AN INVESTIGATION ON THE FUNCTIONAL PROPERTIES OF 1600 KG/M^3 FOAMED CONCRETE WITH CALCIUM STEARATE

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

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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.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **“AN INVESTIGATION ON THE FUNCTIONAL PROPERTIES OF 1600 KG/M^3 FOAMED CONCRETE WITH CALCIUM STEARATE”** was prepared by **LIM YU TONG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering with Honours at Universiti Tunku Abdul Rahman.

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ABSTRACT

As global warming intensifies, the construction industry seeks a substitute for ordinary concrete due to its high dead weight and thermal conductivity. The current trend is using foamed concrete, lightweight concrete with a more strength-to-weight ratio with a density ranging from 300 to 1800 kg/m^3. It decreases dead loads on the structure, manufacture costs, construction labor expenses and shipping costs. In addition, the large number of pores in foamed concrete decreases heat absorption, making the structure suitable for all climates. However, lightweight foamed concrete (LFC) is typically utilised on the exterior of buildings, such as walls and roof slabs, where it is frequently subjected to natural weathering such as rain. Since water is a detriment to the long-term durability of LFC, calcium stearate (CS) is incorporated. CS is a water repellent agent that minimises water penetration into LFC. This study aims to investigate the functional properties of 1600 kg/m^3 foamed concrete with calcium stearate. The functional properties including sound absorption and thermal conductivity of foamed concrete were tested and evaluated based on the ASTM standards. Besides, one of the mechanical properties, namely compressive strength was also evaluated in this research. A trial mix was performed to get an optimum water-cement (w/c) ratio and the optimum w/c ratio of 0.58 was obtained and used in the actual mix. Six types of LFC with different shapes and dimensions containing different concentrations of CS were casted and water cured for 7 and 28 days before being tested for their compressive strength, water absorption and functional properties. The dosage of CS added ranged from 0 % - 1.0 % with an interval of 0.2 %. It was found that the presence of CS may reduce the fresh concrete's permeability and water absorption and thus producing low fluidity. Besides, the finding also showed CS dosage only affected overall compressive strength at early ages of LFC. Besides, adding CS may reduce the LFC mix's water absorption until a certain dosage. If an overdose of CS, it may have a negative impact on the LFC mix by limiting its waterproofing performance. Lastly, introducing CS into LFC can enhance sound absorption and thermal resistance.

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LIST OF SYMBOLS / ABBREVIATIONS

A	cross-sectional area, mm^2
D	diameter
D_E	estimate density, kg/m^3
D_f	density of foam, kg/m^3
D_T	target density, kg/m^3
H	height
h	thickness of specimen, mm
k	thermal conductivity, W/mK
L	length
Q	heat conduction, kN
T_1	average temperature of hot plate
T_2	average temperature of cold plate
W	width
W_f	weight of foam required, kg
W_m	weight of total mix, kg
W_{sat}	weight of saturated surface dry concrete specimen, kg
W_{dry}	weight of oven-dried concrete specimen, kg
φ	hygroscopic moisture

CLFC	cement-based lightweight foamed concrete
CS	calcium stearate
C-S-H	calcium silicate hydrate
FM	fineness modulus
LAC	lightweight aggregate concrete
LFC	lightweight foamed concrete
LFC-0.0CS	lightweight foamed concrete without calcium stearate
LFC-0.2CS	lightweight foamed concrete with 0.2 % calcium stearate
LFC-0.4CS	lightweight foamed concrete with 0.4 % calcium stearate
LFC-0.6CS	lightweight foamed concrete with 0.6 % calcium stearate
LFC-0.8CS	lightweight foamed concrete with 0.8 % calcium stearate
LFC-1.0CS	lightweight foamed concrete with 1.0 % calcium stearate

NRC	noise reduction coefficient
NRC	noise reduction coefficient
OPC	Ordinary Portland Cement
OPC	Ordinary Portland Cement
PCC	Portland composite cement
PCC	Portland composite cement
PI	performance index
PT	potassium trimethylsilanolate
RS	strength retention coefficient
SAC	sound absorption coefficient
SCC	self-compacting concrete
SP	siloxane-based polymer
TC	thermal conductivity
w/c	water-cement
w/cm	water-to-cementitious materials
WAP	water absorption percentage

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Today, concrete is the construction material that is utilised in most construction projects. Aggregates and paste are the two components that produce concrete. Aggregates are classified as fine or coarse, accounting for approximately 60 % to 80 % of the volume of concrete. The paste comprises cement, entrained air and water, accounting for 20 % to 40 % of the total volume. The compressive strength of concrete is one of the most valuable aspects (Shetty and Jain, 2019). Concrete is mainly applied to resist compressive loads in most structural applications. In addition, concrete is a popular building material for three primary reasons. Concrete is weather resistant, comes in various sizes and shapes and is the most economical and widely accessible material in the construction industry (Mehta and Monteiro, 2014).

Normal-weight, lightweight, and heavyweight concrete are the three different types of concrete, depending on their unit weight. First, normal-weight concrete is a kind of frequently utilised structural concrete weighing about 2400 kg/m^3. The unit weight of concrete less than 1800 kg/m^3 is defined as lightweight concrete, and it can be adopted where a greater strength-to-weight ratio is desired. Besides, the unit weight of concrete can also be decreased by using the lower bulk density of the natural or pyro-processed aggregates. Lastly, high-density aggregates are used to create heavyweight concrete, which typically weighs more than 3200 kg/m^3 and is utilised for radiation shielding (Mehta and Monteiro, 2014).

Foamed concrete is a light cellular concrete that belongs to the category of lightweight concrete. Mixing foam in mortar produced scattered air voids in lightweight foamed concrete (LFC) (Amran, Farzadnia and Ali, 2015). Sand, water and cement are mortar constituents without coarse aggregates (Mehta and Monteiro, 2014). Good thermal insulation, strong flowability, low cement content, and minimum aggregate consumption are all properties of foamed concrete. Additionally, foamed concrete is considered an affordable alternative in manufacturing broad-scale lightweight building materials and elements. This is due to the simple production procedure of foamed concrete from production plants to the applications' ultimate positions. Nations like Germany, the United Kingdom, the Philippines, Turkey, and Thailand have extensively employed foamed concrete in building applications (Amran, Farzadnia and Ali, 2015).

The lightweight property of LFC is achieved by introducing stable air bubbles into the concrete slurry. To distinguish LFC from concrete with air-entraining admixture, at least 20 % of the volume of concrete is filled with air voids. The density of LFC could be reached between 400 and 1600 kg/m^3 by adequately adjusting the foam amount. The water penetration into the concrete may affect its durability. However, several approaches for making the concrete waterproof are external coating, integral mixing, and an external membrane. According to American Concrete Institute (ACI) Committee 515, waterproofing concrete prevents moisture from penetrating and seeping out from the concrete (Lee, et al., 2022).

Water-repellent chemicals may be made from various materials, including calcium or sodium salts of stearates, liquid fatty acids, bitumen emulsions, wax emulsions, and silicates. Calcium stearate (CS), a chemical water repellent, was employed in this study. CS is produced by burning calcium oxide with stearic acid (Lee, et al., 2022). Furthermore, CS is an oil-based water-repellent additive used in concrete production by forming hydrophobic layers on LFC surfaces. LFC must be appropriately separated to preserve its strength as the air bubbles within it are very fragile and burst easily (Lee, et al., 2018). Therefore, this study will discuss the functional properties of 1600 kg/m^3 foamed concrete with calcium stearate.

1.2 Importance of the Study

Undeniably, concrete is significant in the building sector. Growing demands from the construction sector have resulted in several forms of concrete development. Foamed concrete is lightweight and may reduce the building's dead loads while decreasing the overall expenditures associated with a construction project. However, it has a high percentage of porosity as there are a lot of air bubbles inside the LFC. As a result, the penetration of toxic substances into foamed concrete compromises its entire durability and functionality (Lee, et al., 2018).

Many factors, namely mixed design compositions, curing methods and foam agents may influence the porosity of hardened concrete. It has been noticed that a high water-cement (w/c) ratio has a substantial impact on foamed concrete and causes porosity (Amran, Farzadnia and Ali, 2015). Thus, calcium stearate is added to the foamed concrete as a water repellent to reduce water penetration into LFC.

Then, an investigation of its functional properties is also carried out in this study. Functional properties, such as acoustic and thermal insulation, describe LFC's real behaviour over time. Foamed concrete absorbs sound ten times faster than dense concrete. The frequency of sound transmitted by the foamed concrete cellular wall is 3 % greater than that of the standard concrete wall. The quantity, size, distribution of pores and consistency of the foamed concrete may influence its sound insulation (Amran, Farzadnia and Ali, 2015).

Foamed concrete is well-known for its low heat conductivity, density reduction, self-compacting concrete, excellent flowability, ease of production, and inexpensive cost. The thermal conductivity of foamed concrete, which has a closed-cell structure and a density of 1600 kg/m^3, can reach 0.66 W/mK. It was discovered that thermal conductivity responds according to density and that thermal insulation reduces as density volume rises. When the thickness of foamed concrete sample increases, the thermal conductivity values will decrease. As a result, foamed concrete is used in various structural and civil engineering fields. Other uses of foamed concrete include lightweight block and precast panel production, thermal insulation, fire and acoustic insulation, and shock absorption barriers (Amran, Farzadnia and Ali, 2015).

Lastly, compressive strength is considered the main aspect of this lightweight concrete, which may eventually be utilized to produce structural, semi-structural, or non-structural components as a basic function of the intended density design. Furthermore, the durability of foamed concrete must be at a point that permits it to survive harsh conditions. This may be accomplished by adding the most appropriate foam agent (Amran, Farzadnia and Abang Ali, 2015).

1.3 Problem Statement

LFC is usually utilized on buildings’ exterior roof slabs and walls subjected to natural weathering such as rain. Malaysia has a tropical rainforest climate. Thus, it is hot and humid throughout the year. Excessive rainfall and humidity increase the probability of water being absorbed into the concrete, which may impact the long-term durability of LFC. CS, a type of water-repellent agent, is added to LFC to solve this problem by reducing water penetration into LFC (Lee, et al., 2022). Not only that, but CS in concrete also aided in lessening the corrosion caused by chloride ions and avoiding algal growth by minimizing moisture absorption (Lee, et al., 2018).

The ongoing research and manufacture of different kinds of concrete seek to address the varying demands of the building industry. Lightweight concrete is one of the contributions made to address the problem, as mentioned earlier, with the ultimate goal of decreasing the overall expenses associated with a construction project by reducing the dead loads of buildings. In addition, the air voids present in the LFC must be well maintained to maintain their lightweight properties (Lee, et al., 2018). The strength retention coefficient (RS) increased as the adhesive force between the water vapour and the porous surface decreased. The amounts of hygroscopic moisture reduced as the water repellent content increased (Raj, Sathyan and Mini, 2019).

This study’s challenge is obtaining the foamed concrete’s optimum w/c ratio. This is because the w/c ratio in foamed concrete is a regulating factor that controls its compressive strength. A sufficient amount of water increases the stability and uniformity of the mixture, removes large foam bubbles and increases compressive strength (Amran, Farzadnia and Ali, 2015). A w/c ratio of at least 0.35 was required to avoid the cement from pulling water from the foam. A low w/c ratio leads to a stiff mix and bubble breakup during mixing. At the same time, a greater w/c ratio caused a mix that was too weak in retaining the bubbles, which may lead to segregation. According to ACI 523.3R-93, foamed concrete should only be prepared using pure, contaminant-free water (Raj, Sathyan and Mini, 2019). Hence, an optimum w/c ratio should be obtained and used for the following step of the experimental study to get an accurate result.

1.4 Aim and Objectives

This study aims to examine the functional properties of 1600 kg/m^3 foamed concrete with calcium stearate. Several objectives are required to be achieved and are listed as follows:

1. To produce foamed concrete with a concrete density of 1600 kg/m^3.
2. To obtain an optimum water-cement ratio of foamed concrete.
3. To examine the effect of calcium stearate on the functional properties of foamed concrete.

1.5 Scope and Limitation of the Study

This study evaluates the functional properties of 1600 kg/m^3 foamed concrete with calcium stearate. The functional properties include thermal conductivity and sound absorption.

There are some scopes and limitations of this study that must be justified. Firstly, only lightweight foamed concrete will be adopted for this research which is limited to a density of 1600 kg/m^3. Then, only one type of water repellent will be adopted in this study which is calcium stearate. The proportion of CS added to the foamed concrete in the research is limited from 0 % to 1.0 %, with intervals of 0.2 %.

In this study, two tests will be conducted: fresh properties test and hardened test respectively. For the fresh properties test, the stability and consistency of the fresh density of concrete are vital. Hence, some data are also required to collect during the fresh properties test. These data include the amount of foam added into the concrete, inverted slump value, flow table value and the result of sieve analysis. On the other hand, this study will also carry out the hardened tests comprising compressive test, water absorption test, thermal conductivity test, and sound absorption test.

Furthermore, this study conducted stage 1 (trial mix) and stage 2 (actual mix). An optimum w/c ratio within 0.5 to 0.6 with an interval of 0.2 will be obtained in the trial mix. Meanwhile, 0 % of CS is used to test for the trial mix as the previous study has shown that the CS percentage did not affect the water-cement ratio (Lee, et al., 2022). Stage 1 is only limited to 7 days of compressive strength. For the actual mix, the scope of all the hardened tests is limited to 7 and 28 days of compressive strength and functional properties: thermal conductivity and sound absorption. Lastly, the cement-sand ratio is limited to 1:1 while the cement utilized in this research is Ordinary Portland Cement and the sand used must be sieved passed 0.6 mm sieve size.

1.6 Contribution of the Study

This research aims to apply calcium stearate to foamed concrete and increase its durability by decreasing water absorption. It is vital to lower the permeability of concrete as the water absorption into the concrete may affect its durability. In addition, the maintenance fee due to water penetration is costly. Hence, incorporating CS into foamed concrete can contribute to the construction industry by improving the durability of LFC (Lee et al., 2022).

Lastly, including CS in concrete also aided in minimizing corrosion caused by chloride ion attacks and avoiding algal contamination on porous concrete by lowering the water absorption by utilizing water repellent. In conclusion, LFC with CS significantly impacts the building sector due to its low density and high strength-to-weight ratio. LFC also aids in energy conservation, minimizes labour costs associated with construction and lessens dead loads on the building and foundation (Amran, Farzadnia and Ali, 2015).

1.7 Outline of the Report

There are five chapters in this report. Chapter 1 includes the general introduction, significance of the study, problem statement, purpose and objectives, limitation, scope and contribution of the study.

The literature review in Chapter 2 includes the earlier research on the applications of water repellent agents and their impacts on lightweight foamed concrete.

Chapter 3 covers the methodology, summarising the study's approach. Some tests will be conducted such as the fresh properties test and hardened test. The details of these tests were discussed and elaborated on.

Chapter 4 is the results and discussion, comprising the data analysis related to foamed concrete's functional and mechanical properties with calcium stearate. The functional properties include thermal conductivity and sound absorption while the mechanical properties include compressive strength. A detailed analysis of how CS impacts the functional properties and mechanical properties of lightweight foamed concrete was conducted in this chapter.

Chapter 5 summarises the whole research study. Several conclusions are drawn using various data and following the study objectives. Additionally, this chapter has presented several recommendations for further study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Every concrete structure must continue to fulfill its intended duties, namely retain its required strength and serviceability, throughout the stated or historically expected service life. Concrete must survive the deterioration processes to which it is likely to be subjected and this type of concrete is said to be durable. Deterioration, caused by internal and external sources inside the concrete, indicates poor durability. The different actions might be mechanical, chemical, or physical. The external chemical attack happens mostly due to aggressive ions, such as carbon dioxide, sulphates, or chlorides. This action may include both direct and indirect. The durability of concrete under different exposure circumstances depends on how easily air, certain gases, and water vapour penetrate it (Neville, 2011). The resistance of concrete to sulphate and other chemical attacks and chloride ion penetration is enhanced by decreased permeability.

The permeability of concrete may be characterized as a measure of the amount of water, air and other chemicals that pass through it, which is the concrete's ability to resist the penetration of any material that enters the concrete matrix. This is because the concrete includes voids that allow these elements to enter or exit. Foamed concrete is lightweight concrete that contains a significant amount of air voids within the cement paste mixture. Hence, the water will penetrate the foamed concrete easily. As a result, the durability and intended use of foamed concrete as a lightweight building material may be lost.

Therefore, studies on lightweight foamed concrete (LFC) with the introduction of calcium stearate (CS) are evaluated to investigate the functional properties of foamed concrete with CS (Lee, et al., 2018).

2.2 Lightweight Concrete

Lightweight concrete contains an expanding agent to increase the volume of the mixture and provide additional advantages which are low density and reduction in dead loads. Lightweight concrete is lighter than conventional concrete (Ismail, Fathi and Manaf, 2004). Therefore, using concrete with a lower density might result in significant advantages for smaller cross-section load-bearing parts and a corresponding decrease in foundation size. Concrete density can be lessened by substituting part of the solid material in the mix with air voids (Neville, 2011).

Low heat conductivity and low density are the key advantages of lightweight concrete. The benefits include increased building rates during construction, lessening the dead load and cheaper handling and hauling expenses (Ismail, Fathi and Manaf, 2004). Sometimes, construction on the ground with a poor load-bearing capacity mainly results from using lower-density concrete. Additionally, lighter concrete reduces the overall mass of materials to be handled, which increases efficiency. Then, formwork will resist less pressure than it would with normal-weight concrete. Lower-density concrete also gives excellent thermal insulation compared to normal concrete (Neville, 2011).

Lightweight concrete can be manufactured by adding air to the mix, eliminating the smaller aggregate sizes, or substituting them with a porous or hollow aggregate. Lightweight concrete can be classified into 3 categories: no-fines concrete, aerated or foamed concrete and lightweight aggregate concrete (Ismail, Fathi and Manaf, 2004).

2.2.1 No-Fines Concrete

No-fines concrete is a lightweight concrete created by leaving out the fine aggregate and only consisting of water, cement and coarse aggregate. Therefore, no-fines concrete is an amalgamation of coarse aggregate particles individually coated in a layer of cement paste up to 1.3 mm thick. As a result, the concrete’s body includes huge voids contributing to its low strength. However, water capillary movement cannot occur due to its large size (Neville, 2011).

No-fines concrete must be laid quickly as the thin coating of cement paste might dry out and will reduce the strength of the concrete. No-fines concrete does not segregate, making it possible to drop it from great heights and place it in three-story high lifts; in this aspect, the low pressure applied to the formwork is beneficial. Young no-fines concrete demonstrates very less cohesiveness. Hence, formwork must be kept in place until adequate strength has been established to keep the material together. Due to the thin cement paste involved, moist curing is crucial, particularly in dry weather or windy situations (Neville, 2011).

No-fines concrete is mostly used for load-bearing walls in residential buildings and infilling panels in framed constructions. In reinforced concrete, no-fines concrete is rarely used. Still, if it is, the reinforcement must be covered with a thin cement paste coating (approximately 3 mm) to enhance the bonding properties and avoid corrosion. Shotcreting is the simplest reinforcement coating method (Neville, 2011).

2.2.2 Lightweight Aggregate Concrete

Lightweight aggregate concrete (LAC) is made from lightweight or low-density aggregates such as volcanic pumice, clay and pellite (The Constructor, 2021). This lightweight aggregate is differentiated by its high porosity, contributing to its low specific gravity (Ismail, Fathi and Manaf, 2004). The cement content needs, coarse-to-fine aggregate ratio, workability, and water demand of concrete mixtures may all be influenced by lightweight aggregates' particle shape and surface texture.

There are several applications for LAC. First of all, lightweight aggregate concrete can be used for screeding and general-purpose thickening, especially when applied to floors, other structural components and roofs with such screeds or thickening and weight. Besides, for architectural reasons or as a coating, LAC can be applied to structural steel casting to shield it from corrosion and fire. Other than that, LAC can also be used for insulating water pipes and providing heat insulation on roofs. Lastly, LAC is also utilized in rendered surfaces for small dwellings’ exterior walls (The Constructor, 2021).

LAC is divided into two categories based on its function: structural LAC and partially compacted lightweight aggregate. The two main uses for the partially compacted LAC are precast concrete panels and cast-in-situ walls and roofs. The most important criteria for this kind of concrete are low density and sufficient strength to provide the optimum thermal insulation and little drying shrinkage to prevent cracking (Ismail, Fathi and Manaf, 2004).

Currently, lightweight structural concrete is a popular building material because an adequate strength of lightweight concrete combined with steel reinforcement is more cost effective than traditional concrete. Similar to dense aggregate reinforced concrete, structural lightweight aggregate concrete is completely compacted. It may be combined with steel reinforcement to provide the steel and the concrete with a strong link. Concrete must protect the steel from corrosion. Tough concrete mixes are produced due to the fine aggregate's coarse quality, size and texture of the aggregate particles. Only heavier lightweight aggregate types are suitable for structural concrete (Ismail, Fathi and Manaf, 2004).

2.2.3 Lightweight Foamed Concrete

A cement mortar type called foamed concrete contains air bubbles that have been added using the proper foaming agent. It has unique qualities including low aggregate consumption, high porosity, great flowability, powerful heat insulation, low self-weight, fire resistance, airborne sound insulation, and good compressive strength. It is also known as cellular concrete, where the density ranges from 300-1800 kg/m^3 (Raj, Sathyan and Mini, 2019).

According to Amran, Farzadnia and Ali (2015), foamed concrete has excellent properties such as a low density that reduces foundation size, labour, shipping, and operational expenses as well as structural dead loads. Furthermore, it improves sound absorption, thermal conductivity, and fire resistance due to its textured surfaces and microstructure cells. Additionally, foamed concrete is affordable for producing large-scale, lightweight construction components and materials due to its easy manufacturing technique. Foamed concrete is made up of both supplementary and basic constituents. The fundamental components of mortar are sand, cement, water, and fine aggregates, while the supplemental materials include plasticizers, fly ash and fibers (Amran, Farzadnia and Ali, 2015).

2.2.4 Aerated Concrete

Aerated concrete is divided into two types based on the pore formation method: foamed concrete and air-entrained concrete. The air-entraining technique includes the addition of chemicals that produce gas into the mortar. During mixing, a chemical reaction will release gas to create a porous structure. Aerating agents commonly used include calcium carbide, aluminium powder and hydrogen peroxide. On the other hand, pores are produced mechanically in the foaming method by either the pre-foaming process (mixing of foaming agent in water) or the mixed foaming process (mixing of foam in the mortar) (Raj, Sathyan and Mini, 2019).

Aerated concrete is categorized into two categories based on its curing approach: autoclaved concrete (autoclaved under heat and pressure to achieve its distinctive qualities) and non-autoclaved. It is also categorized based on its density. Densities between 300 kg/m^3 and 600 kg/m^3 are often used for insulation and filling. Then, non-load-bearing constructions like precast blocks, exterior building panels, thermal insulation and soundproofing screeds are made using densities between 600 kg/m^3 and 1200 kg/m^3. Lastly, high-density foamed concrete (1200-1600 kg/m^3) is widely employed to construct load-bearing structures (Raj, Sathyan and Mini, 2019).

2.3 Water Repellent Agents

Exterior wall materials have recently included aerated concrete, lightweight concrete and foamed concrete with good thermal insulation features. Additionally, foamed concrete is used for running tracks, playgrounds, and earthen barriers because of its great fluidity and minimal cement and aggregate consumption (Ma and Chen, 2016). Due to the pore and capillary structure of cementitious building materials including concrete, mortar, and masonry, water is often easily absorbed.

Moisture contributed to most concrete structure deterioration processes, such as frost damage and reinforcement corrosion (Johansson et al., 2008). The porosity and pore structure of foamed concrete determine its permeability, which is the key aspect in regulating the transportation of moisture such as pore diameter. Sorptivity and hygroscopicity, defined by water vapour absorption, are the appropriate criteria to comprehend the process of water penetration in foamed concrete (Ma and Chen, 2016).

Water-repellent agents, namely silanes and siloxanes, provide adequate protection against chlorides and moisture, hence extending the service life of concrete structures (Johansson, et al., 2008). The following sub-section will discuss various types of water repellent introduced into foamed concrete such as calcium stearate, silanes and siloxanes.

2.3.1 Calcium Stearate

The water-repellent agent chosen in this study is calcium stearate (CS). White granular CS is a non-toxic material. It is stearic acid–derived calcium salt. In addition, it is an oil-based water repellent additive often applied in concrete production (Lee, et al., 2018). The durability of reinforced concrete structures weakens when moisture and aggressive ions permeate the concrete. To solve this issue, damp-proofing admixtures, such as calcium stearate, can be added to the concrete mix design to prevent water entry and aggressive ions. CS is a damp-proofing agent that may form a water-repellent coating along capillary pores. Consequently, it may lower the permeability of concrete under non-hydrostatic conditions (Chari, Naseroleslami and Shekarchi, 2019).

2.3.2 Zinc Stearate

Zinc stearate is a non-toxic white hydrophobic powder soluble in acids but not water. It has strong water resistance and good water-repellent properties. Depending on the intended purpose, technical grade zinc content might change (PubChem, 2022). Zinc stearate is zinc salt of hydrogenated, distilled fatty acids. It can be manufactured by either precipitation or fusion process. Due to its good water-repellent properties, it is normally adopted in the paint and plastic industry. In addition, zinc stearate also acts as an activator in the rubber vulcanization process. Zinc stearate is used in cosmetics as a lubricant, thickening and binding the liquid and oily components together. Lastly, it should be kept in a dry and well-ventilated area as it can be stable in a dry and cool environment.

2.3.3 Silane

Silane is the most common type of water-repellent derived from the silicone molecule. 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. The substrate must contain calcium hydroxide and be alkaline (high pH) for this chemical reaction. As a result, silanes designed for concrete and masonry are ineffective for sealing alternative substrates like wood, clay brick, or natural stone. Silanes often penetrate more than siloxanes because they comprise smaller molecules than siloxanes. Hence, silanes perform well on dense surfaces such as precast concrete. In addition, silanes are quite volatile due to their small molecular size. Thus, the silane water repellent should have a high enough solid content to compensate for the evaporation of reactive material during application and curing (Concrete Construction, 1995).

2.3.4 Siloxane

The substrate pH does not influence siloxane to react. The reaction of siloxanes with ambient moisture and any moisture present in the substrate can form the hydrophobic resin. Siloxanes are therefore perfect for treating non-cementitious building materials namely brick, stucco, and stone. Siloxanes have a slightly bigger molecular size. Siloxanes are relatively effective on substrates up to medium porosity such as heavyweight, smooth-faced, etc. Their chemical composition does not promote quick evaporation as silanes do. As a result, they often have lower solid content than silanes. As siloxanes are less volatile than silanes, they often provide good water-repellent properties at a cheaper initial cost (Concrete Construction, 1995).

2.4 Effects of Calcium Stearate on the Different Types of Concretes

Chari, Naseroleslami and Shekarchi (2019) examined the effect of CS on the properties of freshly poured and cured concrete. Twelve mixtures were prepared and were moist-cured for 180 days. The mixtures had varying water-to-cementitious materials (w/cm) ratios but fixed cement paste-to-aggregate ratios. The main findings of the research on fresh concrete revealed that a high dose of CS at low w/cm ratios enhanced the fresh concrete’s air content and decreased its density. Irrespective of the w/cm ratio and CS amount, it also reduced the workability of fresh concrete. Then, the outcomes of the study of compressive strength showed that calcium stearate lowered compressive strength even when a small amount of calcium stearate was applied to the concrete mixture. CS may also enhance permeability when subjected to non-hydrostatic pressure according to the outcomes of permeability tests. However, it was shown that including calcium stearate was not feasible for reducing permeability under hydrostatic pressure. Lastly, microstructure investigation demonstrated that CS negatively impacts the transient interfacial zone.

According to Maryoto, et al. (2020), the goal is to examine the effect of CS on the concrete’s properties by utilizing Portland composite cement (PCC) and fly ash. The CS content of the concrete is 0, 1, 5 and 10 kilograms per m^3 of concrete volume. Compressive strength, accelerated corrosion, water absorption and chloride ion infiltration tests have all been carried out for each of the constituents. Compared to self-compacting concrete (SCC) without fly ash and CS, introducing CS at 1 kg/m^3 in SCC with 10 % fly ash enhances its physical and mechanical qualities. This eventually results in less water absorption, less chloride ion penetration, more stable compressive strength and fewer corrosion attacks.

Furthermore, the study on the effects of three types of water repellent on the physical and mechanical properties of foamed concrete was done by Ma and Chen (2016). In this research, ordinary Portland cement produces foamed concrete with a low density of approximately 550 kg/m^3. Water repellents such as CS, potassium trimethylsilanolate (PT) and siloxane-based polymer (SP) are adopted to lower the water absorption of the foamed concrete. This is because foamed concrete’s physical and mechanical qualities would be substantially damaged after the moisture entry into it. This study evaluated thermal conductivity, sorptivity, hygroscopicity, and compressive strength for 7 and 28 days. The experimental findings show that the water repellents help enhance the foamed concrete's compressive strength to some level without compromising its thermal insulation. Then, the sorptivity as measured by 48 hours of water absorption and the strength retention coefficient (RS) improves dramatically when the dosage of water repellent increases.

Numerous studies have shown that thermal conductivity increases when CS content increases because of improved compressive strength. The strength first increases as the CS percentage rises and then slightly decreases as the CS content exceeds 1.0 %. However, the thermal conductivity range is relatively narrow; with a CS content of 1.0 %, the highest value is only 0.159 W/mK, just 6.7 % greater than the minimum value. Furthermore, it can be inferred that CS can likewise enhance foamed concrete’s water resistance, which is consistent with earlier findings. Water repellent can lower the foamed concrete's hygroscopic moisture W(φ) content for the hygroscopic moisture test. When the calcium stearate contents increase from 0.2 % to 1.2 %, W (φ) decreases gradually (Ma and Chen, 2016).

According to Lee, et al. (2018), a water repellent, CS, is added to foamed concrete and its impact on different engineering properties will be examined. There were two key research stages for this study. The first stage (trial mix) aimed to determine the optimum w/c ratio for foamed concrete without water repellents. The mix proportions remained unchanged at this stage, with a cement-to-sand ratio of 1:1, while the w/c ratio will be adjusted from 0.44 to 0.50 at increasing intervals of 0.02. The trial mix was performed to identify the ideal w/c ratio for the final mix proportions, as shown by the best overall uniformity, compressive strength, and stability. Each sample with a different w/c ratio was evaluated for its 7-day strength.

The second stage of this study used the optimal w/c ratio from the first stage to investigate how 0.2 % and 0.4 % of CS influence the fresh and engineering properties of foamed concrete. Adding CS to foamed concrete altered its mechanical properties, reducing its compressive strength. Nevertheless, it has been crucial in enhancing foamed concrete's physical properties, such as sorptivity, initial surface absorption and absorption. As the dose of CS increased, the rate decreased. Additionally, it was observed that the ideal dose for CS inclusion was 0.2 % of cement weight to minimize the detrimental impacts of water-repellent overdosing (Lee, et al., 2018).

Lastly, Lee, et al. (2022) studied the impact of CS in the LFC mix on its strength performance. In their study, four kinds of LFC were cast and water cured for 7, 28 and 56 days before being evaluated for strength with CS concentrations varying from 0 % to 0.6 % of cement weight. It was revealed that CS in the FC does not affect the workability of fresh concrete. Besides, the overall strength of the LFC will not be affected by using CS, but CS will affect the strength of the LFC during an early age as the strength development rate of the LFC will be retarded. Continuous curing of LFC with CS may obtain the same strength acquired by the control mix. If early LFC strength is not a concern, adding CS to LFC will have the additional benefit of reducing water absorption and improving LFC durability.

2.5 Testing Properties of Foamed Concretes

The following section discusses the foamed concrete’s mechanical properties, such as compressive strength. It was discovered that the compressive strength of foamed concrete depends on many factors and the relationship between these factors and its compressive strength was discussed in the following sub-section. Then, the functional properties namely thermal conductivity and acoustic properties also will be discussed. Foamed concrete’s cellular microstructure provides it with good thermal insulation properties. This is due to the foamed concrete’s porous structure which may lower its thermal conductivity. Lastly, foamed concrete possesses a comparatively strong acoustic absorption compared to conventional concrete.

2.5.1 Compressive Strength

According to Falliano, et al. (2018), their research is performed to determine the factors governing foamed concrete’s compressive strength. This experimental research includes three types of curing conditions (air, cellophane sheet and water), three w/c ratios, three foaming agents with either a synthetic (SLS and FoamTek) or protein nature (Foamin C) and two kinds of cement (limestone Portland CEM II A-L42,5 R and Portland CEM I 52,5 R).

In low-density concrete, compressive strength development is directly influenced by the amount of entrapped and entrained air and hence by the (water+air) / cement ratio. Hence, a higher compressive strength can be obtained by increasing the w/c ratio, particularly for those lower densities and up to a critical (water+air)/cement ratio. Besides, the protein-based foaming agent (Foamin C) and cellophane sheet curing conditions yield the highest compressive strength values. For a w/c ratio of 0.3, the compressive strength of the samples using CEM I 52,5 R and protein-based foaming agents is ten times larger than that of synthetic foaming agent samples. This is attributed to the overall fluid state and the influence of the combined (water+air) / cement ratio in low densities of foamed concrete samples. Furthermore, the curing conditions of foamed concrete samples in cellophane and water improve mechanical properties compared to those cured in the air (Falliano, et al., 2018).

Next, the w/c ratio also had been analyzed in depth in this study. Depending on the foaming agent, this ratio has a different effect in the various curing conditions. Adjusting the w/c ratio from 0.3 to 0.5 in synthetic-based foaming agents causes a substantial improvement in compressive strength. Nevertheless, if the w/c ratio increases from 0.5 to 0.7, the compressive strength will not increase further but instead a moderate decrease. Except for air, an increase in the w/c ratio will not result in considerable changes in the compressive strength of the protein-based foaming agents in all the curing conditions. In addition, different foaming agents have varied properties, which is a major factor in varying compatibility with the cement type (Falliano, et al., 2018).

Furthermore, it has been discovered that when the CEM I 52,5 R is used in contrast to the CEM II A-L 42,5 R, protein-based foaming agents produce samplings with greater strength values. Synthetic foaming agents, however, behave oppositely (Falliano, et al., 2018).

According to Raj, Sathyan and Mini (2019), the foam concrete’s compressive strength with evenly distributed spherical air voids was greater. In contrast, the compressive strength of foam concrete with irregular perimeters or merged form bubbles with huge uneven openings was lower. Lastly, foamed concrete with finer sand offered evenly distributed air spaces compared to coarse sand.

2.5.2 Thermal Conductivity

Thermal conductivity, the k value, is the heat transfer via conduction through the material. Using materials with poor thermal conductivity may greatly reduce the energy used during building design and construction. From the perspective of thermal insulation, foamed concrete is lightweight concrete with a density range from 400 to 1850 kg/m^3. It is considered one of the suitable materials in the current construction industry. It is generally a cement paste or mortar with air voids drawn in by an appropriate foaming agent. Besides, it has unique qualities including low self-weight, great flowability, little aggregate consumption, and good thermal insulation properties. Since air is the poorest heat conductor, LFC with more porosity has poorer thermal conduction, which changes with the extent of porosity (Wagh, Ranjani and Kamisetty, 2020).

Thermal conductivity is measured using the transient and steady-state methods, which have different requirements for heat transmission through materials. The air void system and density are parameters that influence foamed concrete’s thermal properties. According to studies, thermal resistance is inversely proportional to foamed concrete density and directly proportional to porosity. Besides, moisture content, temperature and curing conditions influence foamed concrete's thermal properties considerably. In addition to improving mechanical qualities, foamed concrete using lightweight aggregates exhibits much higher thermal resistance (Wagh, Ranjani and Kamisetty, 2020).

In reality, foamed concrete slabs exhibit excellent thermal insulation behaviour that is improved by reduced sorptivity and greater strength. According to some research, the degree of thermal insulation in foamed concrete is affected by the mixture composition, such as aggregate type and mineral admixtures. In addition, it was previously observed that using lightweight particles in foamed concrete reduced thermal conductivity. Other than that, mineral admixtures may also alter the thermal characteristics of foamed concrete by modifying its density. Lastly, it has been discovered that the mortar/foam ratio influences density performance and significantly affects insulating capacity (Amran, Farzadnia and Ali, 2015).

The study thus emphasizes the necessity for further organized research to assess the thermal behaviour of foamed concrete and building energy use under various weather situations (Wagh, Ranjani and Kamisetty, 2020).

2.5.3 Sound Absorption

A proper foam dose is added to a mixture of cement and water with or without fine aggregate to produce foamed concrete with a lower density than ordinary concrete. The amount of foam incorporated determines the reduction in foamed concrete density (Tie, et al., 2020). Because of its cellular structure, foamed concrete is expected to have a strong capability for sound absorption. Since it does not include coarse aggregates, it is considered homogeneous concrete.

Due to changes in tortuosity, porosity, pore size and increment of foam dosage, it enhanced the sound absorption from 0.10 to 0.22 at a frequency of 800-1600 Hz (Zhang, et al., 2015). This is supported by Mastali, et al. (2018) whereby a maximum of 35 % foam content in fibre-reinforced alkali-activated slag cellular concrete may generate a huge porous structure. Its high porosity enables it to have a sound absorption coefficient greater than 0.94 between 2000 and 3000 Hz as shown in Figure 2.1. Hence, it is undeniable that concrete with high foam content may greatly improve foamed concrete's acoustic performance.

In short, concrete mixes may be modified in several ways to increase their acoustic performance, including using lighter or more porous particles, adding a foaming agent to create foamed concrete, and creating pervious concrete mixtures. To improve sound absorption performance and optimise the materials' porosity formation, it is important to consider the type and size of aggregate and the quantity of foam agent to be added while designing these modified mixes. The higher the porosity, the smaller the density of the concrete (Tie, et al., 2020).

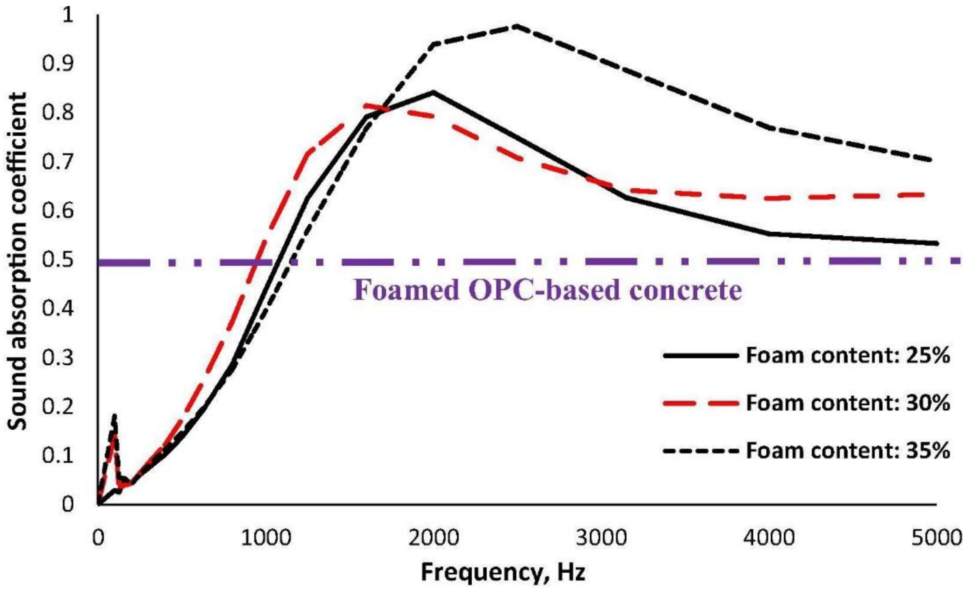


Figure 2.1: Acoustic Absorption Profile for 25 %, 30 % and 35 % Alkali-Activated Slag Foam Concrete Samples (Mastali, et al., 2018).

2.6 Raw Materials

Mortar and foam are the main raw materials of foamed concrete. Mortar is typically fresh concrete made of water, fine sand, and cement. Foam protein-based or additional synthetic mix is used to lighten the concrete. While synthetic-based foaming agents are easier to control, less expensive, need less energy, and can be kept longer, hydrolyzed proteins perform better in strength (Sari and Sani, 2017). Hence, the following section will discuss raw materials such as Ordinary Portland Cement, fine aggregate or sand, foam agent and water.

2.6.1 Ordinary Portland Cement (OPC)

The main binder in foamed concrete is cement. There are several types of Ordinary Portland Cement available on the market. As per ASTM C150, OPC is classified into five types: Type I, Type II, Type III, Type IV and Type V. Table 2.1 shows the general characteristics of various Portland Cements. OPC is good at resisting cracking and shrinking. Then, it is also less expensive than other kinds of cement such as rapid-hardening cement. In addition, the structure will become strong and durable after hydration. Lastly, it is simpler to handle and set than other cement types.

Table 2.1: General Characteristics of Various Portland Cements.

Types	Characteristics
I	• General purpose cement. • Unless another type is stated, it is normally assumed.
II	• Moderate sulphate resistance and produces less heat when hydrated.
III	• Relatively high early strength. • Ground finer.
IV	• Low heat of hydration.
V	• High sulphate resistance. • Very low (C_3A) composition.

2.6.2 Fine Aggregate / Sand

About 60 to 80 percent of the concrete mix comprises aggregates. They provide concrete bulk and compressive strength. For a good concrete mix, the aggregates must be pure and devoid of any components that might deteriorate the concrete. Aggregates can be divided into fine aggregates and coarse aggregates. The diameter of coarse aggregates is more than 4.75 mm, whereas the diameter of fine aggregates is less than 9.55 mm.

Typically, the production of foam concrete does not include coarse aggregate. This is because the bubble in foamed concrete will not be stable and eventually burst out if using coarse aggregates. Compared to coarse sand, foamed concrete with finer sand produces more evenly distributed air voids (Raj, Sathyan and Mini, 2019). Additionally, the strength of concrete is considerably enhanced using fine sand and the constant distribution of pores formed in the concrete mix design matrix (Amran, Farzadina and Ali, 2015).

The physical properties of lightweight foamed concrete will alter when the sand gradation varies (Lim, et al., 2014). Lim, et al. (2014) studied the fresh and hardened characteristics of lightweight foamed concrete with a density of around 1300 kg/m^3 formed by varying sand gradations. The four sand sizes used in this study are sand with 100 % passing through sieves of 0.60 mm, 0.90 mm, 1.18 mm and 2.36 mm. In this study, the raw materials included are OPC, water, synthetic foaming agent and oven-dried river sand with different gradations.

The experimental findings lead to several conclusions. According to Lim, et al. (2014), the usage of sieve size 0.60 mm sand (the study’s finest grading) provided higher quality in the manufacturing of cement-based lightweight foamed concrete (CLFC) than the coarser gradations of sand (2.36 mm to 0.90 mm). To obtain optimal consistency and stability, the w/c ratio of CLFC was raised when the CLFC was formed with finer sand gradation. Then, using finer sand enhanced the compressive, flexural strengths, flexibility and flexural toughness of CLFC.

In conclusion, sand that passes through the 0.60 mm sieve is the optimum sand size, giving LFC the most stable and higher strength. Hence, the sand distribution size of 0.60 mm will also be adopted in the study to produce LFC.

2.6.3 Water

Water requirement depends on components and admixtures used in the foamed concrete. The amount of water also depends on the required mix’s uniformity, consistency and stability. Additionally, a correct amount of water must be used to ensure that the premixed mortar can be easily worked into the fresh design mix for foamed concrete. Otherwise, the foam would rapidly degrade because of the cement absorbing water from it (Amran, Farzadina and Ali, 2015).

Potable water with a pH close to 7 is optimal for producing foam concrete. A minimum w/c ratio of 0.35 was necessary to avoid the cement absorbing water from the foam. When the w/c ratio is low, it results in a stiff mix and bubble breakup during the mixing process. On the other hand, a higher w/c ratio will lead to segregation. Under ACI 523.3R-93, the water used in foamed concrete should be pure and free of pollutants (Raj, Sathyan and Mini, 2019). This is due to the British Cement Association’s specification that the foamed concrete mix formation can negatively impact organic infection when using protein-based foam agents (Amran, Farzadina and Ali, 2015).

2.6.4 Foaming Agent

A foaming agent regulates the concrete density by producing air bubbles in the cement paste mixture. Enclosed air voids, known as foam bubbles, form when introducing a foaming agent. The most common foaming agents are synthetic and protein-based. The synthetic foaming agents produce bigger expansion and thus lesser density. On the other hand, protein-based foaming agents enable the incorporation of higher volumes of air and offer a more stable air void network. In addition, foaming agents such as protein-based rather than synthetic foam agents significantly impact the compressive strength of foamed concrete. The amount of foam agent in the mixture significantly affects the properties of both fresh and cured concrete. The excessive foam dosage causes a decrease in flow. Nevertheless, mixing time has a considerable influence on flow. When the mixing duration is long, more entrained air will be formed, yet extended mixing may cause entrained air loss by reducing air content (Amran, Farzadnia and Ali, 2015).

Furthermore, chemical water-reducing admixtures that might cause foam instability are seldom applied. The foam agent’s stability should be verified using the ASTM C 869-91 and ASTM C 796-97 test protocols. Air voids in most foamed concrete applications vary from 6 % to 35 % of the total volume of the final mix. The foam quality was critical since it indicated the stability of foamed concrete and influenced the stiffness and strength of the final foamed concrete. Instead of the w/c ratio mixture, the foam content mostly determines the compressive strength of foamed concrete construction. To ensure the foam’s stability, it should be added shortly after formation in a viscous form (Amran, Farzadnia and Ali, 2015).

2.7 Summary

Ordinary Portland cement, water, fine sand and synthetic foam produce lightweight foamed concrete (LFC). LFC is a modern concrete technological innovation in civil engineering. LFC minimizes dead loads on the building and base, aids in energy saving, and saves construction expenditures. Besides, foamed concrete is a kind of light cellular concrete that contains air voids. The voids can be incorporated by air or gas, which can be done by adding foam agents into the concrete. LFC has a high percentage of porosity as there are a lot of air bubbles inside the LFC. Hence, water repellents can be introduced into foamed concrete to provide adequate protection against moisture.

The water repellent adopted in this study is calcium stearate. The functional properties of 1600 kg/m^3 foamed concrete with calcium stearate were investigated. This project conducted several tests to assess compressive strength, water absorption, sound absorption and thermal conductivity. These tests assessed calcium stearate's impact on the LFC's functional and mechanical qualities. Table 2.2 shows the research gap, which summarises the study that previous researchers had done.

Table 2.2: A Summary of the Different Types of Concrete and Water Repellent Agents.

Authors	Types of Concrete Used	Density of Concrete (kg/m^3)	Types of Water Repellent Agents	Properties That Had Been Determined
Lee, et al. (2018)	Foamed Concrete	1200	Calcium stearate (CS)	Compressive strength, water absorption, sorptivity and initial surface absorption
Lee, et al. (2022)	Lightweight Foamed Concrete (LFC)	1200	Calcium stearate (CS)	Compressive strength, flexural strength, splitting tensile strength and water absorption.
Falliano, et al. (2018)	Foamed Concrete	400, 600, 800	Protein-based (Foamin C) and Synthetic-based foams (FoamTek and SLS)	Compressive strength
Ma and Chen (2016)	Foamed Concrete	550	Potassium trimethylsilanolate (PT), calcium stearate (CS) and siloxane-based polymer (SP)	Mechanical and physical properties of the foamed concrete (7-day and 28-day compressive strength, thermal conductivity, hygroscopicity and sorptivity).
Maryoto, et al. (2020)	Self-compacting Concrete	Not stated	Calcium stearate (CS)	Compressive strength, water absorption, chloride ions infiltration, and degree of corrosion attack.

Table 2.2 (Continued)

Chari, Naseroleslami and Shekarchi (2019)	Fresh and Hardened Concrete	Range from 2260 - 2341	Calcium stearate (CS)	Electrical resistivity, density, workability, compressive strength, water penetration depth and water absorption.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter describes all the procedures and techniques of testing to study the functional properties and compressive strength of 1600 kg/m^3 of lightweight foamed concrete (LFC) with the incorporation of calcium stearate (CS). There were two stages: trial mix and actual mix in this study. An optimum water-cement (w/c) ratio was obtained in the trial mix and this ratio was applied in the actual mix with different portions of the CS. Then, fresh properties tests and hardened tests were conducted. This chapter also discusses the preparation, mix proportion and casting procedures. Figure 3.1 shows the overall project workflow chart with their respective objectives.

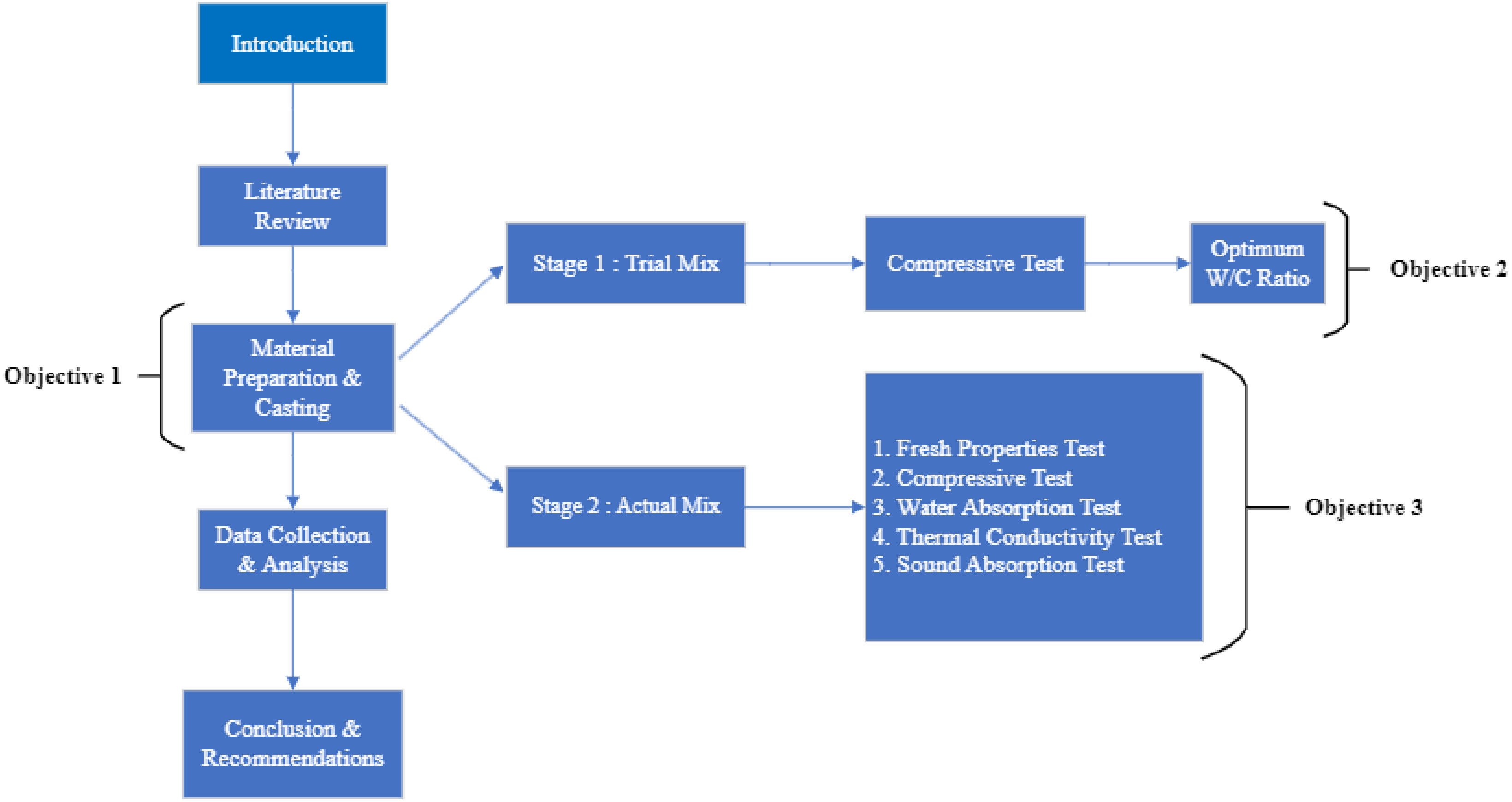


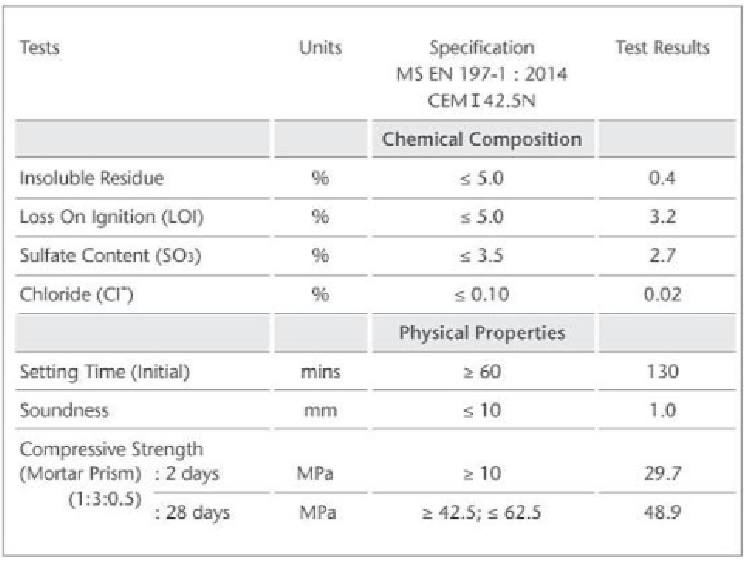
Figure 3.1: Flow Chart of Overall Project Work.

3.2 Raw Materials

This section discusses and describes the raw materials used in the study, which comprised Ordinary Portland cement (OPC), sand, water and foaming agent and calcium stearate as water repellent.

3.2.1 Ordinary Portland Cement (OPC)

Ordinary Portland Cement (OPC) is the most common form of cement. YTL Orang Kuat, CEM I cement with a cement grade of 52.5 N was adopted in this study. It fulfilled all the ASTM C150 standards for Type I cement (2004). If the cement is not fresh, the cement must pass a sieve to prevent the occurrence of a slump as this may affect the strength of the concrete in the later stage. If OPC requires a sieve, it must pass through 45 µm of sieve size. Furthermore, OPC must be kept in an airtight container to avoid exposure to air, which will harden the cement. Figure 3.2 shows the properties of YTL Orang Kuat Cement.



Tests	Units	Specification MS EN 197-1 : 2014 CEM Ⅰ 42.5N	Test Results
		Chemical Composition	
Insoluble Residue	%	≤ 5.0	0.4
Loss On Ignition (LOI)	%	≤ 5.0	3.2
Sulfate Content (SO_3)	%	≤ 3.5	2.7
Chloride (Cl^-)	%	≤ 0.10	0.02
		Physical Properties	
Setting Time (Initial)	mins	≥ 60	130
Soundness	mm	≤ 10	1.0
Compressive Strength (Mortar Prism) (1:3:0.5) : 2 days	MPa	≥ 10	29.7
: 28 days	MPa	≥ 42.5; ≤ 62.5	48.9

Figure 3.2: Properties of YTL Orang Kuat Cement (YTL Cement, 2022).

YTL Orang Kuat Cement as shown in Figure 3.3 was used in this study due to some reasons. First, Orang Kuat, CEM I is a high-strength Ordinary Portland Cement designed specifically for early demoulding, handling and usage. It is a good choice for high-strength concrete applications where time is limited. Besides, it is ideal for prefabricated, brickmaking, structural concrete work and other general-purpose applications requiring high strength to boost efficiency. In addition, Orang Kuat was manufactured utilizing the most modern energy-efficient cement manufacturing technique. All efforts were taken to minimise the environmental impact of this cement production.

Orang Kuat cement was obtained from major construction materials distribution enterprises and hardware shops at 50 kg per pack. Orang Kuat was manufactured following strict quality assurance, environmental management, health and safety, and energy management systems. Then, it is MS ISO 9001, MS ISO 14001, OHSAS 18001, and MS ISO 50001 certified. While using this cement, Personal Protective Equipment (PPE) such as eye, hand, and skin protection, as well as dust masks is encouraged. This is because wet cement or mortar on the skin may cause irritation dermatitis.

Figure 3.3: YTL Orang Kuat Cement.

3.2.2 Sand

The sand was used for sieve analysis and LFC casting. For LFC casting, the sand used in this study should be fine and was sieved through the 0.6 mm sieve size. The sieved sand was then stored in a plastic container with a cover. If the sand is wet, it may not be sieved. Before sieving and casting, 24 hours of drying at around 105 °C in the oven is necessary to eliminate the water content in the sand particles as shown in Figure 3.4. Finer sand has a bigger total surface area and needs more water to hydrate, providing consistent fresh mixes. The mixes’ consistency aided in a more uniform distribution of stable foam in the freshly mixed cement mortar, which may improve the foamed concrete's performance in terms of strength (Lim, et al., 2014).

Figure 3.4: Drying of Sand Using Oven.

3.2.3 Water

Water is important for casting concrete and producing foam. Normal tap water was used for preparing the foamed concrete as long as it was clean. This is because the low water quantity will make the mixture excessively stiff, which leads to bubbles bursting during mixing and may increase its density. However, the slurry was too thin to contain the bubbles with high water content, resulting in foam segregation from the mix and increased final density (Nambiar and Ramamurthy, 2006). Lastly, the quantity of water used must be sufficient to ensure that the workability of the premixed mortar is satisfactory for foamed concrete fresh design mix (Amran, Farzadnia and Ali, 2015). Hence, tap water from the civil laboratory was used to produce foam.

3.2.4 Foaming Agent

A foaming agent is necessary to generate foam. Sika® Aer 50/50 foaming agent as shown in Figure 3.5, manufactured by Sika Kimia Sdn. Bhd was chosen to apply to the study. Its properties are shown in Table 3.1. Different brands of foam agents may have different specifications. For Sika® Aer 50/50, the manufacturer discovered that the ideal ratio for generating stable foam is 1: 20 of a foaming agent to the water. After the foaming agent and water were poured into the generator, the valve was closed and the compressed air valve should open to allow the compressed air to flow into the foam generator. This ensures the pressure is up to 0.5 MPa in the foam generator to produce a stable bubble to regulate the foamed concrete's density. Then, the stable foam was produced and flowed through the nozzle as shown in Figure 3.6.

Figure 3.5: Sika® Aer 50/50 Foaming Agent.

Figure 3.6: Foam Generated from Foam Generator.

Table 3.1: Properties of Sika® Aer 50/50 (Sika Kimia, 2020).

Type	Aqueous Solution
Appearance	Light straw liquid
Shelf Life	1 year from the date of production
Packaging	20 L pail or 200 L drum

Sika Aer 50/50 used in this project is a user-friendly product. Then, it is suitable for concrete where a high proportion of air is desired. Sika Aer 50/50 can also be used for lightweight pumped or poured concrete or grout used in constructions with extremely high noise and thermal insulation, as well as for fills with low-strength concrete.

In addition, Sika® Aer 50/50 is a highly concentrated liquid foaming additive for lightweight aggregate concrete and other types of concrete requiring a high air content. Due to its stabilizing components, this foaming agent will produce a large volume of stable air during the work and pumping. Thus, the concrete volume produced is relatively constant. Sika® Aer 50/50 enables concrete production with a specific weight of 800-1000 kg/m^3, based on the quality of sands, cement, lightweight aggregate and water content.

Lastly, Sika should keep original, closed, and undamaged packaging in dry situations. It must also be kept away from direct sunlight.

3.2.5 Calcium Stearate (CS)

The reaction between stearic acid with lime produces calcium stearate. It is a fine, smooth, white powder as shown in Figure 3.7. CS is water resistant and possesses water-repellent characteristics. Besides, it is very stable at high temperatures and non-toxic. The properties of CS are shown in Table 3.2. CS was used in this study due to the necessity to study the effect of different concentrations of CS on the functional properties of LFC. The amount of CS added was calculated based on the % of cement weight range from 0 % to 1.0 %.

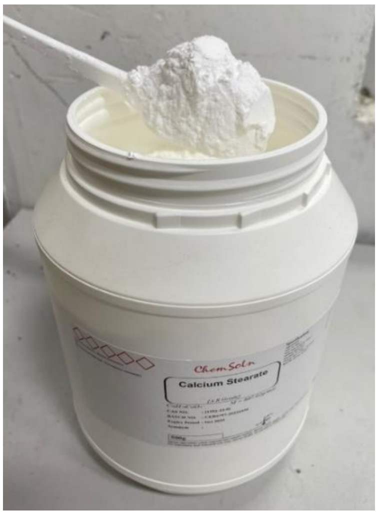


Figure 3.7: Calcium Stearate.

Table 3.2: Calcium Stearate Properties and Specification (Sime Scientific, 2017).

Molecular Formula	$C_{36}H_{70}CaO_4$
Molecular Weight	607.02 g/mol
Appearance	White Powder
Melting Point	150 °C
Moisture	4.0 %
Ash	10.5 %
Particle Size (thru 200 mesh)	90 %
Free Fatty Acid	1.0 %
Specific Gravity	1.01 g/cm^3

3.3 Mould

The mould’s internal surface was applied with a layer of oil as shown in Figure 3.8 to prevent concrete from sticking to the surface. This results in a surface free of stains, clean, and smooth on concrete blocks. There were various mould sizes used in this study. Table 3.3 lists the various types of moulds for their corresponding tests.

Figure 3.8: Slab Mould Applied with A Layer of Oil.

Table 3.3: Types of Moulds for Corresponding Tests.

Type of Tests	Dimension of Mould	Type of Mould
Thermal Conductivity	50 mm (H) x 300 mm (L) x 300 mm (W)	Slab
Sound Absorption	30 mm (D) x 20 mm (H)	PVC
Sound Absorption	60 mm (D) x 20 mm (H)	PVC
Compressive Strength	100 mm (H) x 100 mm (L) x 100 mm (W)	Cubical
Note: H = Height, L = Length, D = Diameter and W = Width		

3.4 Mix Procedure

Generally, the methods for producing foamed concrete are identical to those for producing normal concrete. First, a mixing bowl was prepared before performing the dry mix evenly within it. The dry mix includes cement, sand and with or without calcium stearate. Then, the bowl was gently filled with water to reach the correct water-cement ratio. The foam was produced by the foam generator with a foaming agent-to-water volume ratio of 1: 20. Simultaneously, the generated stable foam was poured into the mixtures to attain the proposed density of 1600 ± 50 kg/m^3. The mixing process was done with the bare hand as shown in Figure 3.9 without using the concrete mixer or any equipment to prevent bubbles from bursting.

After all the mixing steps, the fresh foamed concrete was poured into the different prepared moulds. The sample cannot be compacted as any compaction will burst the bubbles. This will result in a change in the density of foamed concrete. The hardening and settling processes took up to 24 hours, while the curing phase required between 7 and 28 days.

Figure 3.9: Mixing Process with Bare Hand.

3.5 Trial Mix

The trial mix was designed to achieve the optimal w/c ratio of the specific mix, corresponding to the maximum compressive strength, without affecting the stability and consistency of fresh LFC (Lim, et al., 2014). The trial mix was conducted a few times to get an optimum w/c ratio of 0.5 - 0.6 with an interval of 0.02. After 7 days, a compression test was performed to evaluate the compressive strength of each foamed concrete with varied w/c ratio. Then, the data obtained was recorded and used to plot a compressive strength to water-cement ratio graph. The plotted graph defines the w/c ratio with the highest compressive strength as the optimum w/c ratio. Lastly, the fresh and hardened densities were recorded for stability and consistency checks.

3.6 Mix Proportion

Foam generator was used to generate the foams, which were then mixed with cement mortar (Wong, et al., 2019). An optimum w/c ratio obtained in the trial mix was utilized in the actual mix. Then, the amount of foam required to be used in foamed concrete production for each mix was calculated using Equation 3.1. For all foamed concretes, a cement-to-sand ratio of 1:1 was adopted.

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

where

W_f = weight of foam required, kg

D_f = density of the foam, kg/m^3

W_m = weight of total mix, kg

D_T = target density, kg/m^3

D_E = estimate density, kg/m^3

Cement, sand, water, and foam have densities of 3150 kg/m^3, 2600 kg/m^3, 1000 kg/m^3, and 45 kg/m^3, respectively. Each base material's mass was allocated according to its ratio, using 1600 kg as the total mass for 1 m^3 of LFC. In the calculation, 40 % of wastage was included. This compensates for the wastage due to the concrete slurry sticking to the mixing bowl and when the fresh property tests were conducted.

3.7 Sieve Analysis (ASTM C136, 2014)

Sieve analysis is a technique for determining aggregate gradation by examining the particle size distribution. The distribution of sand particles in sand volume is crucial for high-quality concrete and mortar. Firstly, a typical oven-dried sample weighing 500 g was placed onto the tray as shown in Figure 3.10. If the particles are lumped, the pestle and mortar will be used to crush the lumps but not the particles. Then, a stack of test sieves was placed on the shaker. The sieves were stacked with the biggest aperture size (4.75 mm) on top and the smallest (0.15 mm) at the bottom as shown in Figure 3.11. Then, the 500 g sand was poured onto the top sieve. The top of the stack was enclosed with a sieve pan cover to prevent fine sand particles from diffusing into the air. This is followed by screwing the sieves firmly on the shaker machine. Next, the power supply was switched on for 15 minutes to enable the machine to shake completely to prevent excessive shaking, which will degrade the sand.

Then, each sieve's retained soil particles were weighed, and the proportion of the entire sample that passed through each sieve according to weight was also computed. After that, the weight of aggregate retained in grams, the weight of aggregate retained in percent, cumulative percentage of coarser particle grain, and cumulative percentage of finer particle grain were recorded and calculated. The fineness modulus of the sand was computed using Equation 3.2 and a graph depicting particle size distribution was plotted.

$$FM = \frac{\Sigma\, TPR}{100} \tag{3.2}$$

where,

FM = fineness modulus

Σ TPR = summation of total percentage retained from the biggest size observed to and including sieve size 150 μm

Figure 3.10: 500 g of Oven Dried Sand.

Figure 3.11: Stack of Sieves.

3.8 Concrete Curing

For the freshly cast concrete to become stronger, curing is essential. Curing the concrete can prevent moisture loss while supplying a continuous humidity stream for hydration. The water curing method was adopted in this research. The hardened concrete samples were weighed to assess the hardened density before curing. The hardened foamed concretes were demoulded after 24 hours. Then, foamed concrete samples were fully submerged in the water as shown in Figure 3.12. The water temperature was maintained between 25 °C to 30 °C. Before performing the corresponding properties tests, concrete samples were cured for 7 and 28 days, respectively.

Figure 3.12: Foamed Concrete Samples Being Cured in Water Tank.

3.9 Type of Concrete Tests

3.9.1 Fresh Density Test (ASTM C796, 2004)

This study's required density for the foamed concrete was 1600 kg/m^3. A test known as the fresh density test may determine if the generated foamed concrete falls within the permissible limit of ± 50 kg/m^3. A 1-litre volume of the empty container was filled with freshly foamed concrete. The excess foamed concrete was cleaned to validate the accuracy of the data. Foamed concrete fresh density was determined using Equation 3.3.

$$Density = \frac{Mass}{Volume} \tag{3.3}$$

3.9.2 Inverted Slump Test (ASTM C1611, 2005)

First of all, an empty inverted slump cone was placed on a tray. Then, foamed concrete was poured into this inverted cone until fully filled. The inverted cone was located firmly on the tray to prevent foamed concrete from leaking while pouring. No compaction was done during this inverted slump test as this action may burst out the bubbles. Then, handling it gently when pouring the foamed concrete is necessary. However, a gentle shake was allowed to ensure no void between the concrete within the cone. After that, the mould was lifted vertically. The spread's outer and hollow diameter were measured and recorded as shown in Figure 3.13.

After this, the density of the foamed concrete was checked again to determine whether the density was still within range. This is because the inverted slump test may burst out some bubbles and cause the density to increase and eventually run out of the range. If the density was not within the range, more foam had to be added, and the amount of foam added was recorded. Lastly, the foamed concrete was poured into the respective moulds for the casting.

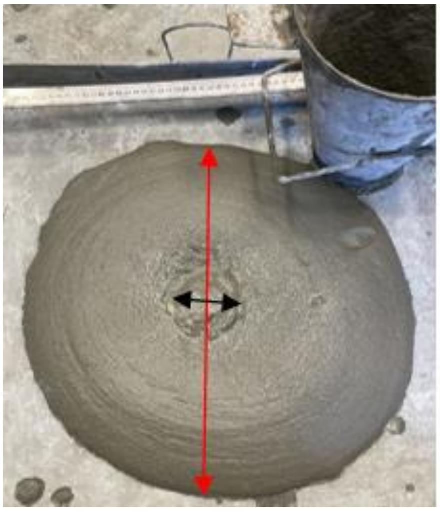


Figure 3.13: Outer Diameter and Hollow Diameter of the Spread.

3.9.3 Flow Table Spread Test (ASTM C230, 2004)

This test evaluates the workability and consistency of freshly mortar mix. It is a common test for high-fluidity concrete, which cannot be assessed using the slump test, particularly foamed concrete since it will not hold its shape once the cone is removed. First, the flow table had to be completely dry and free of dust or debris.

Two layers of freshly mixed concrete were poured into the cone, and each layer was tamped 25 times using a tamping rod. Then, the overflowing concrete on the cone was removed after the final layer was tamped. Next, the mould was lifted vertically up slowly and let the concrete stand independently without support. After removing the mould, the table was lifted to a maximum height of 12.5 mm and dropped 25 times. Lastly, the number of drops and the diameter of both diagonal spreading widths, as shown in Figure 3.14 were measured and recorded.

Figure 3.14: Diameter of the Spread.

3.9.4 Compressive Strength Test (BS EN 12390, 2002)

A compressive machine was used to assess the concretes' compressive strength and the setting must remain consistent throughout the experiment. This is because the result may vary if the setting is not constant. The concrete cubes curing for 7 and 28 days were evaluated. After being cured for 7 and 28 days, the samples were dried using the oven before this test was conducted. Before starting the compressive strength test, the specimens' dimensions were measured and recorded. Then, a concrete cube was put into the compression machine and was located at the machine's centre as shown in Figure 3.15. Then, the concrete was subjected to a steady axial load of 0.2 kN/s until its fracture point. Lastly, the machine's optimal reading was then recorded. This step was repeated for the next two cubes and computed an average value of their compressive strength.

Figure 3.15: Set Up for the Compression Test.

Equation 3.4 was used to calculate the compressive strength of the foamed concrete. Compressive strength is the maximum load applied to the cross-section of the sample area resisting the force.

$$Compressive\ Strength = \frac{Maximum\ load}{Cross-sectional\ area} \tag{3.4}$$

3.9.5 Water Absorption Test (ASTM C642-13)

According to ASTM C642-13 (ASTM, 2013), an absorption test was conducted to determine the percentage of water absorption the foamed concrete specimen can attain. Then, this test can also identify the number of void spaces available in the foamed concrete. The cube samples with 100 mm x 100 mm x 100 mm were adopted in the water absorption test.

The specimens were taken from the curing tank and kept indoors for 24 hours to produce a saturated surface dry condition. Their respective saturated surface dry weight was then determined by weighing each of them on a calibrated weighing scale. After that, the foamed concrete specimen was oven-dried for 24 hours until bone-dry. Lastly, the weight of oven-dried concrete specimens were measured and used to compute their respective concrete specimen's water absorption using Equation 3.5.

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

where

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

W_{dry} = weight of oven-dried concrete specimen, kg

3.9.6 Thermal Conductivity Test

The thermal conductivity test was used to evaluate the thermal conductivity of foamed concrete. The concrete slab with the dimensions of 300 mm x 300 mm x 50 mm was removed from the curing tank at 28 days. Subsequently, the specimen was dried in an oven at 105 °C for 24 hours since moisture within the foamed concrete might alter the test reading. The specimen was then taken out and allowed to cool at ambient temperature. Then, the specimen was placed in the machine with a hot and cold plate at both ends as shown in Figure 3.16. After this, the heat transmission through the specimen from the hot to the cold end was measured per minute. Lastly, the thermal conductivity value (k) was determined using Equation 3.6. This test took around 20 hours to complete for each slab.

$$Thermal\ Conductivity = \frac{Qh}{A(T_1 - T_2)} \tag{3.6}$$

where

Q = heat conduction, kN

h = thickness of specimen, mm

A = cross-sectional area, mm^2

T_1 = average temperature of hot plate, ℃

T_2 = average temperature of cold plate, ℃

Figure 3.16: A Foamed Concrete Sample Between a Hot and Cold Plate.

3.9.7 Impedance Tube Test (ASTM E1050-12, 2012)

According to ASTM E1050-12 (ASTM, 2012), the impedance tube test was conducted to identify the sound insulation properties of foamed concrete based on the sound absorption coefficient. This is because foamed concrete absorbs sound rather than reflects it. A software known as VA-Lab was used to collect the data.

The internal diameter of the impedance tubes, as shown in Figure 3.17 used in this study, comprises 30 mm and 60 mm for the sound absorption test. A frequency range of up to 250 - 6300 Hz can be produced from the speaker through amp control to attain the highest value for sound absorption efficiency. Then, the microphones with the sound level meter collected all the sound energy before and after it passed through the specimen.

Figure 3.17: Impedance Tube.

3.9.8 Consistency and Stability

Fresh and hardened densities were used to assess the foamed concrete's stability and uniformity. Fresh density was obtained by weighing the foamed concrete mixture before pouring it into the moulds. On the other hand, hardened density was obtained after 24 hours of demould. The consistency and stability values were calculated using Equations 3.7 and 3.8, respectively.

$$Consistency = \frac{Fresh\ Density}{Targeted\ Density} \tag{3.7}$$

$$Stability = \frac{Fresh\ Density}{Hardened\ Density} \tag{3.8}$$

3.10 Summary

There were two main stages: trial and actual mix in testing the foamed concrete's properties in this study. In Stage 1, casting 1600 kg/m^3 of the foamed concrete with dimensions of 100 mm x 100 mm x 100 mm was performed without incorporating calcium stearate (CS). Before that, a sieve analysis was conducted to obtain 0.6 mm fine sand. Next, cement, sand and water were mixed to form mortar with different water-cement (w/c) ratios. The w/c ratio ranged from 0.5 to 0.6 with an interval of 0.2. Then, the foam generated from the foam generator was added to the mortar to produce foamed concrete with a density of 1600 $\pm$ 50 kg/m^3. After 7 days, all hardened foamed concretes were tested for their compressive strength and the results were recorded. Lastly, a compressive strength to the w/c ratio graph was plotted and an optimum w/c ratio was determined from the graph.

For the actual mix, the optimum w/c ratio obtained from the trial mix was adopted for casting 1600 kg/m^3 foamed concrete with the incorporation of CS from 0 % - 1.0 %. The foamed concretes were casted in different mould sizes according to their hardened tests. Fresh properties tests, namely inverted slump and flow table tests were carried out before the hardened test. The hardened test comprises compressive, water absorption, thermal conductivity and sound absorption tests. All results and data obtained from fresh properties and hardened tests were recorded and analysed.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the outcome of this study. The optimum water-cement (w/c) ratio obtained from the trial mix will further cast the foamed concrete samples with calcium stearate (CS) in the actual mix. The discussion regarding the various sizes of foamed concrete (FC) with different dosages of CS ranging from 0 % - 1.0 % will be based on their correlations between compressive strength, water absorption, thermal conductivity and sound absorption. The compressive strength, water absorption percentage and acoustic properties with the introduction of CS into the foamed concrete after 7 and 28 days of curing in the water tank were evaluated and discussed. On the other hand, the thermal conductivity test was conducted only after 28 days of curing age.

4.2 Sieve Analysis

Sieve analysis was performed to determine the particle size distribution. 500 g of sand was adopted for the test. The sieve size with openings from 4.75 mm to 150 μm was arranged in descending order. After the test, the mass of sand particles retained on each sieve was measured and recorded, then calculated by its percentage respectively. Then, the cumulative percentage of finer passing is computed as shown in Table 4.1. Lastly, a graph of the cumulative percentage of finer sand passing against sieve size was plotted with the logarithmic scale as shown in Figure 4.1.

As shown in Figure 4.1, all finer passing percentages were within the range of ASTM C33 (2013). The fineness modulus (FM) value was determined to define the aggregates' fineness grade. The FM of fine aggregates must fall within the range of 2.1 to 3.1, as ASTM C33 (2013) specified. This study's fineness modulus obtained from sieve analysis is 2.41, which falls within the required range. FM of 2.41 means the average size of a particle of a given fine aggregate sample is between 2nd and 3rd sieves which is between

0.30 mm and 0.60 mm. The aggregate is finer if the fineness modulus value is smaller, and vice versa. As a result, the sand is suitable for casting foamed concrete. Proper distribution of sand particle size is crucial owing to the ability of finer particles to fill in the gap between coarser particles. Up to 51.23 % of the sand particles may pass through the 600 µm sieve, which is subsequently utilised for foamed concrete casting.

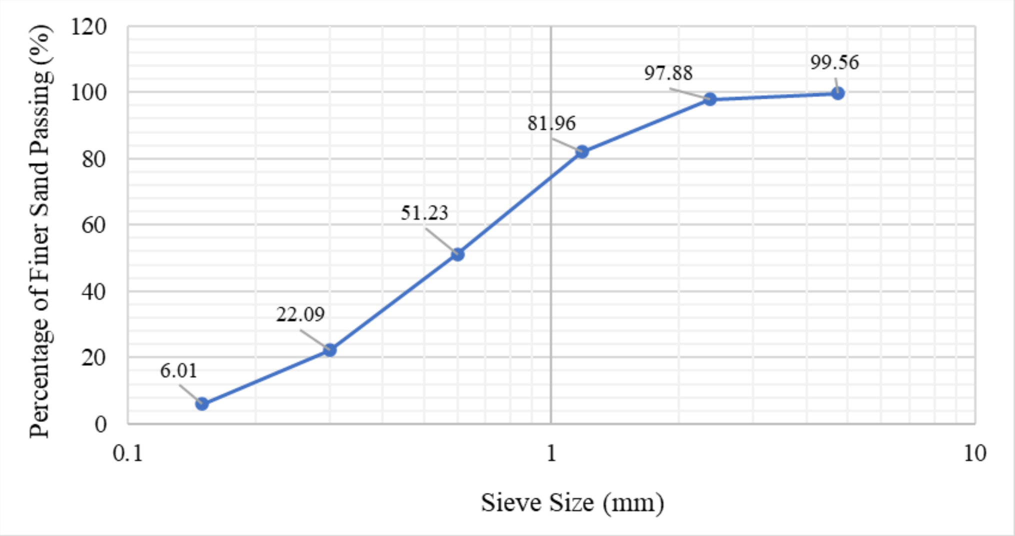


Figure 4.1: Distribution of Sand Particles Size.

Table 4.1: Sieve Analysis Result.

Sieve Size (mm)	**Weight**				**Cumulative Percentage**		**Grading Requirements for Total Percent Passing by ASTM C33 (%)**
	Empty sieve (g)	**Sieve + Aggregate Retained (g)**	**Aggregate Retained on Each Sieve (g)**	**Aggregate Retained on Each Sieve (%)**	**Coarser (%)**	**Finer (%)**	
4.75	489.18	491.38	2.2	0.44	0.44	99.56	95 to 100
2.36	468.09	476.49	8.4	1.68	2.12	97.88	80 to 100
1.18	371.37	450.77	79.4	15.92	18.04	81.96	50 to 85
0.60	334.49	487.79	153.3	30.73	48.77	51.23	25 to 60
0.30	340.99	486.39	145.4	29.14	77.91	22.09	5 to 30
0.15	333.89	414.09	80.2	16.08	93.99	6.01	0 to 10
Pan	239.99	269.99	30	6.01	100.00	0.00	-
Total			498.9	100			

4.3 Trial Mix (Stage 1)

The trial mix was conducted to obtain an optimum w/c ratio where the sample achieved the highest compressive strength. The w/c ratio adopted ranges from 0.50 to 0.60 with an interval of 0.02. The cement-to-sand ratio was fixed during the trial mix, which is 1:1. There was no water repellent, which is CS, added during the trial mix. This is because it has been shown that CS does not affect the w/c ratio of fresh concrete (Lee, et al., 2022). Hence 0 % CS is used in the trial mix. Eventually, compressive strength tests were carried out after lightweight foamed concrete (LFC) curing for 7 days.

4.3.1 Flow Table Test

Before introducing the foam into the mortar slurry, a flow table test was done to check its workability and consistency. The w/c ratio determines the amount of water added per unit weight of cement. Concrete that has a w/c ratio of less than 0.4 is not workable. So, the w/c ratio is kept between 0.4 and 0.6. A lower w/c ratio results in stiffer, less workable concrete whereas a higher w/c weakens the strength and durability of the material.

Table 4.2 shows the results of the flow table test with the different w/c ratios. Different w/c ratios will influence the workability and flowability of the foamed concrete produced. Then, the number of drops in the flow table test is also affected by the w/c ratio. Next, the average spread value is obtained by measuring the diagonal’s spread diameter and dividing it by two. From Table 4.2, the average spread value is directly proportional to the w/c ratio. The greater the w/c ratio, the higher the water content inside the foamed concrete. Thus, its fluidity will be enhanced. Then, it will spread faster and further on the flow table within a few drops. Hence, the higher the w/c ratio, the bigger the average spread value. This demonstrated clearly that the amount of water in the mixes affects the fluidity of foamed concrete.

Table 4.2: Flow Table Test Results.

	Flow Table Test	
w/c ratio	**Number of Drop (s)**	**Average Spread Value (cm)**
0.50	25	18.75
0.52	25	19.40
0.54	25	20.25
0.56	25	20.75
0.58	25	22.75
0.60	25	23.25

4.3.2 Consistency and Stability

The fresh and hardened density results were recorded to determine the consistency and stability. The targeted density in this project is 1600 kg/m^3 and the allowable density was in the range of 1600 ± 50 kg/m^3 to attain consistent results. The targeted density of the LFC can be adjusted by adding more foams to the concrete mixture. The fresh mixed foamed concrete's consistency was obtained by computing the fresh density over the targeted density. The samples' consistency must range from 0.969 to 1.031. If the hardened density is larger than the fresh density, this predicts that the foam bubble may burst during the process of hardening.

The amount of foam added to the sample is inversely proportional to its consistency. When the amount of foam added is less, the foamed concrete produced will be denser and hence the consistency value calculated will be bigger than one and vice versa. All the consistency for the foamed concrete formed generally falls within the acceptable range as indicated in Table 4.3.

Table 4.3: Consistency and Stability Checking for Target Density 1600 kg/m^3 with Different w/c Ratio.

w/c ratio	**Fresh Density (kg/m^3)**	**Hardened Density (kg/m^3)**	**Consistency**	**Stability**	**Actual Foam Added (g)**	**Theoretical Foam Added (g)**	**Percentage Difference of Foam (%)**
0.50	1611	1635	1.007	0.985	40.00	38.58	0.04
0.52	1610	1650	1.006	0.976	41.94	32.40	0.29
0.54	1648	1629	1.030	1.012	29.08	29.08	0.00
0.56	1605	1632	1.003	0.983	38.62	29.08	0.33
0.58	1628	1647	1.018	0.988	29.08	29.08	0.00
0.60	1648	1632	1.030	1.010	29.08	29.08	0.00

On the other hand, stability checking on the foamed concrete is also performed by computing the ratio of fresh density over hardened density. The stability with value 1.0 showed that the foam in the foamed concrete was stable with a low bursting condition during the casting and hardening process. All the stability values are within the range which around 1. Hence, different w/c ratios do not affect the foamed concrete's stability. Lastly, the percentage difference between the actual foam and theoretical foam added for all the samples is small, ranging from 0 % to 0.33 %.

4.3.3 Compressive Strength

During the trial mix, LFC samples were water cured for seven days before being tested for compressive strength. The w/c ratios utilised during the trial mix (Stage 1) ranged from 0.50 to 0.60. Figure 4.2 shows a bell-shaped curve with a peak compressive strength. From Figure 4.2, the highest compressive strength stood at 16.59 MPa for the w/c ratio of 0.58. Hence, 0.58 was the optimum w/c ratio for the trial mix and will be adopted in the following actual mix (Stage 2) incorporated with CS in this study.

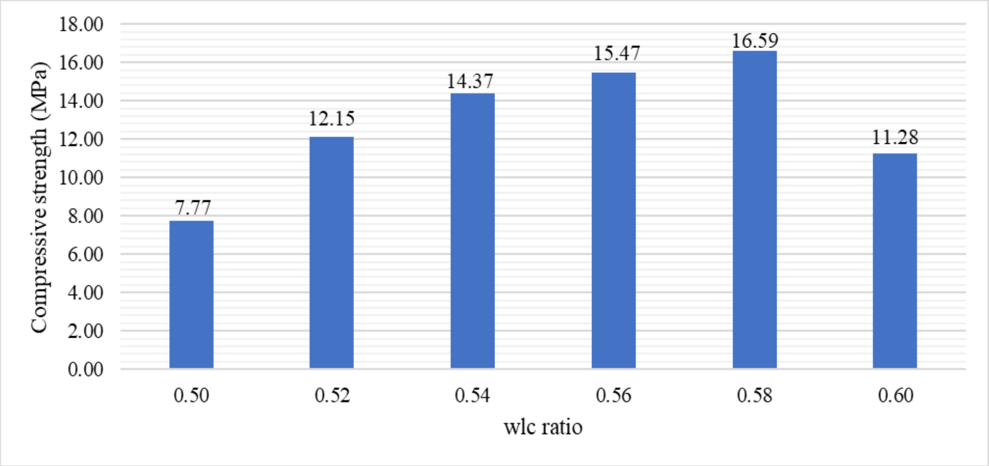


Figure 4.2: Trial Mix’s Compressive Strength Against w/c Ratio.

Figure 4.2 shows that the compressive strength slowly increased until it reached the highest compressive strength, which was 16.59 MPa and eventually dropped to 11.28 MPa at the w/c ratio of 0.60. When the w/c ratio is low, the amount of water will be lesser and insufficient for the foamed concrete to carry out the hydration process and produce the calcium silicate hydrate (C-S-H) gel, contributing to the strength gain. Hence, the compressive strength will be lower with a smaller w/c ratio.

However, excessive water may also lead to segregation, eventually decreasing the compressive strength of foamed concrete, as shown in Figure 4.2. Thus, it is necessary to determine an optimum w/c ratio to ensure the water is sufficient for the hydration process and achieve good workability of foamed concrete. In short, it can be concluded that the optimum w/c ratio is 0.58. This is because it achieved the maximum compressive strength with the value of 16.59 MPa among the other w/c ratios in the trial mix.

4.4 Actual Mix (Stage 2)

The optimum w/c ratio of 0.58 obtained from the trial mix was used in the actual mix. The various types of foamed concrete comprising cubes, cylinders and slabs were cast and evaluated for compressive strength, sound absorption, and thermal conductivity respectively. CS concentrations ranging from 0 % to 1.0 % were adopted during the actual mix. The cement-to-sand ratio remained the same as the trial mix, which is 1:1.

4.4.1 Mix Proportion

Table 4.4 shows the mix proportion for the foamed concrete in the actual mix with various concentrations of CS which are 0, 0.20, 0.40, 0.60, 0.80 and 1.0 % respectively. The cement-to-sand ratio was fixed at 1:1 throughout the actual mix. Meanwhile, all materials are prepared according to the optimum w/c ratio (0.58) in the trial mix. There will be discrepancies between the actual foam added and the theoretical value as shown in Table 4.4. This is due to the foam bubbles that may burst during the casting process.

Table 4.4: Mix Proportion for the Foamed Concrete with w/c Ratio of 0.58 in 0.0115 m^3 Included 40 % Wastage.

Materials (kg)							
Specimens	**w/c ratio**	**Cement**	**Sand**	**Water**	**CS**	**Theoretical Foam added (g)**	**Actual Foam Added (g)**
LFC-0.0CS	0.58	15.63	15.63	9.066	0	114.08	156.59
LFC-0.2CS	0.58	15.63	15.63	9.066	10.419	114.08	135.98
LFC-0.4CS	0.58	15.63	15.63	9.066	20.837	129.69	129.69
LFC-0.6CS	0.58	15.63	15.63	9.066	31.256	114.08	114.08
LFC-0.8CS	0.58	15.63	15.63	9.066	41.674	114.08	156.59
LFC-1.0CS	0.58	15.63	15.63	9.066	52.093	97.64	97.64

4.4.2 Flow Table Test and Inverted Slump Test

After adding calcium stearate, the flow table and the inverted slump tests are conducted to evaluate fresh concrete's consistency or workability. As shown in Table 4.5, the spread value of the flow table test and inverted slump test decreased when the concentration of CS in the foamed concrete increased. This is due to the incorporation of CS decreasing the foamed concrete's fluidity. CS is a damp-proofing additive that can form a water-repellent barrier along capillary pores. Hence, it can decrease the permeability of non-hydrostatic concrete (Chari, Naseroleslami and Shekarchi, 2019).

Moreover, including calcium stearate significantly reduces the water absorption capacity of concrete. According to Maryoto, et al. (2020), this could be interpreted as calcium stearate reacting with cement and water to generate a wax-like substance. During the evaporation process, this hydrophobic wax-like substance covers the capillaries' surface. Due to its hydrophobic nature, the contact angle formed between water and cement is large. As a result, water is hard to penetrate the concrete.

In short, the presence of CS may reduce the fresh concrete's permeability and water absorption, producing low fluidity.

Table 4.5: Results of Flow Table Test and Inverted Slump Test.

CS (%)	Flow Table Test		Inverted Slump Test
	Drops	**Spread Value (cm)**	**Spread Value (cm)**
0.0	25	23.50	50.00
0.2	24	23.50	48.00
0.4	25	23.25	45.75
0.6	23	23.00	44.00
0.8	24	22.50	43.50
1.0	24	20.75	41.50

Note:
Spread Value = Average Diameter of Two Diagonal Spreadings

4.4.3 Compressive Strength Test

In this project, 100 mm x 100 mm x 100 mm cubic-shaped lightweight foamed concretes (LFC) with a w/c ratio of 0.58 mixed with different concentrations of CS ranging from 0 % - 1.0 % with an interval of 0.2 % were cast. After being water cured for 7 and 28 days, these samples are tested for a compressive test. The compressive strength of the specimens was calculated from the average of three cracked cubic samples.

Figure 4.3 shows the compressive strength of the cube samples with various dosages of CS at 7 and 28 days of curing age respectively. The compressive strength for all the samples with 28 days of curing age was higher than those with only 7 days of curing age as shown in Figure 4.3. This is consistent with the study of Lee, et al. (2022) which found that the compressive strength of the LFC increases as the curing duration increases.

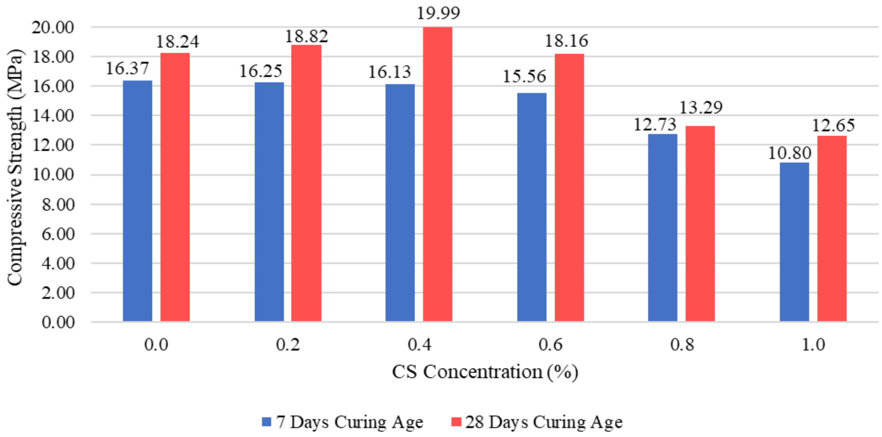


Figure 4.3: Compressive Strength for 7 and 28 Days of Curing Age.

During the early stage, cement takes longer to hydrate due to the hydrophobic effect of CS. Hence, these properties produce less C-S-H gel and eventually lower its compressive strength (Lee, et al., 2022). However, it showed that adding CS will only retards the growth of compressive strength in the early phases. The outcome shows a similar result obtained by Lee, et al. (2022). When the duration of water curing is long and continuous hydration leads to the formation of C-S-H gel. Meanwhile, the C-S-H gel enhances their compressive strength (Lee, et al., 2018).

For 7 days of curing age, the compressive strength of all types of LFC decreases linearly when the CS concentration increases, as shown in Figure 4.3. According to Maryoto, et al. (2020), CS forms a wax-like component when it reacts with cement and water. The bond of this component is weaker than the bond produced by the C-S-H compound. Thus, the compressive strength gradually decreases due to wax-like components in the concrete. This showed a similar result obtained by Chari, Naseroleslami and Shekarchi, (2019) in which a higher dosage of CS might result in a significant drop in compressive strength. Over the first seven days of water curing, LFC-0.0CS attained the highest compressive strength which is 16.37 MPa, while LFC-1.0CS attained the lowest early strength of merely 10.80 MPa. This might be attributed to the highest CS concentration in LFC-1.0CS, which inhibited water absorption capacity. As a result, the hydration process was impeded, reducing its compressive strength. In short, adding CS to the mixture design decreased compressive strength (Chari, Naseroleslami and Shekarchi, 2019).

According to Figure 4.3, the LFC compressive strength with 28 days curing age increases initially and then shows a downtrend. LFC-0.4CS with 28 days of curing age had the highest compressive strength which is 19.99 MPa among all the samples. LFC-0.4CS had the greatest increment of compressive strength from 7 days to 28 days which is 23.93 %, while LFC-0.8CS had the lowest increment of only 4.40 %. In comparison, the compressive strength development in LFC-0.4CS increased swiftly among the remaining samples throughout the 28 days curing period. This is because the rest of the samples were increasing slower in the range of 4.40 % – 17.13 %.

The compressive strength for all the samples with 28 days of curing age was higher than those with only 7 days of curing age as shown in Figure 4.3. This scenario showed that the CS dosage no longer affected the overall compressive strength at later ages. One of the reasons is due to the water-curing method. All the casted LFC samples were fully submerged in the water tank during curing. CS is weak in preventing water penetration under hydrostatic pressure, so its performance as a water-repellent agent decreases. Water will need some time to permeate the concrete, which permits the cement to hydrate later on while continuously water cured. In addition, retarding effect is not significant at 28 curing days as CS can be decomposed by biological deterioration (Lee, et al., 2022). Hence, more C-S-H gel was produced after 28 days of curing and eventually enhanced their compressive strength.

In addition, Table 4.6 depicts the performance index (PI) of compressive strength for cubes' foamed concrete with different concentrations of CS with 7 and 28 days of the curing period. According to Table 4.6, LFC-0.0CS achieved the highest performance index for 7 days of curing age with 10.04 MPa per 1000 kg/m^3, while LFC-1.0CS had the lowest PI with only 6.61 MPa per 1000 kg/m^3. On the other hand, the highest PI for 28 days of curing age was attained by LFC-0.4CS which is 12.19 MPa per 1000 kg/m^{3,} while LFC-1.0CS had the lowest PI which is only 7.72 MPa per 1000 kg/m^3. Based on Table 4.6 and Figure 4.3, it can be concluded that the higher the compressive strength, the higher the PI. Furthermore, the percentage difference of foam for the actual mix is quite small, ranging from 0 % - 0.37 %

as shown in Table 4.6. This indicates no significant difference exists between the theoretical and actual values for the foam added to the mortar.

Table 4.6: Performance Index and Percentage Difference of Foam of Different Types of Foamed Concrete.

Types of Foamed Concrete	**Performance Index, PI (MPa per 1000 kg/m^3)**		**Theoretical Foam Added (g)**	**Actual Foam Added (g)**	**Percentage Difference of Foam (%)**
	7 Days	**28 Days**			
LFC-0.0CS	10.04	11.16	114.08	156.59	0.37
LFC-0.2CS	9.88	11.42	114.08	135.98	0.19
LFC-0.4CS	9.79	12.19	129.69	129.69	0.00
LFC-0.6CS	9.56	11.16	114.08	114.08	0.00
LFC-0.8CS	7.83	8.19	114.08	156.59	0.37
LFC-1.0CS	6.61	7.72	97.64	97.64	0.00

Note:

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

4.4.4 Water Absorption Test

The cured cube specimens with 100 mm x 100 mm x 100 mm were also used to evaluate their percentage of water absorption. Figure 4.4 shows the percentage of water absorption of different types of LFC for 7 and 28 days of the curing period. It can be observed that the percentage of water absorption for both curing periods drops from LFC-0.0CS to LFC-0.6 CS, where the value is lowest, then slightly increases from LFC-0.6CS to LFC-1.0CS, like an inverted bell curve.

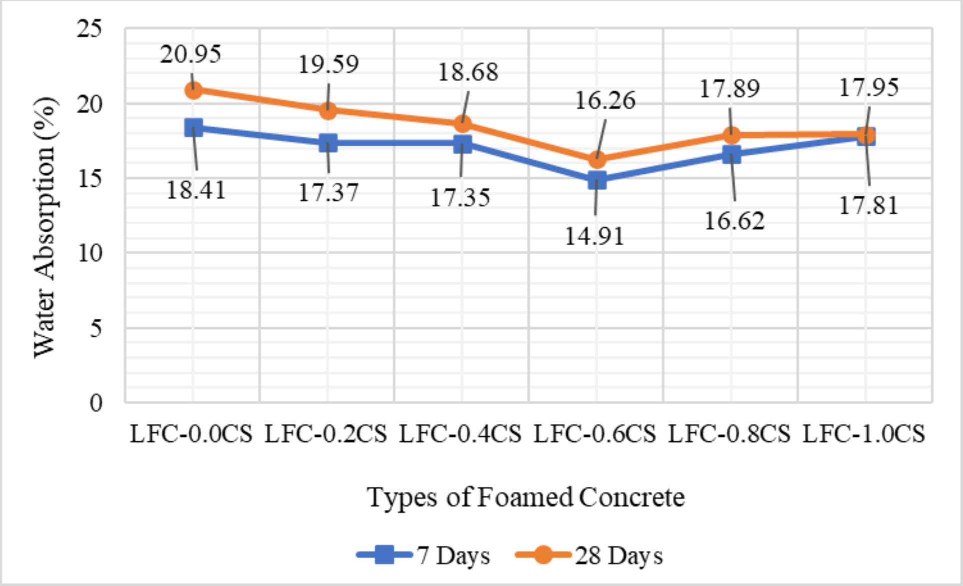


Figure 4.4: Water Absorption of LFC with Different Dosages of CS for 7 and 28 Days of Curing Period.

For 7 days of curing age, adding CS reduces the LFC mix's water absorption percentage (WAP). The WAP of LFC-0.2CS, LFC-0.4CS, LFC-0.6CS, LFC-0.8CS and LFC-1.0CS was decreased by 5.65 %, 5.76 %, 19.01 %, 9.72 % and 3.26 % respectively compared to LFC-0.0CS. It is feasible to infer that CS can increase the water resistance of foamed concrete which is consistent with the research done by Ma and Chen (2016). In addition, this might be explained by CS reacting with cement and water to generate a wax-like substance (Maryoto, et al., 2020). During the evaporation process, this hydrophobic wax-like material covers the capillaries' surface. Hence, the contact angle between water and cement is large, making water hard to penetrate the concrete. This demonstrates that CS improved the waterproofing properties of LFC by filling the capillaries, pores, cavities, and air pockets with crystalline structures (Lee, et al., 2022).

For 28 days curing age, the trend is similar to 7 days curing age. The water absorption percentage of the LFC with CS decreased in the range of 6.49 % to 22.39 % compared to the LFC without CS. The concept is similar as mentioned earlier for 7 days curing age. However, all the WAP was higher than those with 7 days curing period. In short, the longer the curing period, the higher the WAP.

Based on Figure 4.4, the ideal and maximum amount of CS that should be added to the LFC for both curing periods is 0.6 % CS. This is because the WAP of LFC-0.8CS and LFC-1.0CS increased indicating a reduction in the LFC's waterproofing capabilities. Hence, any more CS above 0.6 % applied provides no additional benefits in terms of waterproofing. Nevertheless, it had a negative impact on the LFC mix by limiting its waterproofing performance. This might be due to an overdose of CS, resulting in some CS not reacting with the cement mix (Lee, et al., 2022). According to Maryoto (2015), any unreacted CS compound will fill the capillaries when fresh concrete hardens. Then, the unreacted CS will subsequently be released when the hardened LFC comes into contact with water. This will result in a minor increase in the radius of the produced capillaries, facilitating water entry into the LFC.

4.4.5 Sound Absorption Test

In this research, two different sizes of cylinders with the dimension of 30 mm (D) x 20 mm (H) and 60 mm (D) x 20 mm (H) were casted and evaluated for their sound absorption. The sound absorption coefficient (SAC) of each foamed concrete specimen tested from 250 Hz to 6300 Hz was recorded and combined. The SAC is a measurement of the amount of sound energy that is absorbed by a surface (Neville, 2011). Each type of foamed concrete with its respective SAC from 250 Hz to 6300 Hz for both curing periods was plotted individually as shown in Appendix A.

Figure 4.5 shows that all the foamed concretes have a low SAC at the low frequency range from 0 Hz to 1000 Hz. As the frequency increased from 1000 Hz to 2000 Hz, all types of foamed concrete increased gradually in their SAC. According to Figure 4.5, LFC-0.2CS and LFC-0.4CS showed a similar trend. Then, the trend for all samples fluctuated from 2000 Hz to 3000 Hz. However, all the foamed concrete samples except LFC-0.0CS will reach an optimum sound absorption coefficient from 1600 Hz to 3150 Hz according to Table 4.7. Meanwhile, LFC-0.0CS achieved its highest SAC at the highest frequency which is 6300 Hz. Lastly, all SAC shows an increase in high frequency ranges from 5000 Hz to 6300 Hz.

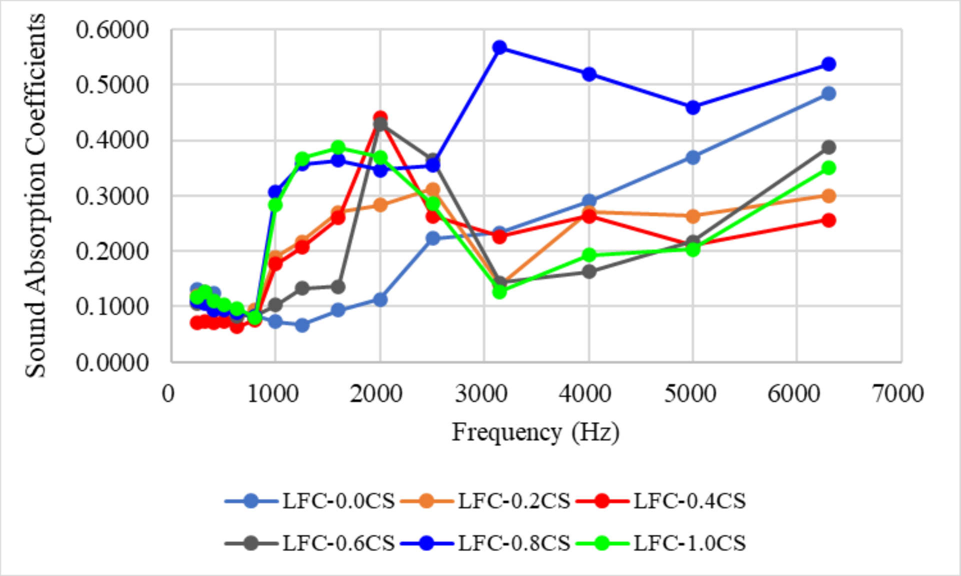


Figure 4.5: Sound Absorption Coefficients of Different Types of LFC For 7 Days Curing Period.

Sound absorption coefficient with their respective noise reduction coefficient (NRC) values of foamed concrete with different dosages of CS after 7 days curing period are tabulated in Table 4.7. According to Fediuk, et al. (2021), the absorption coefficient ranges from 0 to 1, with 0 denoting materials that reflect sound and 1 denoting optimum sound absorption materials. It is difficult to express the acoustic absorption coefficient as a single value. This is due to the coefficient of acoustic absorption varying with sound frequency. As a simplification, NRC is applied. The average of the SAC at 250, 500, 1000 and 2000 Hz is called the NRC.

Based on Table 4.7, the lowest NRC value is 0.10 for foamed concrete with 0 % CS, while the highest is 0.22 for foamed concrete with 1.0 % CS. Comparing the NRC value of LFC-0.0CS and the remaining foamed concrete samples, it is clearly shown that LFC-0.0CS exhibited the lowest NRC value. Hence, it can be concluded that adding CS can enhance the NRC.

Table 4.7: Sound Absorption Coefficient and NRC Value for Different Types of Foamed Concrete for 7 Days Curing Period.

Frequency (Hz)	**Sound Absorption Coefficients**					
	LFC-0.0CS	**LFC-0.2CS**	**LFC-0.4CS**	**LFC-0.6CS**	**LFC-0.8CS**	**LFC-1.0CS**
250	0.1300	0.1200	0.0700	0.1067	0.1100	0.1167
315	0.1200	0.1100	0.0733	0.1267	0.1067	0.1267
400	0.1233	0.0933	0.0700	0.1067	0.0933	0.1100
500	0.1000	0.0933	0.0733	0.0967	0.0933	0.1033
630	0.0900	0.0800	0.0633	0.0833	0.0900	0.0967
800	0.0833	0.0933	0.0767	0.0833	0.0833	0.0800
1000	0.0733	0.1900	0.1767	0.1033	0.3067	0.2833
1250	0.0667	0.2167	0.2067	0.1333	0.3567	0.3667
1600	0.0933	0.2700	0.2600	0.1367	0.3633	0.3867*
2000	0.1133	0.2833	0.4400*	0.4300*	0.3467	0.3700
2500	0.2233	0.3117*	0.2633	0.3650	0.3550	0.2850
3150	0.2333	0.1400	0.2267	0.1433	0.5667*	0.1267
4000	0.2900	0.2700	0.2633	0.1633	0.5200	0.1933
5000	0.3700	0.2633	0.2100	0.2167	0.4600	0.2033
6300	0.4833*	0.3000	0.2567	0.3867	0.5367	0.3500
NRC	0.10	0.17	0.19	0.18	0.21	0.22

Note: **NRC** = Mean of sound absorption coefficients at 250, 500, 1000 and 2000 Hz
The number written with * indicated the largest SAC in that LFC.

Figure 4.6 shows the SAC of different types of LFC for 28 days of the curing period. Figure 4.6 shows a trend similar to Figure 4.5, which is from 0 to 1000 Hz; the SAC is low and then increases dramatically from 1000 to 2000 Hz. In addition, the trend of SAC for all samples, as shown in Figure 4.6 and Figure 4.5 fluctuated in the range of 2000 to 3000 Hz. Based on Figure 4.6, all types of foamed concrete also dropped in their SAC when the frequency was 3150 Hz. However, all the foamed concretes attained their respective highest SAC at 6300 Hz except for LFC-0.2CS achieved the highest SAC at 2500 Hz as shown in Table 4.8.

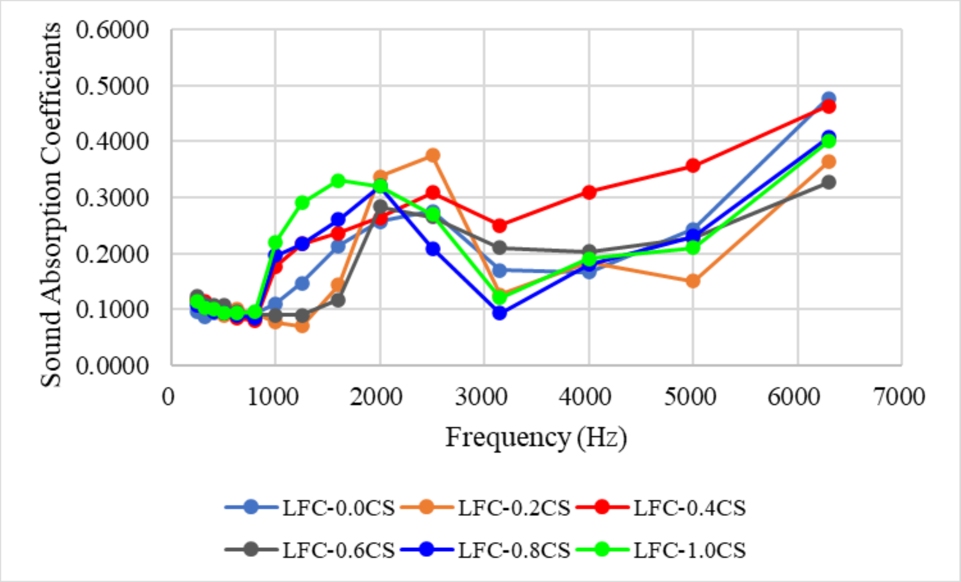


Figure 4.6: Sound Absorption Coefficients of Different Types of LFC for 28 Days Curing Period.

Based on Table 4.8, the lowest NRC value is 0.14 for foamed concrete with 0 % CS, while the highest is 0.19 for foamed concrete with 1.0 % CS. Comparing the NRC value of LFC-0.0CS and the remaining foamed concrete samples, it is clearly shown that LFC-0.0CS exhibited the lowest NRC value. Hence, it can be concluded that adding CS can enhance the NRC for both curing periods.

Table 4.8: Sound Absorption Coefficient and NRC Value for Different Types of Foamed Concrete for 28 Days Curing Period.

	Sound Absorption Coefficients					
Frequency (Hz)	**LFC-0.0CS**	**LFC-0.2CS**	**LFC-0.4CS**	**LFC-0.6CS**	**LFC-0.8CS**	**LFC-1.0CS**
250	0.0967	0.1167	0.1167	0.1233	0.1067	0.1133
315	0.0867	0.1033	0.1133	0.1100	0.1033	0.1033
400	0.0933	0.1033	0.1000	0.1067	0.0967	0.1000
500	0.0933	0.0900	0.0933	0.1067	0.0933	0.0933
630	0.0933	0.1000	0.0833	0.0967	0.0900	0.0933
800	0.0933	0.0933	0.0800	0.0900	0.0833	0.0967
1000	0.1100	0.0767	0.1767	0.0900	0.1967	0.2200
1250	0.1467	0.0700	0.2167	0.0900	0.2167	0.2900
1600	0.2133	0.1433	0.2367	0.1167	0.2600	0.3300
2000	0.2567	0.3367	0.2633	0.2833	0.3200	0.3200
2500	0.2750	0.3750*	0.3083	0.2650	0.2083	0.2700
3150	0.1700	0.1267	0.2500	0.2100	0.0933	0.1200
4000	0.1667	0.1833	0.3100	0.2033	0.1800	0.1900
5000	0.2433	0.1500	0.3567	0.2267	0.2300	0.2100
6300	0.4767*	0.3633	0.4633*	0.3267*	0.4067*	0.4000*
NRC	0.14	0.16	0.16	0.15	0.18	0.19

Note: **NRC** = Mean of sound absorption coefficients at 250, 500, 1000 and 2000 Hz
The number written with * indicated the largest SAC in that LFC.

Figure 4.7 shows that all the LFC at 28 days of the curing period except LFC-0.0CS has a lower NRC value than those 7 days of curing periods. In addition, LFC-0.0CS had the lowest NRC value for both curing periods. Meanwhile, all the samples with the inclusion of CS had higher NRC compared to LFC-0.0CS for 7- and 28-day curing periods. The results reveal that as curing times increase, the noise reduction coefficient of the LFC decreases. A similar pattern was noticed in the sound absorption coefficient depending on the frequencies of its third-octave bands. According to Lim, et al. (2021), more cement hydrations or pozzolanic reactions may occur as curing times increase. This ultimately produces more hydrated cement pastes, which fill in the voids and empty spaces in a sample. As a result, the LFC batches' capacity to absorb sound waves is reduced since there are fewer porous and void structures to do so during the 28 days of the curing period.

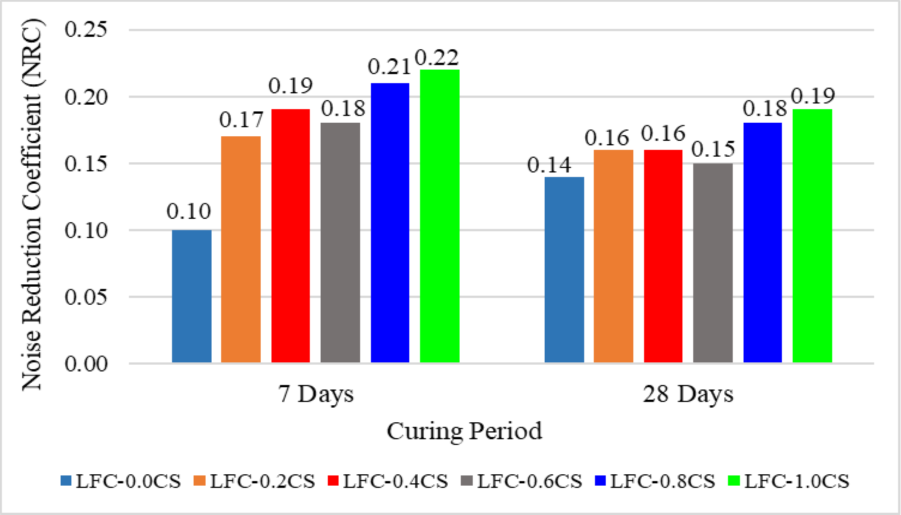


Figure 4.7: NRC Value of Different Types of Foamed Concrete with 7- and 28-Days Curing Period.

Table 4.9 compares sound absorption coefficients of various surface materials (Department of Occupational Safety and Health, 2005) with the casted LFC. The LFC-1.0CS with 28 days of curing period is chosen for comparison.

Table 4.9: Comparison of Sound Absorption Coefficients of Surface Materials (Department of Occupational Safety and Health, 2005) with the Casted LFC.

Material	**Frequency (Hz)**				**NRC**
	250	**500**	**1000**	**2000**	
Concrete block: Coarse	0.44	0.31	0.29	0.39	**0.36**
Painted	0.05	0.06	0.07	0.09	**0.07**
Poured	0.01	0.02	0.02	0.02	**0.02**
Glass: Ordinary window glass	0.25	0.18	0.12	0.07	**0.16**
Large panes of heavy plate glass	0.06	0.04	0.03	0.02	**0.04**
Casted LFC-1.0CS (28 Days Curing Period)	0.11	0.09	0.22	0.32	**0.19**

Based on Table 4.9, coarse concrete blocks achieved the highest NRC of 0.36. However, the NRC of painted and poured concrete blocks decreased by 80.6 % and 94.4 % compared to coarse concrete blocks. In addition, the painted and poured concrete block had lower SAC than LFC-1.0CS, with an NRC of 0.19. This is because painted concrete has a layer of coating on the surface, which may reduce the NRC of the concrete. Besides, the painted concrete had to be repainted once the paint peeled. Hence, it is suggested to adopt the foamed concrete with the incorporation of CS for external usage as it provides the same waterproofing function.

Meanwhile, the NRC of the ordinary window glass is quite close to the LFC-1.0CS, but it is still lower than LFC-1.0CS. Lastly, the NRC of large panes of heavy plate glass is only 0.04. This implies that the LFC will absorb relatively little acoustic energy as NRC is close to 0 (Department of Occupational Safety and Health, 2005).

4.4.6 Thermal Conductivity Test

Six slabs with the dimension of 50 mm (H) X 300 mm (L) X 300 mm (W) incorporated with different dosages of CS were cast. The thermal conductivity test was performed after the samples were cured for 28 days in accordance with BS EN 12664 (2001). The thermal conductivity of foamed concrete with 28 days curing age is shown in Table 4.10.

Table 4.10: Thermal Conductivity of Foamed Concrete for 28 Days Curing Age.

Types of Foamed Concrete	Hardened Density of the Foamed Concrete (kg/m^3)	Thermal Conductivity (W/mK)
LFC-0.0CS	1629	0.8812
LFC-0.2CS	1643	1.4525
LFC-0.4CS	1648	1.8544
LFC-0.6CS	1627	1.7735
LFC-0.8CS	1623	1.2706
LFC-1.0CS	1646	1.0829

Figure 4.8 depicts the effect of CS concentration on the compressive strength and thermal conductivity of foamed concrete after 28 days of curing. The thermal conductivity (TC) increases initially as the CS content increases and decreases when the CS concentration exceeds 0.4 %.

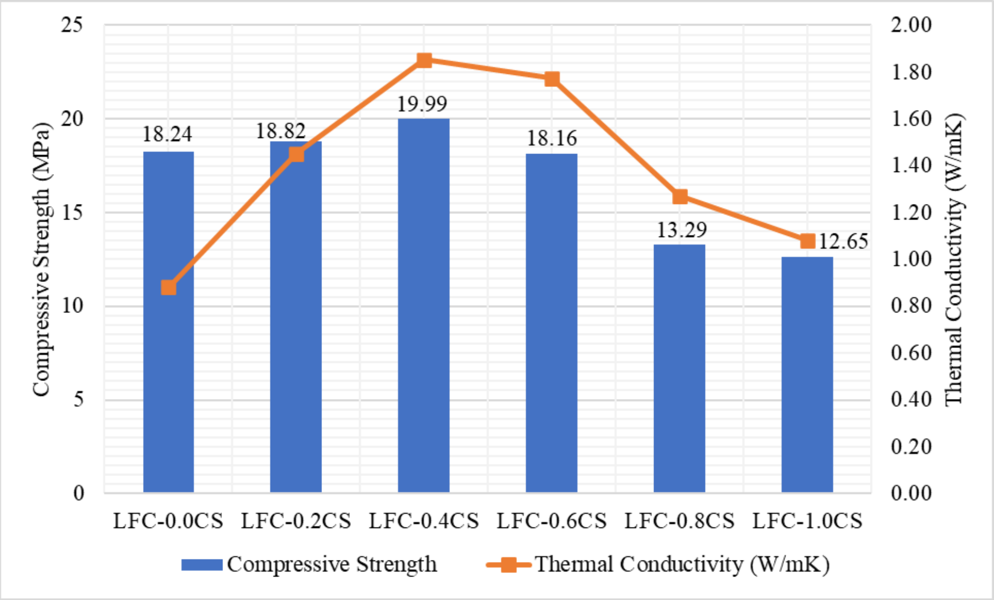


Figure 4.8: Relationship Between Thermal Conductivity and Compressive Strength Test of Different Types of Foamed Concretes.

Porosity is one of the factors that governs thermal behaviour. Generally, the low compressive strength of the LFC is due to its high porosity and vice versa. Since porosity generates voids or empty spaces inside the concrete making the sample more prone to failure under compression. According to Wagh, Ranjani and Kamisetty (2020), thermal conductivity is inversely proportional to the porosity of foamed concrete. As shown in Figure 4.8, the TC values for all types of foamed concretes are directly proportional to their compressive strengths. For LFC-0.6CS, LFC-0.8CS and LFC-1.0CS, the high porosity inside the foamed concrete caused their respective thermal conductivity to drop. The greater amount of air in the foamed concrete reduces its TC since air conducts heat poorly compared to solids and liquids because of its molecular structure (Othuman Mydin, 2013).

According to Wagh, Ranjani and Kamisetty (2020), the directional uniformity of pore distribution also substantially influences TC. The higher the porosity, the lower the thermal conductivity. However, it can sometimes increase due to the intensified pore connection. The location of the pores and their relative orientation has a significant impact on the heat conductivity of foam concrete. If pores are positioned perpendicular to the heat flow, resulting in greater thermal resistance. Yet, if a layer of pores is parallel to the direction of heat flow, it will provide less heat flow resistance. In this case, the pores within the LFC-0.6CS, LFC-0.8CS and LFC-1.0CS could be perpendicular to the heat flow thus enhancing their thermal resistance and reducing their TC.

On the other hand, LFC-0.0CS had the lowest thermal conductivity value among the rest of the samples. However, the TC of LFC increased linearly from 0 % CS to 0.4 % CS. This is due to their low porosity in the samples and the dosage of CS had little effect on them. Besides, the pores are probably parallel to the heat flow direction, providing less heat flow resistance. Hence, they can conduct more heat and subsequently increase their TC.

Lastly, it can be concluded that LFC-0.0CS achieve the optimum result of merely 0.8812 W/mK as shown in Figure 4.8. This is due to LFC-0.0CS having the lowest thermal conductivity value among the rest of the samples. LFC with lower thermal conductivity means it possesses high thermal insulation in concrete which can minimise heat transfer and energy consumption in construction (Asadi, et al., 2018).

4.5 Summary

To summarise, the results obtained in this research were recorded, analysed and discussed on the effect of CS on the foamed concrete with a density of 1600 kg/m^3. For sieve analysis, all finer passing percentages of the sand were within the range of ASTM C33 (2013).

Besides, an optimum w/c ratio of 0.58 was obtained during the trial mix and was adopted in the actual mix. Then, the flow table and the inverted slump tests were conducted to evaluate fresh concrete's consistency or workability after adding calcium stearate. It can be concluded that the presence of CS may reduce the fresh concrete's permeability and water absorption, producing low fluidity. Other than the fresh properties test, the compressive test, water absorption test and functional properties test also had been conducted with different dosages of CS.

For the compressive test, the compressive strength of the LFC increases as the curing duration increases. For 7 days of curing age, the compressive strength of all types of LFC decreases linearly when the CS concentration increases. This is due to CS's hydrophobic effect, which impeded the hydration process and thus reduced its compressive strength. On the other hand, LFC-0.4CS achieved the optimum compressive strength of 19.99 MPa after 28 days of curing age. Then, the most ideal and maximum amount of CS should be added to the LFC for both curing periods is 0.6 % CS. This is due to its maximum waterproofing capabilities in the water absorption test.

For the sound absorption test, it can be concluded that the noise reduction coefficient of the LFC decreases as curing time increases. The NRC can be enhanced with the incorporation of CS. The highest NRC for both curing periods is LFC with 1.0 % CS. Lastly, thermal conductivity is directly proportional to the compressive strength but inversely proportional to the porosity of foamed concrete. However, the thermal conductivity of LFC also depends on the pore distribution. In the thermal conductivity test, LFC-1.0CS had the lowest thermal conductivity value, which means it has the highest thermal resistance among the samples. This may greatly reduce the energy used during building design and construction.

The outcome of each test for 28 days curing period was summarised in Table 4.11. It can be observed that LFC-0.4CS had the highest compressive strength of 19.99 MPa however LFC-1.0CS had both optimum values for NRC as well as thermal conductivity. By comparing LFC-1.0CS to LFC-0.4CS, NRC was increased by 18.75 % while the thermal conductivity had decreased significantly by 41.60 %. On the other hand, the difference in water absorption percentage between the LFC-1.0CS and LFC-0.4CS is merely 3.91 %.

By comparing the results, LFC-1.0CS has the highest NRC value in the sound absorption test, which can minimize noise pollution and create a more quiet interior atmosphere for a building. Furthermore, the lowest thermal conductivity of LFC-1.0CS indicates that the material transfers heat slower.

This can assist in enhancing building energy efficiency by lowering the energy required for heating and cooling. Furthermore, incorporating CS into the LFC can reduce the water absorption percentage to enhance its durability.

Even though the compressive strength of LFC-1.0CS is reduced as compared to LFC-0.4CS but 12.65 MPa is sufficient for non-load bearing. The minimum compressive strength for an individual unit of concrete masonry units is only 3.5 MPa (Mamlouk and Zaniewski, 2011). Hence, it can be concluded that 1.0 % of CS is the optimum dosage of CS to be applied to the LFC.

Table 4.11: Summary of Each Test for 28 Days Curing Period.

CS %	Compressive Strength (MPa)	Water Absorption (%)	Noise Reduction Coefficient	Thermal Conductivity (W/mK)
0.2	18.82	19.59	0.16	1.4525
0.4	19.99*	18.68	0.16	1.8544
0.6	18.16	16.26*	0.15	1.7735
0.8	13.29	17.89	0.18	1.2706
1.0	12.65	17.95	0.19*	1.0829*

Note: The * indicates the optimum value for each test.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Several conclusions can be drawn based on the analysis of results and laboratory testing that has been conducted.

The first objective of this research is to produce foamed concrete with a concrete density of 1600 kg/m^3. This objective was achieved as all the foamed concrete samples were within the required density range.

The second objective is to obtain an optimum water-cement (w/c) ratio of foamed concrete. This objective was achieved during the trial mix. Six sets of cubed foamed concrete with different w/c ratios ranging from 0.5 to 0.6 with an interval of 0.02 were casted and evaluated for their compressive strength. An optimum w/c ratio of 0.58 was determined as the foamed concrete with a w/c ratio of 0.58 obtained the highest compressive strength.

The last objective is to examine the effect of calcium stearate (CS) on the functional properties of foamed concrete. The functional properties test includes sound absorption and thermal conductivity test. This objective was successfully achieved and the results showed that the higher the concentration of CS in the foamed concrete, the higher the noise reduction coefficient and the lower its thermal conductivity.

5.2 Recommendations

The following recommendations could be taken into consideration to validate further and achieve more reliable results for future study:

1. Adopt different water-repellent agents such as zinc stearate, silane and siloxane in the same concrete mix and study their functional properties.
2. Performing other properties test such as the fire resistance and dimensional stability of the 1600 kg/m^3 foamed concrete.

3. Study the effects of calcium stearate on the functional properties of 1600 kg/m^3 foamed concrete with different ratios of foam agent to the water.
4. Compare the functional properties of foamed concrete by considering a different type of cement with a longer curing period such as 56 days, 90 days and 180 days.
5. Investigate the influence of CS on cement hydration using various curing methods such as steam and air curing.
6. Performing microstructural analysis such as scanning electron microscopes to investigate the influence of CS on foamed concrete's properties.

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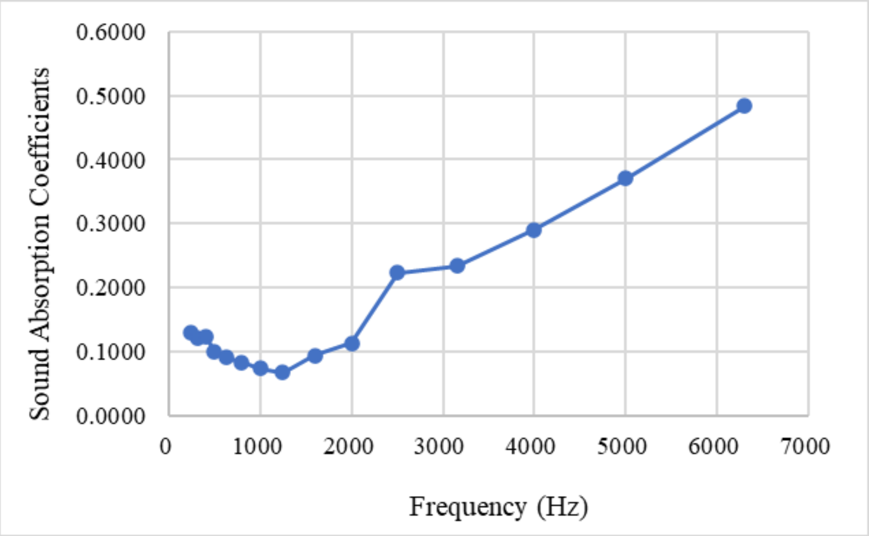
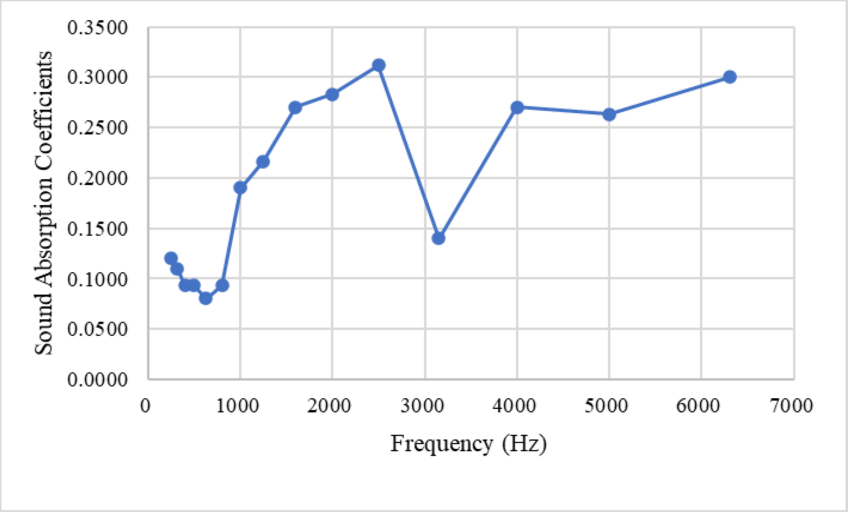
APPENDICES

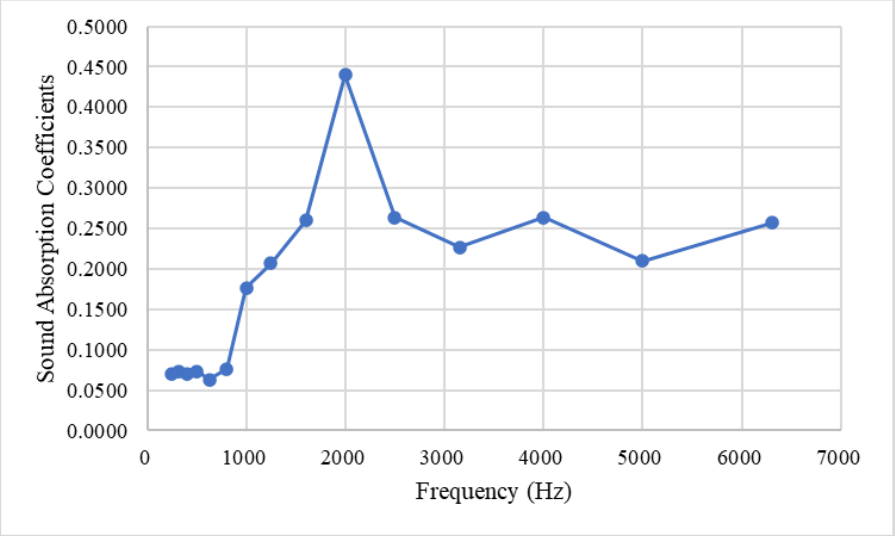
Appendix A: Graphs of Sound Absorption Coefficients for Different Concentration of CS with Different Curing Ages.



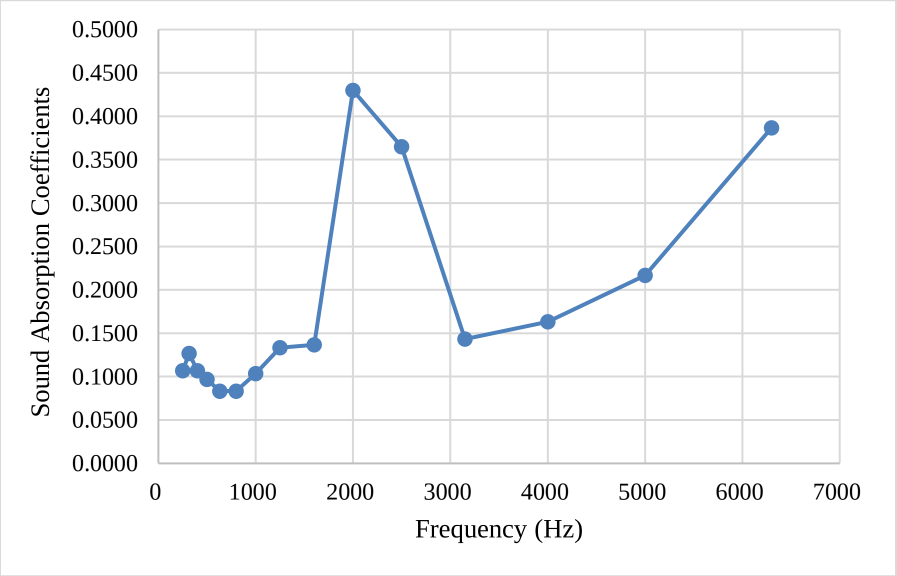
FigureA-1: Sound Absorption Coefficients of LFC-0.0CS with 7 Days Curing Age.



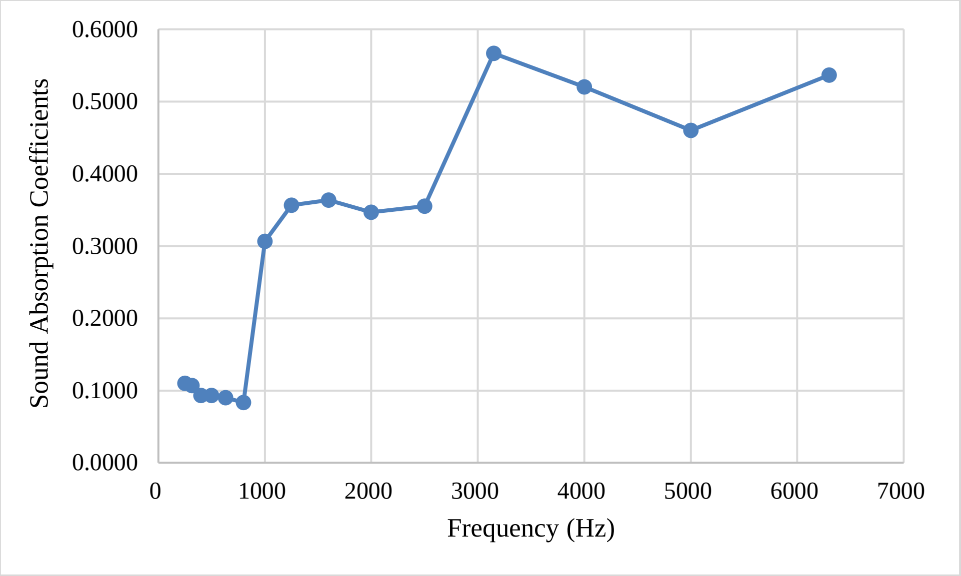
FigureA-2: Sound Absorption Coefficients of LFC-0.2CS with 7 Days Curing Age.



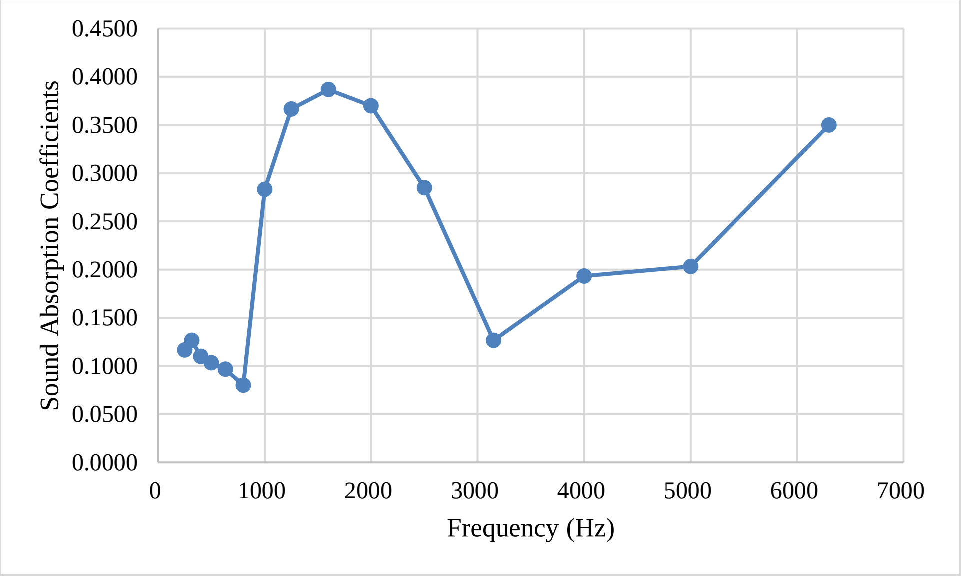
FigureA-3: Sound Absorption Coefficients of LFC-0.4CS with 7 Days Curing Age.



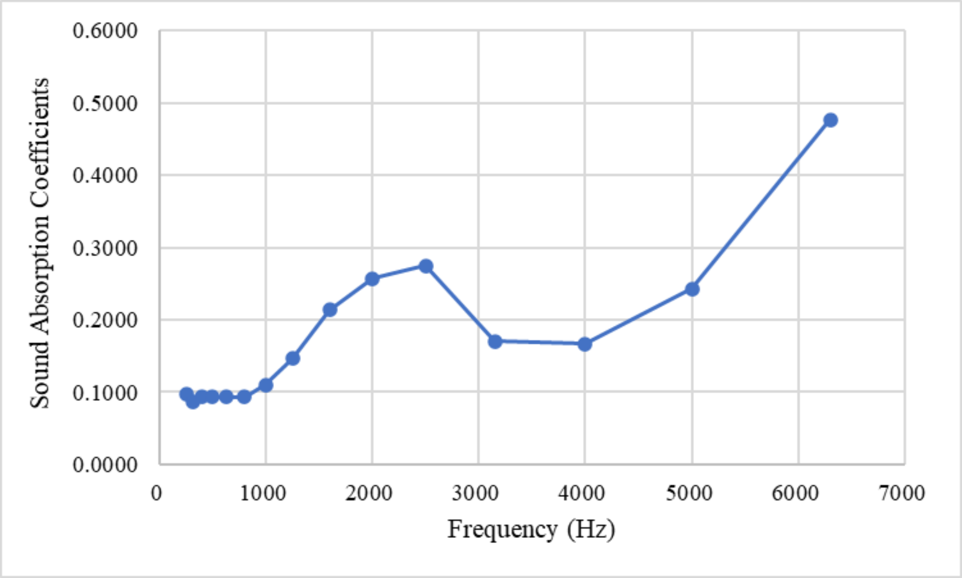
FigureA-4: Sound Absorption Coefficients of LFC-0.6CS with 7 Days Curing Age.



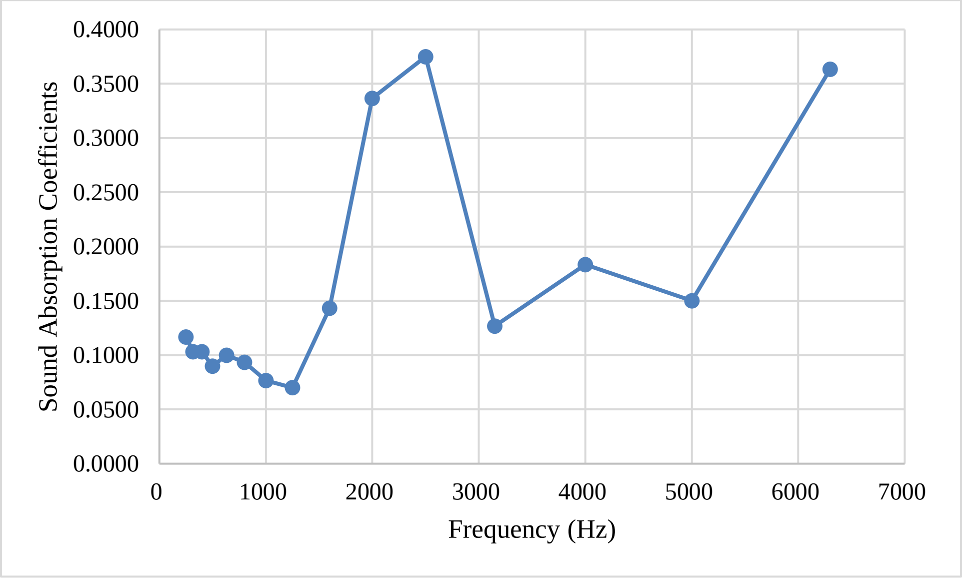
FigureA-5: Sound Absorption Coefficients of LFC-0.8CS with 7 Days Curing Age.



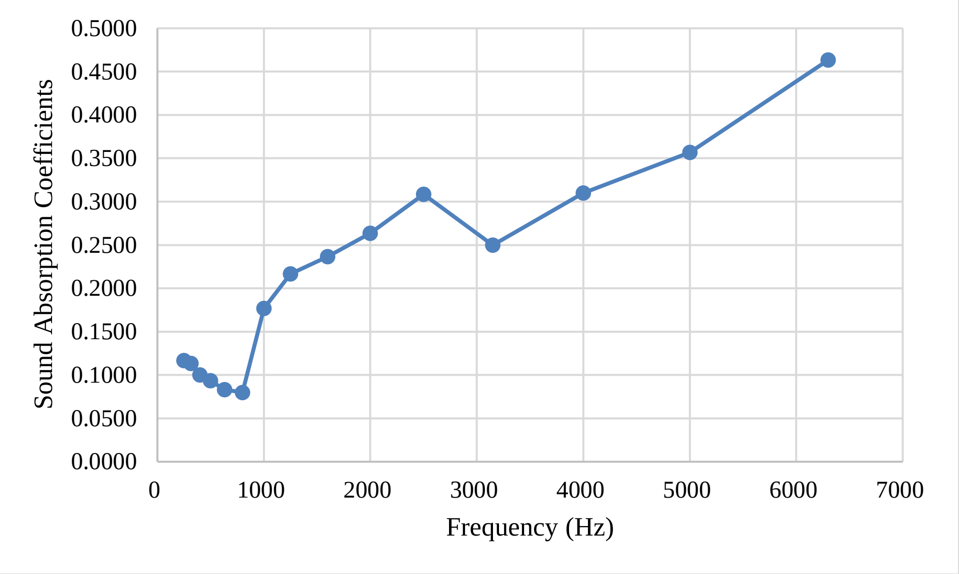
FigureA-6: Sound Absorption Coefficients of LFC-1.0CS with 7 Days Curing Age.



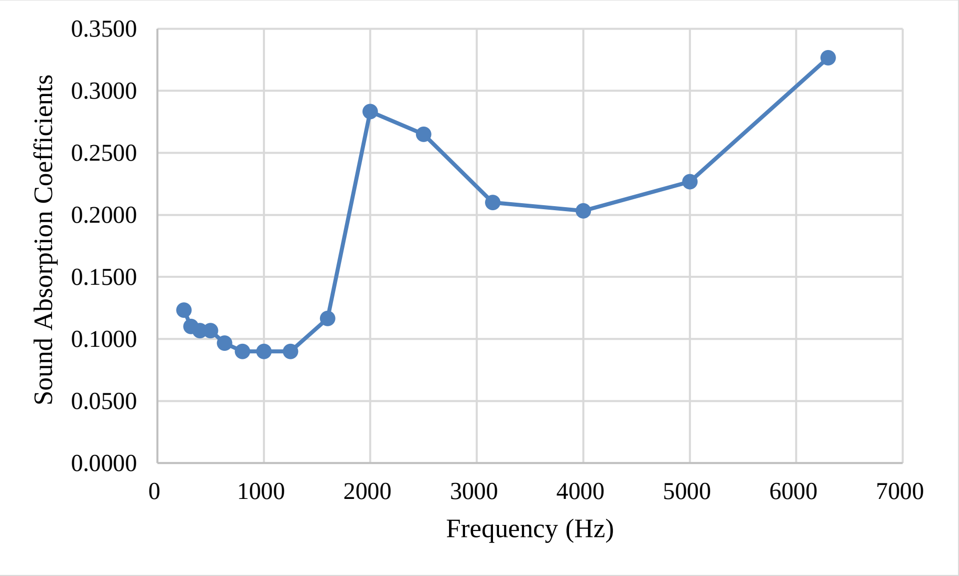
FigureA-7: Sound Absorption Coefficients of LFC-0.0CS with 28 Days Curing Age.



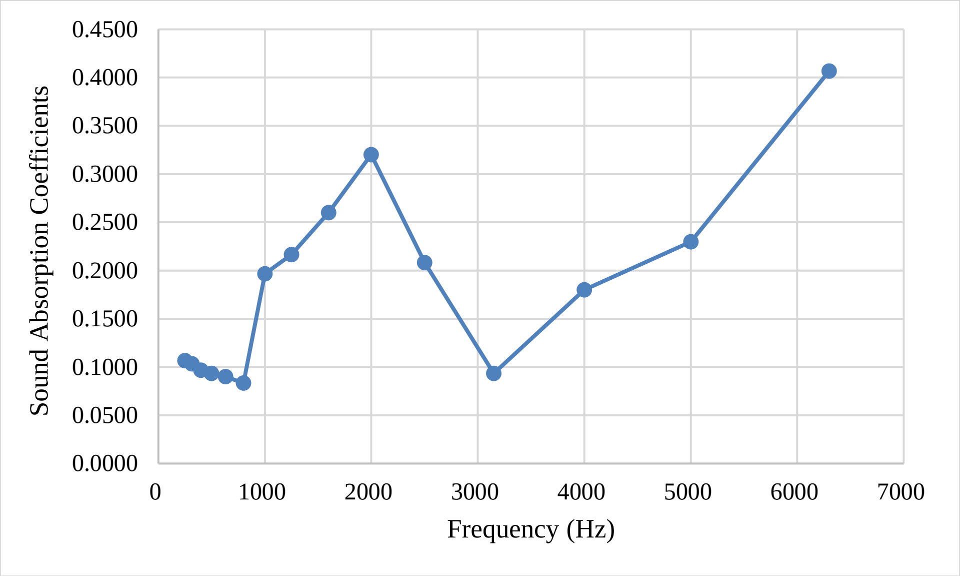
FigureA-8: Sound Absorption Coefficients of LFC-0.2CS with 28 Days Curing Age.



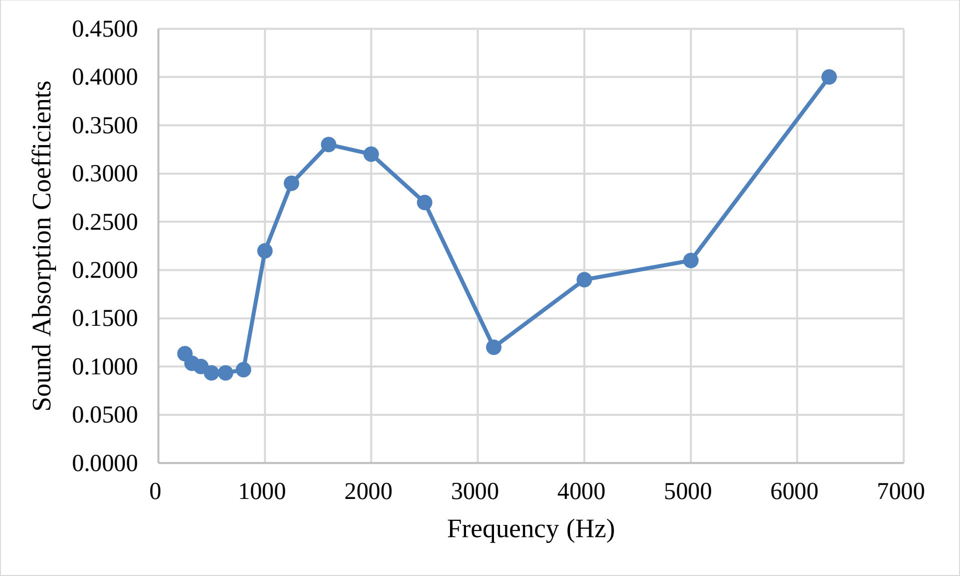
FigureA-9: Sound Absorption Coefficients of LFC-0.4CS with 28 Days Curing Age.



FigureA-10: Sound Absorption Coefficients of LFC-0.6CS with 28 Days Curing Age.



FigureA-11: Sound Absorption Coefficients of LFC-0.8CS with 28 Days Curing Age.



FigureA-12: Sound Absorption Coefficients of LFC-1.0CS with 28 Days Curing Age.