.53		5.453			9.90		6.987		
0.8	7.92	7.91	5.727	5.685	1.61	9.72	9.08	6.811	6.462	-8.31
	7.53		5.425			8.13		5.815		
	8.27		5.903			9.40		6.758		
1	6.94	6.09	4.89	4.30	-24.30	7.58	7.75	5.46	5.62	-13.06
	5.73		4.08			7.62		5.58		
	5.60		3.94			8.04		5.82		

Note:

$$Performance\ Index = \frac{Compressive\ Strength}{Hardened\ Density/1000}$$

For LFC with seven days curing age, the compressive strength reached the highest for LFC-7-CS0.2 and started declining until it reached LFC-7-CS0.6. Next, there was a slight increment of 1.61 % for the performance index and compressive strength of LFC-7-CS0.8 based on Table 4.11. Then, the LFC-7-CS1 had the lowest compressive strength among other different dosages of the LFC, which was 6.09 MPa. For LFC with 28 days curing age, LFC-28-CS0.2 had the highest compressive strength, reaching 11.59 MPa, with a 17.06 % of increment from LFC-28-CS0. After that, the compressive strength declined until it reached LFC-28-CS1. The compressive strength of LFC-28-CS0.4 and LFC-28-CS0.6 had a minor difference of just 0.09 MPa. A dosage of 1 % of LFC had the lowest compressive strength at both curing ages of 7 days and 28 days and had a 7.75 MPa at the curing ages of 28 days.

The result for both development trends of compressive strength is explainable and can be discussed and proved through theoretical research. Initially, both curing ages of the compressive strength of LFC reached the highest at 0.2 % dosage of CS. It shows that a 0.2 % dosage of CS does not bring huge effects on the LFC but provides LFC with the optimum compressive strength when applying this dosage of CS LFC. The reason is that the fluidity of fresh mix decreases when a small amount of CS is added into LFC but does not interrupt the hydration process of mix and slightly decrease in porosity, eventually providing a stronger pore connectivity and an increment in compressive strength. On the other hand, the result shown in Figure 4.4 shows a downtrend for compressive strength of 7 and 28 days of curing ages of LFC. The effect of CS on LFC had shown clearly through this development trend. The water absorption capabilities are reduced when CS is added to LFC, which causes retard of the hydration process. Research by Lee et al. (2022) also stated that CS provides a hydrophobic effect for LFC, delaying the hydration process and causing lesser C-S-H gel to form, where C-S-H gel is the key factor in providing compressive strength for LFC. In addition, calcium stearate forms a wax-like component when combined with cement and water (Maryoto, et al., 2020). Compared to the connection created by the combination C-S-H, this one is weaker. Consequently, the concrete's wax-like components reduce compressive strength.

Besides, as mentioned in subsection 4.4.2, the fluidity of concrete mix decreases when more dosage of CS is added to LFC, causing more foam to be applied to decrease the fresh density of LFC. As a result, more pores are introduced into the mix, causing a decrement in compressive strength. The relationship between porosity and compressive strength is inversely proportional. The hydrophobic water repellent is applied to the inside of the concrete pores, preferentially filling the smallest pores and reducing the connectivity of the porous network. (Namoulniara, et al., 2019). Moreover, when more bubbles are contained in the mix, the possibility for the bubbles to combine and form bigger bubbles increases. The rise in the foam bubbles' size causes LFC's compressive strength to weaken. Eventually, the compressive strength is affected by the pore structure when CS is applied to LFC.

Hence, the overdosage of CS caused the reduction of the overall compressive strength of LFC for several reasons stated above. Furthermore, the result was similar to Maryoto et al. (2020) and Lee et al. (2022) studies. Lastly, it can be concluded that a 0.2 % dosage of CS provides LFC with the optimum and highest compressive strength among the other different dosages of CS between 0 to 1 %.

4.4.5 Sound Absorption Test

This study investigated one of the functional properties, the sound absorption of foamed concrete, which refers to its ability to decrease the amount of sound energy reflected from its surface. This property can be affected by the uniformity, size and distribution of pores and foam content (Amran, Farzadnia, and Abang Ali, 2015). The noise reduction coefficient (NRC) was obtained from the average sound absorption coefficient (SAC) at four frequencies, namely 250, 500, 1000, and 2000 Hz, to measure the sound insulation of foamed concrete. Table 4.12 and Table 4.13 shows the SAC with NRC value for each different dosage of CS added into LFC with 7- and 28-day curing ages, respectively. Figure 4.5 and Figure 4.6 shows the combination of the sound absorption coefficient of each different dosage of CS added into LFC with 7- and 28-day curing ages, respectively, at different frequency. The individual graph of SAC against frequency for each dosage of CS added into LFC, and each curing age of LFC was attached in Appendix A. In addition, the NRC value for each different dosage of CS added into LFC for both 7- and 28-day curing ages were presented in Figure 4.7.

Table 4.12: Sound Absorption Coefficient with NRC Value for Each Different Dosage of CS Added Into LFC with 7 Days Curing Ages.

Frequency (Hz)	Sound Absorption Coefficient (SAC)					
	LFC-7-CS0	LFC-7-CS0.2	LFC-7-CS0.4	LFC-7-CS0.6	LFC-7-CS0.8	LFC-7-CS1
200	0.120	0.103	0.097	0.100	0.110	0.127
250	0.117	0.103	0.093	0.090	0.090	0.133
315	0.107	0.100	0.103	0.093	0.097	0.127
400	0.103	0.097	0.093	0.110	0.100	0.110
500	0.090	0.090	0.090	0.100	0.093	0.107
630	0.087	0.083	0.083	0.103	0.097	0.097
800	0.080	0.090	0.103	0.120	0.110	0.093
1000	0.090	0.180	0.210	0.217	0.227	0.300
1250	0.120	0.217	0.233	0.240	0.247	0.360
1600	0.110	0.257	0.277	0.303	0.350	0.407
2000	0.190	0.307	0.350	0.397	0.333	0.423*
2500	0.372	0.352*	0.393*	0.348	0.305	0.383
3150	0.279	0.207	0.227	0.217	0.223	0.150
4000	0.257	0.167	0.257	0.180	0.220	0.117
5000	0.243	0.153	0.220	0.220	0.217	0.143
6300	0.420*	0.313	0.360	0.493*	0.430*	0.357
NRC	0.12	0.17	0.19	0.20	0.19	0.24

Note:

Blue box: Sound absorption coefficient used to calculate NRC value.

Value with an asterisk*: Highest sound absorption coefficient among all frequency for the particular dosage of CS.

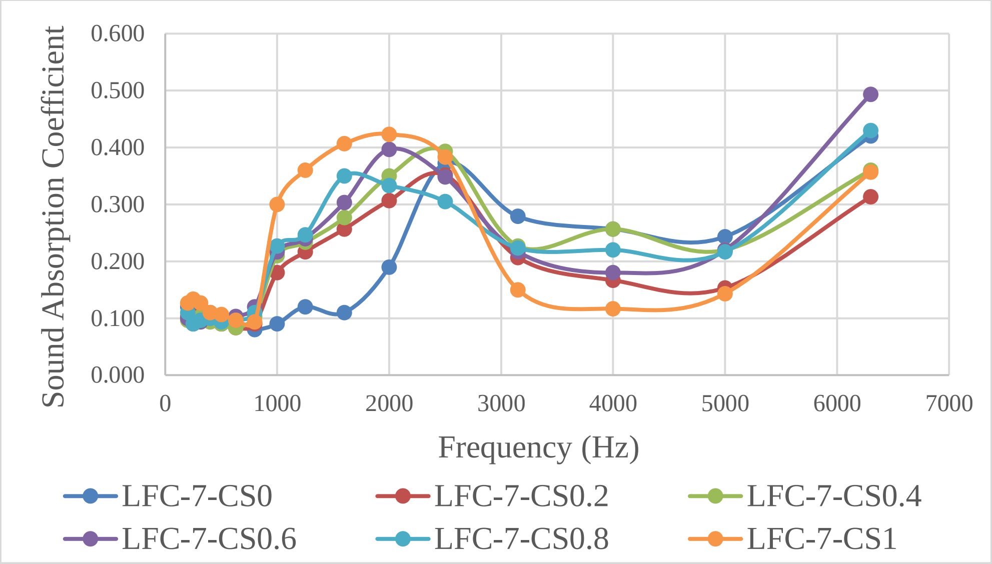


Figure 4.5: Sound Absorption Coefficient against Frequency for Each Different Dosage of CS Added Into LFC with 7 Curing Days.

Table 4.13: Sound Absorption Coefficient with NRC Value for Each Different Dosage of CS Added Into LFC with 28 Days Curing Ages.

Frequency (Hz)	Sound Absorption Coefficient (SAC)					
	LFC-7-CS0	LFC-7-CS0.2	LFC-7-CS0.4	LFC-7-CS0.6	LFC-7-CS0.8	LFC-7-CS1
200	0.133	0.120	0.113	0.137	0.133	0.140
250	0.137	0.117	0.107	0.103	0.107	0.067
315	0.113	0.117	0.110	0.123	0.113	0.113
400	0.117	0.107	0.100	0.110	0.117	0.093
500	0.110	0.107	0.093	0.107	0.107	0.090
630	0.103	0.100	0.090	0.103	0.103	0.093
800	0.107	0.117	0.097	0.087	0.097	0.090
1000	0.103	0.117	0.200	0.177	0.193	0.187
1250	0.107	0.100	0.227	0.207	0.220	0.237
1600	0.147	0.153	0.263	0.250	0.247	0.310
2000	0.243	0.290	0.323	0.297	0.307	0.423*
2500	0.340	0.477*	0.362	0.323	0.290	0.338
3150	0.187	0.283	0.123	0.193	0.230	0.223
4000	0.227	0.403	0.110	0.293	0.497	0.270
5000	0.293	0.283	0.163	0.263	0.507*	0.257
6300	0.540*	0.397	0.413*	0.403*	0.380	0.303
NRC	0.15	0.16	0.18	0.17	0.18	0.19

Table 4.13 (Continued)

Note: Blue box: Sound absorption coefficient used to calculate NRC value. Value with an asterisk*: Highest sound absorption coefficient among all frequency for the particular dosage of CS.

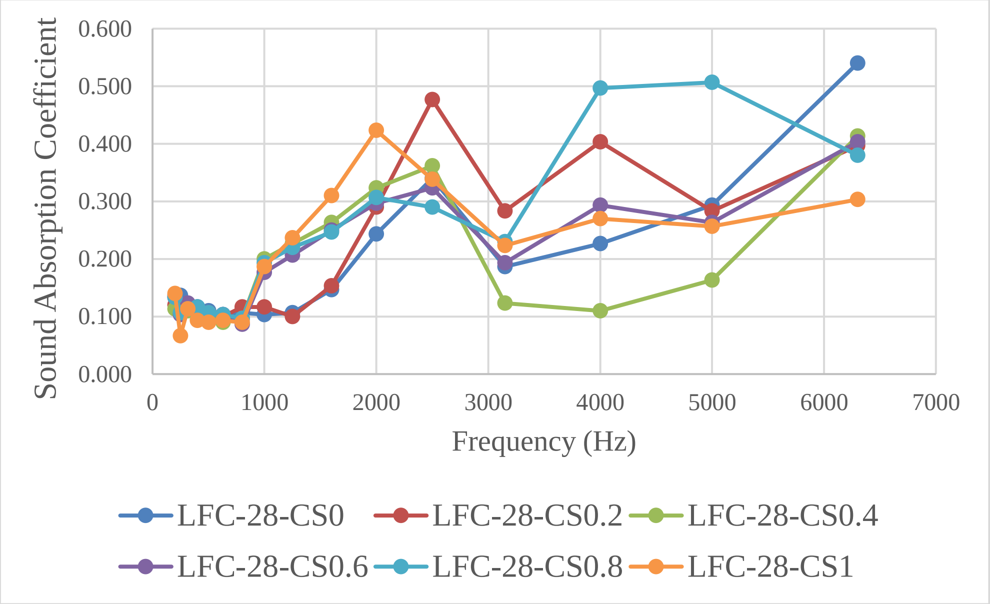


Figure 4.6: Sound Absorption Coefficient Against Frequency for Each Different Dosage of CS Added Into LFC With 28 Days of Curing.

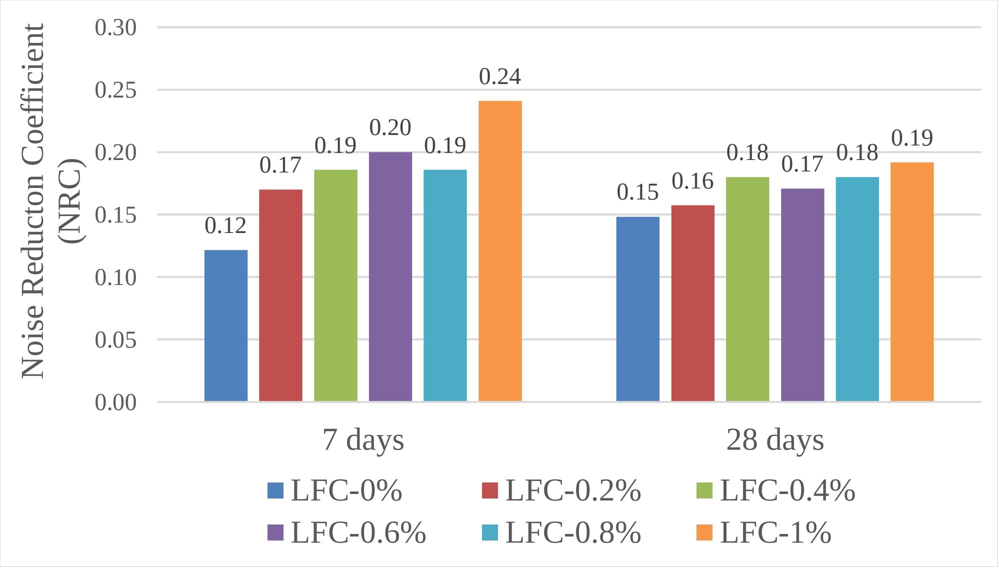


Figure 4.7: Noise Reduction Coefficient for Each Different Dosage of CS Added Into LFC with 7- & 28-Day Curing Ages.

For LFC with seven days curing ages, the SAC had shown an almost similar trend for all LFC of the different dosages of CS, as shown in Figure 4.5. First, the SAC of LFC decreased slightly from 200 to 800 Hz. Then, they increased gradually from 800 to 2500 Hz. After that, a ‘U’ shape was formed between 2500 to 6300 Hz. The highest SAC for each dosage of CS was under different frequencies, and they were within the range of 2000 to 6300 Hz, and the highest coefficient range is between 0.352 to 0.493.

For LFC with 28 days curing ages, the SAC had shown a similar trend initially but went different between 2500 to 6300 Hz, as shown in Figure 4.6. Initially, the sound absorption coefficient of LFC a minor decreased at 200 to 800 Hz. Next, they increased progressively from 800 to 2500 Hz. After that, the SAC between the range of 2500 to 6300 Hz for each dosage of CS became unstable and different from each other. It might be due to the uneven surface of the samples causing the SAC to be unstable at high frequencies. Besides, the highest sound absorption coefficient for each dosage of CS was under different frequencies, which are pointed out in Table 4.13 with an asterisk. For example, the range of 2000 to 6300 Hz and the highest coefficient range was between 0.403 to 0.540. Since all highest SAC for both 7- and 28-day curing ages were under the frequency range of 2000 to 6300 Hz, it indicated that CS provides better sound absorption features for LFC at this particular range of 2000 to 6300 Hz.

Other than that, the 250, 500, 1000, and 2000 Hz SAC were discussed for 7 and 28 days of curing age. For seven days of curing age, the SAC increased from when the dosage of CS increased for 500, 1000, and 2000 Hz. Then, the SAC formed a ‘U’ shape, decreasing slightly from 0 % of CS and increasing back to 1 % of CS at 250 Hz. For 28 days, SAC decreased from 0 to 1% of CS for 250 and 500 Hz. Next, during 1000 and 2000 Hz, the SAC increased from 0 to 1 %. By taking 28 days of curing age as a reference, the CS improved the performance of LFC in sound absorption. When CS was added into LFC, LFC effectively absorbed mid- to high-frequency sound waves. However, CS decreased the LFC performance of sound absorption at low frequencies.

In addition, the relationship between the NRC value and SAC is directly proportional. The only difference between NRC and SAC is NRC only considers sound absorption coefficient at some particular frequency. For example, the NRC value for seven days curing age of LFC for every dosage is higher than the NRC value for 28 days curing age of LFC based on Figure 4.7. It shows similar results to the research done by Lim, et al. (2021). They explained that it is conceivable because longer curing times will result in more cement hydrations or pozzolanic reactions. This eventually produces more hydrated cement pastes, which "fill up gaps and empty places in a sample." As a result, the LFC batches' capacity to absorb sound waves is reduced since fewer porous and void structures are available.

In Figure 4.7, the NRC value for 7 and 28 days of curing age shows a similar trend going up from LFC-0% to LFC-1%. There is a slight difference between the NRC value for 7 and 28 days, with a minor drop at LFC-0.8% for seven days of curing age and at LFC-0.6% for 28 days. However, the overall trend of both NRC values went up from 0 to 1% dosage of CS. This scenario can be explained through the effect of CS on LFC. As mentioned above, when more dosage of CS is applied to LFC, it affects the fluidity and water absorption of LFC, causing an increment in porosity, and LFC becomes more porous compared to 0 % dosage of CS of LFC. It can be ascribed to CS, which can reduce the fresh mix's fresh density. Therefore, additional foam is required to lower the fresh density, resulting in a more porous and interconnecting pore structure in the concrete. Materials with more prominent pores and porosity generally have higher sound absorption coefficients, or more sound energy per unit area, absorbed by them.

Because of this, CS causes expansion of the surface area of the LFC, where sound may be absorbed and dispersed. The surface area exposed to interact with sound waves and convert the sound energy into heat energy through friction increases by reducing the intensity of sound waves as LFC becomes more porous. When the surface of LFC is more porous, more energy of sound waves dissipated, and a higher value of SAC will be obtained. Nevertheless, it should be remembered that if the porosity is too high, sound waves could pass through the LFC. In addition, the microstructure of foamed concrete's increased surface area caused by unreacted calcium stearate particles may further enhance friction. Eventually, these reasons explained the increment of SAC and NRC value when more dosage of CS is applied in LFC.

Furthermore, the SAC for each dosage of CS added into LFC with 28 days of curing age was used to compare with other common construction materials' SAC—for example, coarse concrete blocks, wood, ordinary window glass, plaster, and brick. Table 4.14 shows the SAC of several surface materials in different frequencies by referring to the Department of Occupational Safety and Health (2005). The overall result of the NRC value is calculated and shown in Table 4.14. Based on Table 4.14, most of the LFC with different dosages of CS had higher NRC values than materials such as wood, glass, fabric, and brick. However, the coarse concrete block still has a higher NRC value than all of the LFC with different dosages of CS. It is because different materials perform differently at every frequency. For instance, glass can perform better than all other LFC with different dosages of CS at 250 Hz, but its NRC is still lower than all of the LFC.

On the other hand, the concrete wall is often used as a sound barrier and coated with paint to provide concrete with a waterproofing feature to avoid carbonation and corrosion attack towards reinforcement in the concrete wall. However, the SAC and NRC values are affected by the paint. The SAC and NRC decreased when the paint was applied to the concrete block, based on Table 4.14. CS become essential at this point since it provides a water-repelling feature, reducing water absorption and improving the SAC and NRC value by adding CS when manufacturing the concrete wall. Therefore, CS is useful and valuable at this time to replace paint with the same waterproofing feature but not reduce its SAC and NRC value. Hence, the usage of materials is based on the requirement for the construction, and LFC with the dosage of CS provides better sound absorption and noise reduction features than some of the other materials.

Table 4.14: SAC of Different Surface Materials (Department of Occupational Safety and Health, 2005).

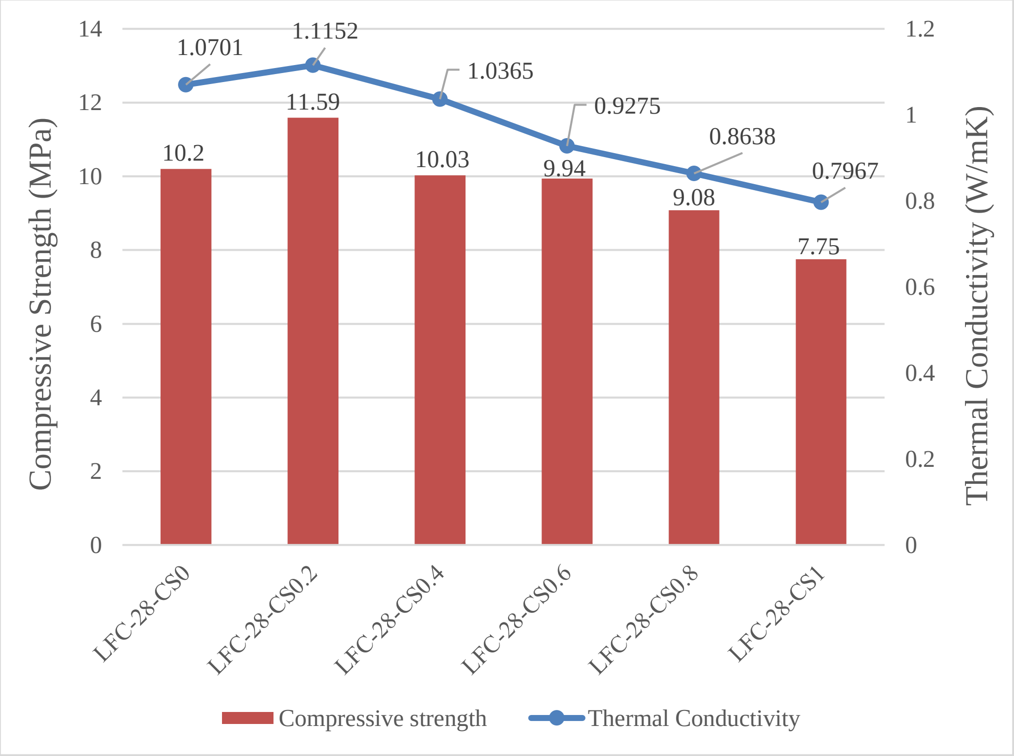
	Material	Frequency (Hz)				NRC
		250	500	1000	2000	
Result from experiment	LFC-28-CS0	0.137	0.11	0.103	0.243	0.148
	LFC-28-CS0.2	0.117	0.107	0.117	0.29	0.158
	LFC-28-CS0.4	0.107	0.093	0.2	0.323	0.181
	LFC-28-CS0.6	0.107	0.107	0.177	0.297	0.172
	LFC-28-CS0.8	0.107	0.107	0.193	0.307	0.179
	LFC-28-CS1	0.067	0.09	0.187	0.423	0.192
Results from the Department of Occupational Safety and Health Guideline	Concrete block: Coarse	0.44	0.31	0.29	0.39	0.358
	Concrete block: Painted	0.05	0.06	0.07	0.09	0.068
	Wood	0.11	0.1	0.07	0.06	0.085
	Glass: Ordinary window glass	0.25	0.18	0.12	0.07	0.155
	Fabrics: Light velour	0.04	0.11	0.17	0.24	0.140
	Plaster: Gypsum or lime, smooth finish on tile or brick	0.015	0.02	0.03	0.04	0.026
	Brick: Glazed	0.01	0.01	0.01	0.02	0.013

When the dosage of CS applied to LFC raises, the NRC value and SAC also increase. Therefore, it will affect LFC's SAC and NRC values in different frequency ranges. Besides, the result shows the effect of CS on LFC and indicates that CS provides better sound absorption features for LFC at this range of 2000 to 6300 Hz. The LFC with 1 % of CS achieves the highest NRC value at 7 and 28 days of curing age. In a nutshell, it can be concluded that 1 % of CS provided LFC with the optimum sound absorption features and highest NRC value in the frequency range of 200 to 6300 Hz.

4.4.6 Thermal Conductivity Test

High thermal conductivity materials can quickly transfer heat or thermal energy, while low thermal conductivity materials can resist heat or thermal energy flow. Figure 4.8 displays the thermal conductivities and compressive strength for 28 days of LFC curing with CS dosages between 0 and 1 %. The thermal conductivity of LFC was in the range of 0.7967 to 1.1152 W/mK. According to Mohd Sari and Mohammed Sani (2017), The thermal conductivity of foamed concrete ranged from 0.1 to 0.7 W/mK for dry densities ranging from 600 to 1600 kg/m^3. However, the result shown might not be within the range due to different mix proportion and the LFC for this research are incorporated with CS. Various factors can influence the thermal conductivity of foamed concrete, such as the type of aggregate and the material's porosity, including moisture content, direction, type, spacing and pore volume. Additionally, the formation of air bubbles during the mixing a foaming agent can also impact the heat transfer mechanism by creating pores.

Figure 4.8: Compressive Strength and Thermal Conductivity for 28 Curing Days of LFC with 0 to 1 % Dosage of CS.



By interpreting the result of the thermal conductivity of LFC, the thermal conductivity went up to the highest when 0.2 % CS was added to LFC. Then, the thermal conductivity declined slowly until it reached the lowest thermal conductivity of 0.7967 at 1 % of CS added to LFC. Overall, the thermal conductivity of LFC decreased when LFC was incorporated with CS except at the dosage of 0.2 % of CS. The effect of CS might not show any obvious impact on LFC due to the small amount of CS being added. The reason is that the fluidity of fresh mix decreases when a small amount of CS is added into LFC, which leads to a slight decrease in porosity, eventually providing a shorter heat transfer channel and, lastly, causes an increment in thermal conductivity. Next, LFC's compressive strength and thermal conductivity also formed a similar trend, as shown in Figure 4.8. On the other hand, the result from research done by Ma and Chen (2016) where both thermal conductivity and compressive strength increased when the dosage of CS applied increased.

On the other side, Figure 4.8 reveals a trend for the thermal conductivity of LFC, which declines when the dosage of CS added to LFC increases. It can be explained through the impact of CS on the porosity or pore structure of LFC. When more CS was added to LFC, more foam was required to reduce the fresh density, leading to an increment of the porosity of LFC. The porosity of LFC will increase when the dosage of CS applied increases, but it does not indicate that the pore size for LFC will increase. Usually, bubbles would easily join to form larger ones in this situation. As a result, the proportion of tiny pores may decline, the average pore size may rise, and the pores may start being rounded off.

Nonetheless, when the LFC was incorporated with CS, CS provided it with the hydrophobic layer. The hydrophobic layer from CS provided better insulation features to LFC. The hydrophobic water repellent is applied to the interior face of concrete pores, filling the tiniest pores primarily and, as a result, reducing the connectivity of the porous network. Eventually, the tiny bubbles failed to combine to form a bigger pore size due to the hydrophobic layer.

In addition, the thermal conductivity drops significantly as the porosity increases (Chen, et al., 2021). The results demonstrated that as pore size rises, so does its impact on heat conductivity. It is because when pore size reduces, more pores are present, the heat transfer channel becomes longer, the thermal bridge effect decreases, and the material's thermal conductivity reduces. According to Chen, et al. (2021), the thermal conductivity will increase when the pore diameter increases. As the pore diameter does not increases, as explained above, the thermal conductivity of LFC also does not increase.

Thus, the thermal conductivity of LFC was reduced when more CS was applied to LFC, and the dosage of 1 % CS into LFC provided LFC with the lowest thermal conductivity for LFC as the lower value of thermal conductivity indicated that it performed better as a thermal insulator. The dosage of 0.2 % CS also provided the highest thermal conductivity for LFC. Lastly, the relationship between thermal conductivity and compressive strength of LFC can be concluded as they perform in a similar trend where both decrease when the dosage of CS increase.

4.5 Summary

In the first stage, which was the trial mix stage, the optimum w/c ratio was obtained. The optimum w/c ratio was 0.56, which was used to proceed to the actual mix stage to determine the effect of CS towards fresh properties, compressive strength, sound absorption and thermal conductivity of LFC. Several tests are conducted in the actual mix stage using the optimum w/c ratio obtained from the trial mix, and the summary of all results is shown in Table 4.15. In addition, the effect of CS on each property of LFC has been analysed and discussed in the section above.

Table 4.15: Summary of Results for Several Tests.

Type of LFC	Compressive Strength Test		Sound Absorption Test		Thermal Conductivity Test
	MPa		NRC value		W/mK
	7 days	28 days	7 days	28 days	28 days
LFC-7-CS0	8.96	-	0.12	-	-
LFC-7-CS0.2	9.78	-	0.17	-	-
LFC-7-CS0.4	8.87	-	0.19	-	-
LFC-7-CS0.6	7.79	-	0.20	-	-
LFC-7-CS0.8	7.91	-	0.19	-	-
LFC-7-CS1	6.09	-	0.24	-	-
LFC-28-CS0	-	10.20	-	0.15	1.0701
LFC-28-CS0.2	-	11.59	-	0.16	1.1152
LFC-28-CS0.4	-	10.03	-	0.18	1.0365
LFC-28-CS0.6	-	9.94	-	0.17	0.9275
LFC-28-CS0.8	-	9.08	-	0.18	0.8638
LFC-28-CS1	-	7.75	-	0.19	0.7967

First, CS affected the fluidity and water absorption of LFC differently. The fluidity of the fresh mix decreased when the dosage of CS increased. Besides, the water absorption decreased initially when 0.2 to 0.4 % of CS was added to LFC and rose back to its highest when 1 % of CS was added to LFC for both curing ages of 7- and 28-days.

Secondly, CS had caused a noticeable impact on the compressive strength of LFC. The compressive strength of LFC for 7- and 28-day curing ages grew to its highest when 0.2 % of CS was added to LFC and decreased to 1 % of CS. CS provided the optimum compressive strength at the dosage of 0.2 % and reduced the compressive strength when overdosage of CS was applied. LFC-28-0.2 provided the highest compressive strength compared with all other LFC, which had an 11.59 MPa of compressive strength.

Next, the sound absorption coefficient and NRC value increased when more dosage of CS was added to LFC. By referring to Table 4.16, the LFC-0.2% provided the optimum NRC value for both 7- & 28-day curing age. It indicated that CS could improve the sound absorption of LFC by providing LFC more porous structure.

Furthermore, the thermal conductivity of LFC decreased when the dosage of CS increased. LFC with 1 % of CS provided the lowest thermal conductivity among the others dosage of LFC. When the thermal conductivity of LFC is lower, it is a better thermal insulator. The result shows that when incorporated with CS, LFC became a better thermal insulator.

Overall, a 1 % dosage of CS provided LFC with the optimum condition of sound absorption and thermal conductivity, while LFC with a 0.2 % dosage of CS had the highest compressive strength. Hence, the data of several tests for both different dosages of CS was tabulated in Table 4.16 to compare both LFC with two different dosages of CS.

Table 4.16: Comparison of Optimum Dosage of CS of LFC.

Tests	LFC-28-CS0.2	LFC-28-CS1	Percentage Difference (%)
Compressive Strength Test (MPa)	11.59	7.75	33.13
Sound Absorption Test	0.16	0.19	18.75
Thermal Conductivity Test (W/mK)	1.1152	0.7967	28.56
Water Absorption (%)	17.69	23.21	5.52

According to Shawnim and Mohammad (2019), foamed concrete can be utilized as a structural material with a minimum strength of 25 MPa. The compressive strength of LFC with 0.2 % of CS was 33.13 % higher than LFC with 1 % of CS, but LFC does not meet the requirement. Commonly, LFC is used for concrete or partition walls, whereby the nature of the wall is only subject to minimal building loading. According to Mamlouk and Zaniewski

(2011), the minimum compressive strength for the non-load bearing of individual concrete masonry units is 3.5 MPa. Thus, the compressive strength of both different dosages of LFC is more than the minimum requirement and considered sufficient for functional or non-structural usage. Besides, the main purpose of using LFC is to provide good thermal and sound insulation. Therefore, LFC-28-CS1 provided a higher NRC value which is 18.75 % higher than LFC-28-CS0.2.

On the other hand, LFC-28-CS1 was way higher than LFC-28-CS0.2 in thermal conductivity, whereby the percentage difference of thermal conductivity for LFC is approximately 29 %. Besides, there was a slight difference in the water absorption for the LFC, which was 5.52 %. Hence, it was evident that the optimum dosage of CS is 1 % which provides a higher and better SAC, NRC value and thermal conductivity.

In short, with the increasing dosage of CS in LFC, LFC's compressive strength and thermal conductivity decreased, and LFC's NRC value increased. Thus, it can be concluded that the optimum dosage of CS was 1 % by providing LFC with excellent thermal insulation, sound absorption, and noise reduction features, but it reduced its compressive strength.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

After analysing the result from several laboratory tests, the following conclusions can be made to attain the objectives stated earlier.

The first objective was to produce foamed concrete with a concrete density of 1400 kg/m^3 with a ± 50 kg/m^3 of acceptable deviation. This objective was achieved since all trial and actual mix samples were produced in compliance with specific requirements.

The second objective was to acquire the optimum water-cement ratio for foamed concrete. This objective was achieved at the trial mix stage, and an optimum water-cement ratio of 0.56 was obtained and used to proceed with the actual mix.

The third objective was to investigate the effect of calcium stearate towards the compressive strength and functional properties of lightweight foamed concrete. LFC's compressive strength and thermal conductivity were affected and became more apparent when the dosage of CS increased, whereby the compressive strength and thermal conductivity of LFC decreased accordingly. Besides, with more dosage of CS added into LFC, the sound absorption of LFC improved as the NRC value increased. Therefore, to improve the sound absorption and thermal conductivity, the optimum dosage of CS will be 1 %, but providing a lower compressive strength of LFC at the same time.

5.2 Recommendation for future work

The future researcher should consider the following recommendations to enhance study outcomes and strengthen the validity, dependability, and viability of the data obtained in this study.

1. To investigate the effects of a higher dosage of calcium stearate towards different properties of LFC, such as water absorption, hygroscopicity and sorptivity, chloride penetration, thermal conductivity, fire resistance, sound absorption and sound transmission.
2. To determine the effect of CS towards fire resistance, noise reduction, sound absorption and sound transmission of LFC with actual sizes, such as an LFC wall or bigger block of LFC.
3. To figure out the effect of CS towards engineering properties and functional properties of LFC with longer curing ages, such as 56 days, 90 days, or 180 days.
4. To assess the effect of calcium stearate on LFC's pore structure/ microstructure. Calcium stearate's affected pore structure can be discussed with the properties of LFC, including compressive strength, thermal conductivity, and sound absorption.
5. To investigate the effect of other water repellents towards the engineering properties and functional properties of LFC. Examples of water repellent can include zinc stearate, silane, siloxane and so on.
6. To determine the engineering and functional properties of LFC incorporated with calcium stearate and other admixtures, such as fly ash, super-plasticizer, and accelerating admixture.

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APPENDICES

APPENDIX A: Graphs for Sound Absorption Test for Each Dosage of CS With 7- and 28-Days Curing Ages.

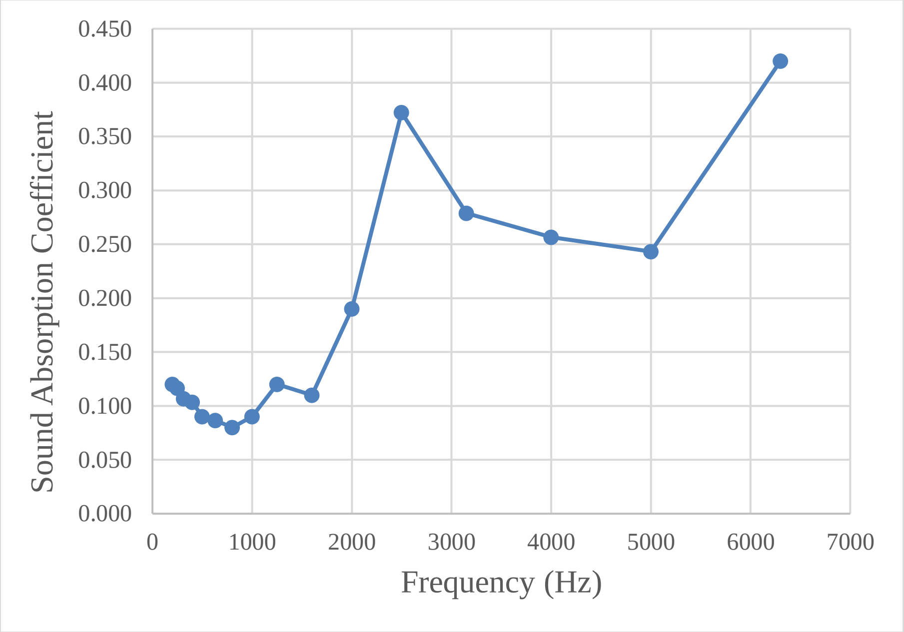

Figure A.1: Graph of Sound Absorption Coefficient against Frequency for LFC-7-CS0 with an NRC value of 0.12.

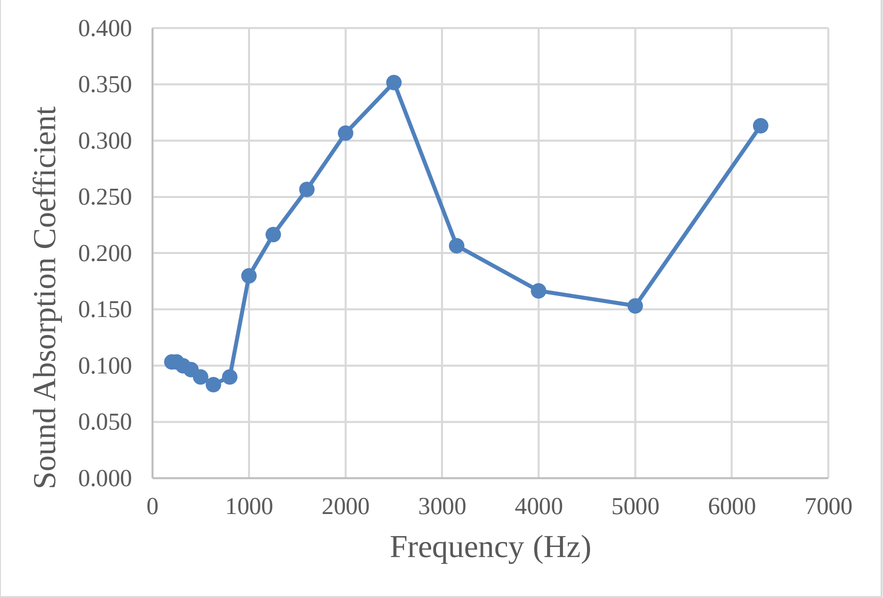

Figure A.2: Graph of Sound Absorption Coefficient against Frequency for LFC-7-CS0.2 with an NRC value of 0.17.

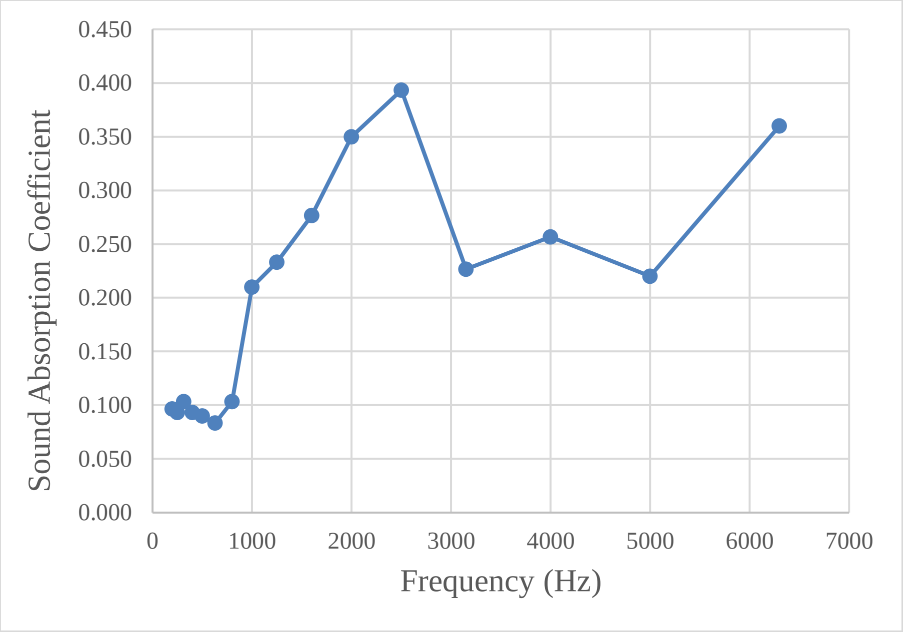

Figure A.3: Graph of Sound Absorption Coefficient against Frequency for LFC-7-CS0.4 with an NRC value of 0.19.

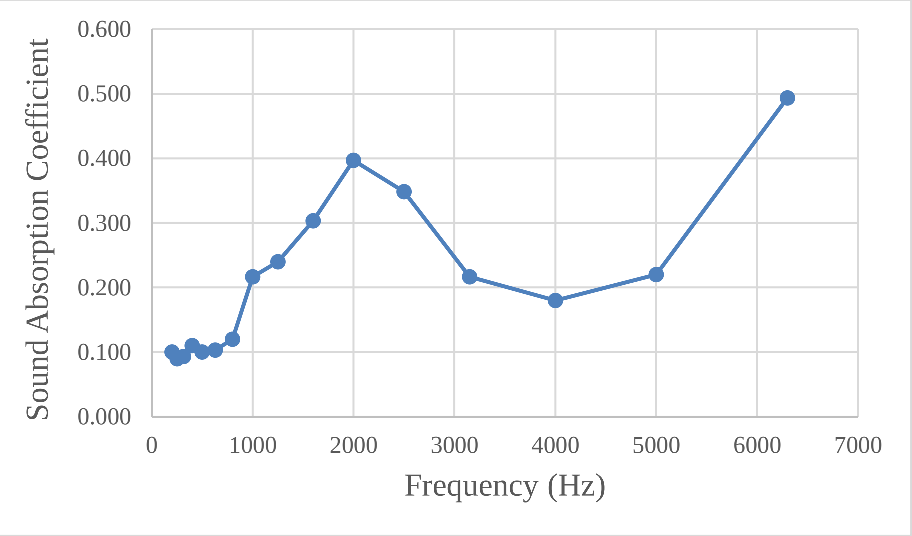

Figure A.4: Graph of Sound Absorption Coefficient against Frequency for LFC-7-CS0.6 with an NRC value of 0.20.

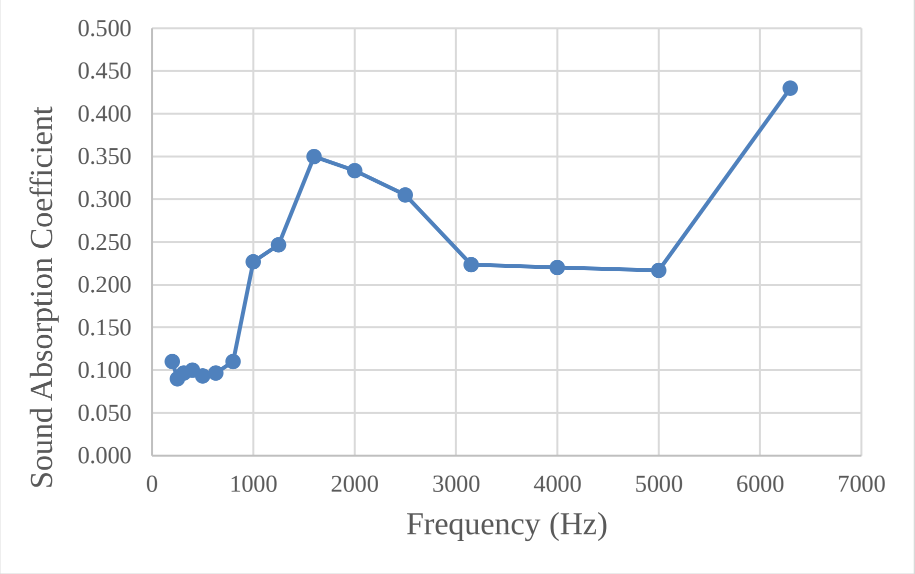

Figure A.5: Graph of Sound Absorption Coefficient against Frequency for LFC-7-CS0.8 with an NRC value of 0.19.

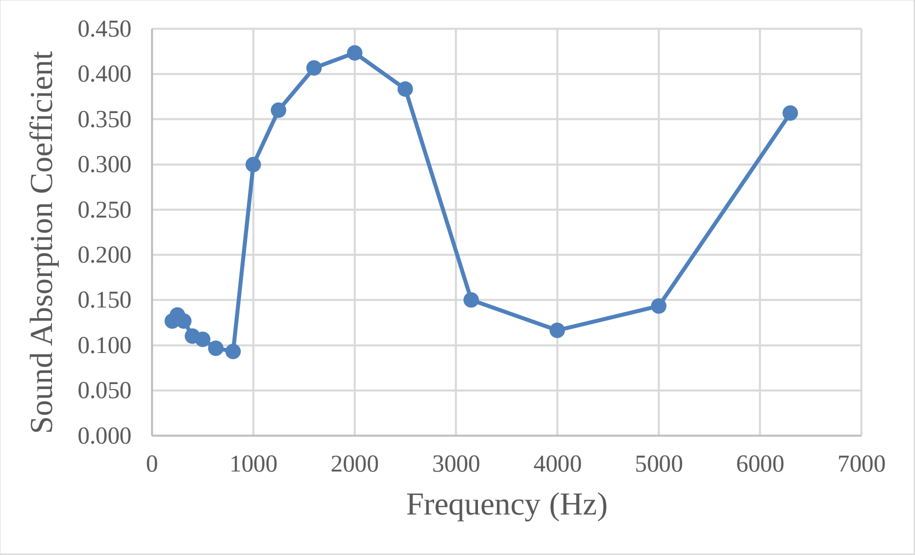

Figure A.6: Graph of Sound Absorption Coefficient against Frequency for LFC-7-CS1 with an NRC value of 0.24.

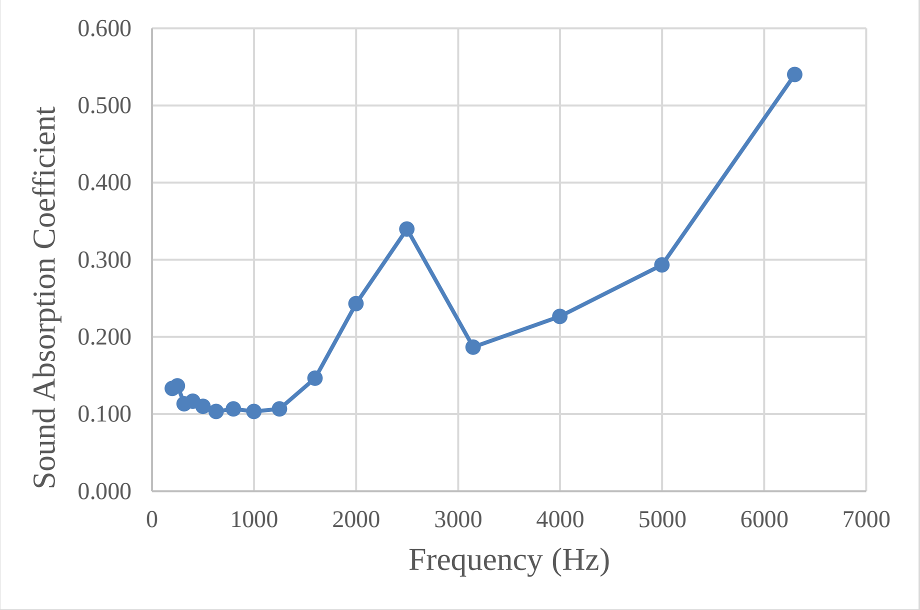

Figure A.7: Graph of Sound Absorption Coefficient against Frequency for LFC-28-CS0 with an NRC value of 0.15.

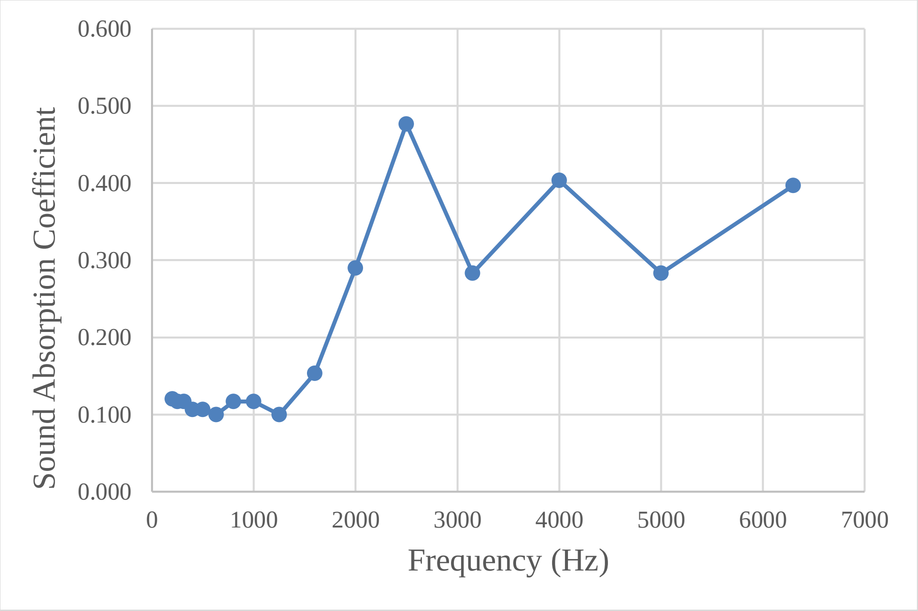

Figure A.8: Graph of Sound Absorption Coefficient against Frequency for LFC-28-CS0.2 with an NRC value of 0.16.

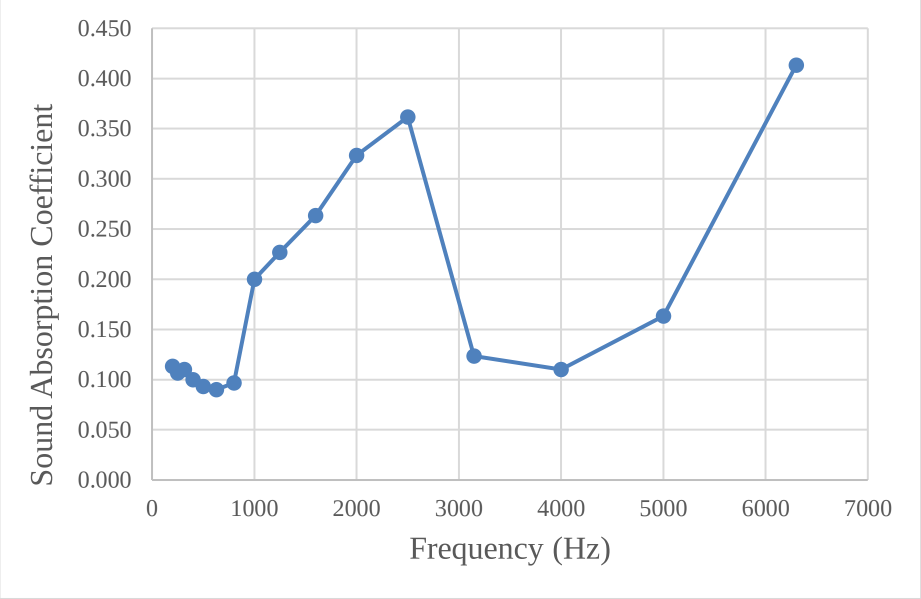

Figure A.9: Graph of Sound Absorption Coefficient against Frequency for LFC-28-CS0.4 with an NRC value of 0.18.

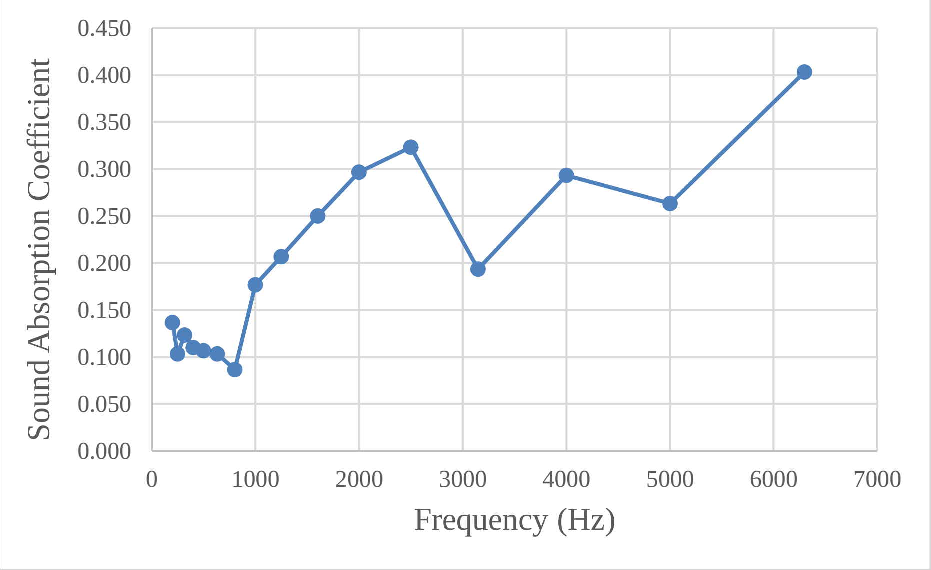

Figure A.10: Graph of Sound Absorption Coefficient against Frequency for LFC-28-CS0.6 with an NRC value of 0.17.

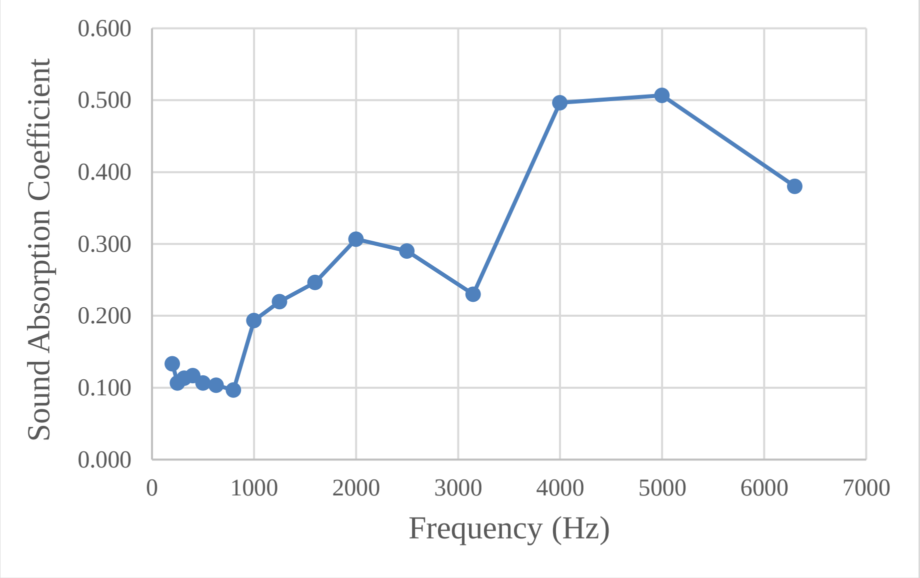

Figure A.11: Graph of Sound Absorption Coefficient against Frequency for LFC-28-CS0.8 with an NRC value of 0.18.

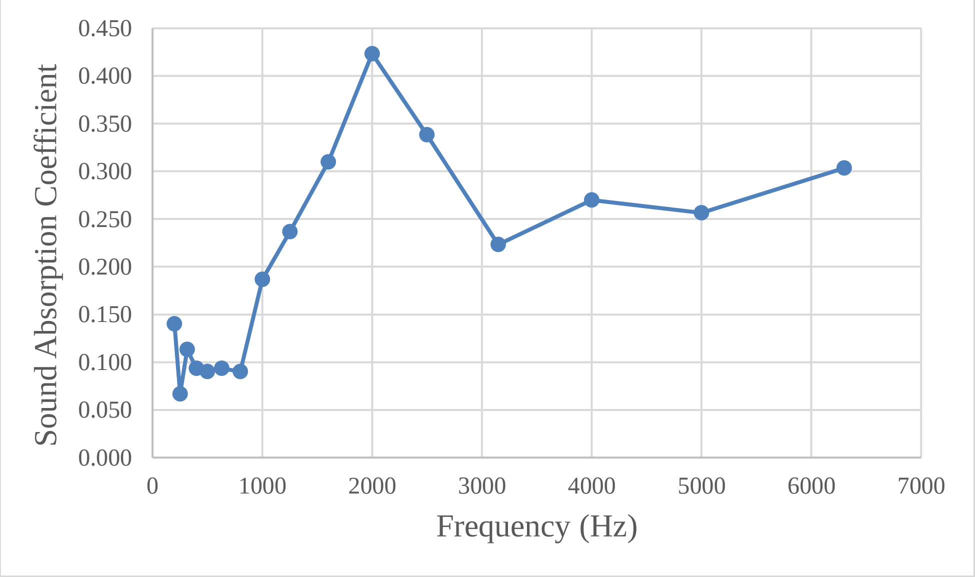

Figure A.12: Graph of Sound Absorption Coefficient against Frequency for LFC-28-CS1 with an NRC value of 0.19.