AN INVESTIGATION ON THE STRENGTH PERFORMANCE OF 1400 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 Engineering
(Honours) Civil Engineering

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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

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ABSTRACT

Concrete is an essential element in the building and construction sector. Numerous types of concrete have been developed over time in response to changing requirements from the construction sector. One of the types is named lightweight foamed concrete (LWFC). The unique characteristic of LWFC is the interior of the concrete with the presence of multiple air bubbles added to the mortar mix and present with a high percentage of porosity. As a result, dangerous elements can penetrate LWFC, affecting its general durability and intended use. Therefore, calcium stearate (CS) as water repellent is applied to LWFC throughout this research and its influence on different strength performant of LWFC are researched. The three main study objectives are to produce LWFC with a density of 1400 kg/m^3, determine the optimal water to cement (W/C) ratio for LWFC and investigate the impact of CS on the mechanical characteristics of foamed concrete. The optimal W/C ratio is used to analyse the strength performance of the hardened concrete on the different percentages of CS added. Two primary research phases are made up in this study. The optimum W/C ratio for LWFC without adding water repellents was achieved in the first phase at 0.54. In order to analyse the effects of 0.0 % to 1.0 % CS on the hardened concrete's qualities of LWFC, the research was carried out using the best W/C ratio that was determined in the first phase of the study. The addition of CS affected the mechanical parameters of LWFC, including compressive strength, splitting tensile strength and flexural strength. The final results of the highest strength performance obtained from the different percentages of CS added were determined at 0.4 % by cement weight in order to avoid the adverse effects of an excess of water repellents. Finally, the 28-days compressive strength rose by 30.85 %, from 8.80 MPa for the control mixture to 18.79 MPa for 0.4 % of CS added.

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LIST OF SYMBOLS / ABBREVIATIONS

^{o}C	Degree Celsius
P	pressure, kPa
ρ	density, kg/m^3

CS	Calcium Stearate
C-S-H	Calcium Silicate Hydrate
CST	Compressive Strength Test
FST	Flexural Strength Test
LWFC	Lightweight Foamed Concrete
MPa	Mega Pascal
OPC	Ordinary Portland Cement
psi	Pound-force per square inch
S/C	Sand to Cement
STST	Splitting Tensile Strength Test
W/C	Water to Cement

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Concrete has been popularly applied in building structures for hundreds of years. There are so many types of concrete products on the market today and it is because of the continuous innovation and creation of concrete. Every concrete has its own features that allow it to satisfy concrete's quality for its industrial demands. The main function of concrete is to provide structure strength that is not ruptured during normal pressure. A key component to providing strong support in the structure is that the contact interface between concrete and rock should be well bonded (Shen, et al., 2019). According to Schneider, et al. (2011), several conditions play an important role in concrete that directly affect concrete properties such as strength, durability and workability in the manufacturing phase. Water is introduced to the cement to initiate the hydration reaction inside the cement, which causes the slurry to solidify into hardened concrete (Lee and Estrada, 2020).

The density of concrete is the most critical variable for classifying concrete types, which include lightweight foamed concrete (LWFC), ordinary weight concrete and heavyweight concrete (Ramamurthy, Nambiar and Ranjani, 2009). According to Chen, et al. (2020), LWFC has a unit weight varying from 800 kg/m^3 to 1800 kg/m^3, normal concrete has a unit weight varying from 2000 kg/m^3 to 2800 kg/m^3 and heavyweight concrete has a unit weight above 2800 kg/m^3 (Ali and Lubloy, 2020). The first process in the production of LWFC is combining the cement with sand and water to make a mortar mixture (Mixture 1). Meanwhile, the foaming agent is mixed with water to produce foam in the manufacture of LWFC. After that, Mixture 1 would then mix with foam to produce LWFC. Furthermore, the fundamental difference between normal weight and heavyweight concrete is that normal concrete contains lower chemicals (Vandanpu and Krishnamurthy, 2018). In contrast, heavyweight concrete introduces coarse aggregates, sand, cement, water and a significantly more potent chemical (Khalaf, Cheah and Ramli, 2019). However, concrete enhancers such as air-entraining additives and retarding additives can be added during the mixing process to improve the concrete's performance. The main purpose of using LWFC is to minimise the dead load of a concrete structure for structural designers to minimise the weight of foundations, columns, beams and other load-bearing parts (Vandanpu and Krishnamurthy, 2018). Furthermore, the main purpose of using heavyweight concrete is to provide higher strength for concrete structures, mainly used in bridge construction, overpasses and some main project.

LWFC can be produced with a cement mixture containing an air-entraining admixture. The main function of applying an air-entraining agent is to create many microscopic air bubbles within the concrete particles. Therefore, the cement composition in LWFC contains a high proportion of air bubbles in stable foam. As a result, water repellent additives are importantly used in lightweight concrete because extra capillary pores will trap water. Water repellent agents can reduce water absorption by blocking the fluid movement within the concrete. Calcium Stearate (CS) is a calcium carboxylate known as a calcium soap. The main ingredient of CS is soap scum mixed with hard water to form a white solid. The criteria of CS insoluble in water are soaps containing sodium and potassium.

Lightweight concrete there are a lot of advantages are consisting of it is better in thermal insulation properties and good in fire resistance because the air bubbles block the pathway of transferring the heat energy throughout the cement particle (Bremner, 2008). Because the concrete contains more air bubbles, it has lower density characteristics to lower the total dead weight on the structure, decreasing the project's cost. Hence, there are a lot of advantages of using LWFC in construction.

1.2 Importance of the Study

Concrete is a necessary building component under building materials in the construction industry. Water is added to the cement and sand to form a mortar mixture. Water undergoes a hydration process inside the cement, causing the slurry to solidify into hardened concrete. CS act as a water repellent agent and it is also combined with the concrete mixture to inhibit fluid mobility and thus reduce water absorption. Furthermore, calcium ion penetration into the concrete through the microspores significantly affects the strength properties of concrete. This research aims to identify various dosages of water repellent in the mixture proportion and optimum water to cement (W/C) ratio to develop LWFC with improved strength performance and durability. This research will guide future researchers on the strength performance of concrete that has been added with a water repellent agent in terms of concrete compressive strength, splitting tensile strength and flexural strength.

1.3 Problem Statement

Nowadays, LWFC is more and more critical applied on construction sites. The formation of the LWFC mainly used materials such as cement, sand, water, foam agent and water repellent agent (Richard and Ramli, 2013). The main characteristics of foamed concrete are a more significant proportion of air gaps and a lower concrete self-weight density. Since foamed concrete has a lower density, the structure's weight may be decreased, which can save expenses for land settlement. Moreover, one of the major components in the production of LWFC is the presence of water repellent agents which can help reduce water absorption by inhibiting fluid motion inside the concrete. Therefore, choosing the type of water repellent agent for the LWFC is the main problem.

Furthermore, moisture would quickly be sucked in by LWFC due to a large number of air gaps inside the concrete. Thus, the density of the LWFC would increase and hence result in a rise in structure loading. Since Malaysia has higher humidity levels than other countries due to high precipitation throughout the year, as a result, LWFC without water repellent agents is less suitable in Malaysia. The equator is sensitive to climate change, which is why Malaysia was recognised as a hot and humid country over the years. Precipitation frequently falls yearly due to climate change and the probability of heavy rainfall events may increase in the future (Fung, et al., 2022). Therefore, using foamed concrete in the construction industry is not recommended under high humidity conditions since the foamed concrete will be quickly exposed to moisture. The tendency for lightweight materials in the construction industry to absorb additional moisture will impact their strength and durability. In addition, there are more voids inside the LWFC, which means that the density of the LWFC is reduced. As a result, the density effect of LWFC is proportional to the LWFC's strength.

For that reason, the construction strategy and design would be affected by the presence of the water repellent agent. Since the moisture level would significantly affect the structure loading the air bubble will absorb the free water into the concrete. Thereby, the higher the moisture level in the LWFC, the lower the strength performance. This is because the LWFC would crack easily due to the higher content of moisture. All in all, the presence of the water repellent agent can significantly affect concrete performance.

1.4 Aim and Objectives

The purpose of this study is to evaluate at the strength performance of 1400 kg/m^3 of foamed concrete with calcium stearate.

Several objectives must be achieved in order to achieve the purpose, which are given below:

1. To produce foamed concrete with a concrete density of 1400 kg/m^3.
2. To acquire the maximum water-cement ratio of foamed concrete with calcium stearate.
3. To investigate the impact of calcium stearate on the mechanical characteristics of foamed concrete.

1.5 Scope and Limitation of the Study

The goal of this study is on the implications of CS on the compressive strength test (CST), hardened density, splitting tensile strength test (STST) and flexural strength test (FST) of LWFC in different experiments. The study of the work plan is separated into two major sections: (1) specimen preparation and (2) performance concrete testing procedures.

This study's scope focuses on preparing raw materials to determine whether concrete strength could comply with ASTM and BS EN standards and requirements. The specified density of the LWFC in this study is 1400 kg/m^3. The targeted density is difficult to obtain in the experiment due to underestimated factors affecting the result. Therefore, a tolerance of ± 50 kg/m^3

for the targeted density, which varies from 1350 kg/m^3 to 1450 kg/m^3. Besides, the ideal proportion to W/C ratio for the LWFC was determined through the screening findings of pre-mix proportions. During pre-mixes, the W/C ratio was increased by 0.02 intervals from 0.50 to 0.60 until the best outcome was achieved. In addition, the restriction of the water repellent utilised in this experiment is CS, whose proportion is 0.0 % to 1.0 %, with each increase of 0.2 %.

The CST, STST and FST with the specimens including cubes, cylinders and prisms concrete were tested after seven (7), twenty-eight (28) and fifth-six (56) days for the curing process. CST was tested on three cubic samples with parameters of 100 mm x 100 mm x 100 mm in respective length, width and height. Furthermore, three cylindrical specimens were conducted on the STST. FST was tested on three prism specimens sized 160 mm in length, 40 mm in width and 40 mm in height.

1.6 Contribution of the Study

As a consequence of this research, CS can be applied to LWFC, which is beneficial for construction projects to promote a lower W/C ratio and obtain higher strength performance throughout the LWFC. Generally speaking, a structure constructed with LWFC weighs less than a traditional building since it has a lower self-weight. Basically, because of its lightweight qualities, it lowers the overall loading impact on the foundation. As a result, it is possible to minimise the size of the structural components, which ultimately lowers the project's cost. Additionally, using CS would reduce the amount of water absorbed inside the concrete structure, providing it with more robust mechanical properties than traditional concrete.

1.7 Outline of the Report

There are a total of main five chapters in this report.

Chapter 1 of the report provides a summary of the introduction, importance of the study, problem statement, aim and objectives of the study, as well as contribution of the study and outline of the report.

Chapter 2 focuses on the engineering properties of LWFC with water repellents and a literature review of other related materials used in this study.

This paragraph discusses the general types and properties of LWFC, the advantages of LWFC and how mechanical testing of LWFC is affected by environmental concerns.

Chapter 3 is the methodology, where it includes the preparation of the raw material, mixing procedure, casting procedure, and curing process. The steps for mechanical testing include compressive, splitting tensile and flexural strength.

Chapter 4 outlines the results obtained from trial mixes in the procedure to determine the ideal W/C ratio in LWFC. In addition, the results of the actual mix of LWFC with the addition of CS are discussed in terms of consistency, stability, compressive strength, splitting tensile strength and flexural strength.

Chapter 5 concludes the entire study of this research. The conclusions were obtained using a variety of sources of information and in accordance with the relevant objectives. This chapter also includes suitable suggestions intended to be used in further advancements and investigations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Foamed concrete is also one type of lightweight concrete made of Ordinary Portland Cement (OPC), clean water, fine aggregate and foam, with a pore structure created by an artificial air void. The article by Ramamurthy, Nambiar and Gandhi (2009) illustrates that foamed concrete is a lightweight substance composed of OPC fluid and regular airspace structure generated by voids encapsulated in a mortar mix using a foaming agent. The standard density of the foamed concrete produced by adequately controlling the amount of foam is 1400 kg/m^3 for the application of mechanical characteristics.

This chapter provides an analysis of the published reading materials to achieve the report's purpose. The various types of lightweight concrete are explained in brief with a full description of each lightweight concrete's pros and cons. A detailed overview of the benefits of LWFC and how to use it. Lastly, the strength properties of 1400 kg/m^3 CS foamed concrete were studied to improve the strength behaviour to provide high-quality LWFC.

2.2 Types of Lightweight Concrete

There are two forms of lightweight concrete (1) structural lightweight and (2) non-structural lightweight concrete. The concrete mixture is different for both types of lightweight concrete. Firstly, in the production of structural lightweight concrete, the mixture consists of lightweight aggregates and it replaces the different proportions of the concrete with lightweight functional additives such as fly ash and blast furnace slag (Zhou and Brooks, 2019). Besides, the non-structural lightweight concrete applies lower density aggregates that can have much more air bubbles which can create a proportion of voids to maintain volume and reduce the density of the concrete during concrete mixing. In general, lightweight concrete can be classified into three categories which are "Lightweight Aggregate Concrete", "No-Fines Concrete" and "Aerated or Foamed Concrete" (Mohammed and Hamad, 2014).

2.2.1 Lightweight Aggregate Concrete

Aggregate that is light in weight is suitable used to manufacture lightweight aggregate concrete products such as concrete blocks, mechanical concrete and pavement. Several industrial by-products produce lightweight concrete, such as fly ash, bottom ash, red mud, waste glass, zeolite and others. The lightweight aggregates can be classified as natural or artificial. Artificial or natural lightweight aggregates are the most common approach to achieving lightweight structural concrete. The primary purpose of using natural or artificial aggregates in lightweight concrete is to minimise the mass of the concrete and thus obtain better strength on concrete. Figure 2.1 demonstrates the different lightweight aggregates included in natural or artificial.

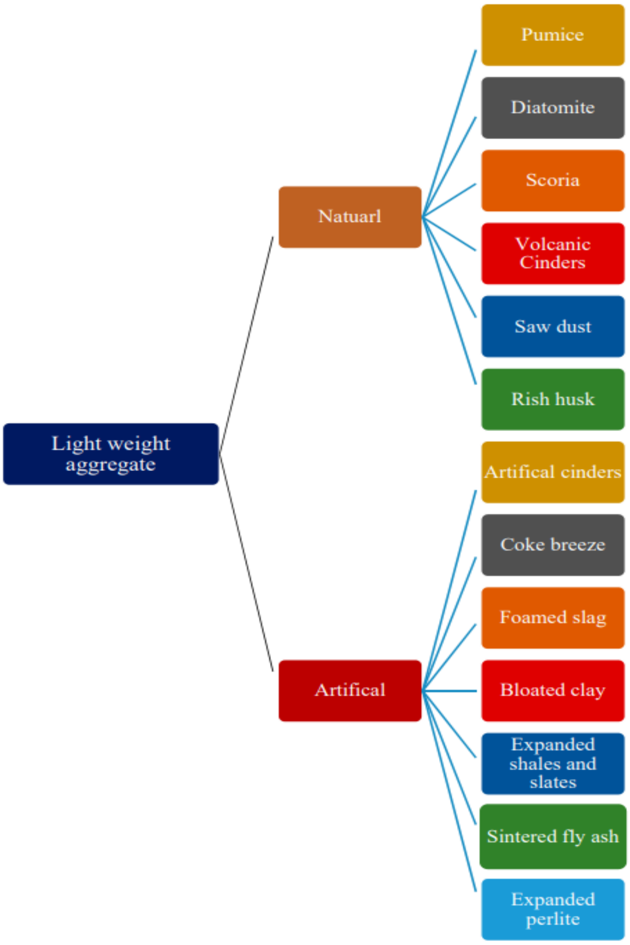


Figure 2.1: Types of Natural and Artificial Lightweight Aggregates (Agrawal, et al., 2019).

Lightweight aggregates can come in many shapes for concrete, which are cubes, rounds and angular or irregular shapes that exist on the market (Agrawal, et al., 2019). The workability of the concrete, the percentage of coarse and fine aggregates, the amount of cement required and the W/C ratio, all of these would influence the shape and surface roughness of aggregates. Kurpinska and Ferenc (2017) mentioned about the amount of lightweight aggregate is used to measure the density of lightweight aggregate concrete, porosity, needed water amount and moisture content. The high-quality lightweight aggregate concrete can be formed when the water absorption rate is much lower than the typical weight of the concrete. So that the density can be maintained as low and the permeability of the lightweight concrete is extremely low. Furthermore, the unit weight and moisture content of concrete also affect the thermal conductivity of concrete. For example, lightweight aggregate concrete has lower density and water content compared to normal concrete due to more pores inside the concrete and eventually lower thermal conductivity (Chung, Elrahman and Stephan, 2017). Some criteria affect thermal conductivity, such as pore size and distribution and the internal structure of lightweight concrete.

Lightweight aggregate concrete has its advantages and disadvantages. The most important advantage of lightweight aggregate concrete is the lower concrete density and reduced weight (Bremner, 2008). The lower the density of concrete, the lower the dead load on the structure, ultimately saving overall construction costs. In addition, its thermal performance is relatively low and has a high fire resistance to protect the building structures. In Malaysia, lightweight concrete is most suitable for construction because most of the time in Malaysia is the hot season, which causes the surrounding temperature to increase. Therefore, lower thermal conductivity can reduce internal temperature. Lightweight aggregate concrete also has its disadvantages. One of the most significant disadvantages of lightweight aggregate concrete is its sensitivity to water content. It has a lot of microporous media that quickly absorb moisture from the exterior surface of the concrete to the internal surface. Besides, concrete is difficult to form due to the porosity and angular nature of aggregates and it also takes a long time to mix these materials to form high-quality lightweight aggregate concrete.

2.2.2 No-Fine Concrete

No-fine concrete is lightweight concrete made without the fine particles found in lightweight concrete (Salih, Gorgis and Abd, 2017). Porous concrete, pervious concrete and zero-fine concrete are used to describe no-fine concrete (Salih, Gorgis and Abd, 2017). No-fine concrete consists only of coarse aggregate, cement and water and does not contain the fine aggregate found in lightweight concrete. This type of lightweight concrete has high porosity that permits water to seep through the medium, which decreases the environmental issues in typical concrete pavements due to its higher void ratios (Kabir and Islam, 2019). Some facilities, such as parking lots, residential roads, driveways and trails, often use this type of lightweight concrete. The density of no-fine concrete is about 25 % to 30 % lower than that of normal concrete due to the lower mass of no-fines aggregate. The aggregate size used in no-fine concrete mixing is typically above 20 mm and is retained at 10 mm for sieving analysis. Generally, the W/C ratio, aggregate cement ratio and dry concrete density play a significant role in the strength of non-fine concrete.

The recommended shape for no-fine concrete is spherical. This is because the spherical shape provides the concrete with the largest bonding area, creating the most substantial strength. The lack of solid bonding strength between the concrete and the rough surface of no-fines concrete leads to the production of a honeycomb surface on the concrete. The appropriate water content range is the criterion for better adhesion between aggregate and cement. For results higher or lower than the optimum moisture content, sufficient bonds cannot be formed between the cement and the aggregate. However, different applications of the structure have different mixing proportions to achieve the structure's primary purpose. Aggregate cement ratios used in construction applications are typically in the range of 6:1 to 10:1 (Harber, 2005). The thinner concrete mixture can ensure optimum porosity and permeability in the same volume and minimises voids for water transport.

Furthermore, the aggregate to cement mix ratio is 4:1, which is best for pavement design to gain better concrete strength. The lower the aggregate to cement ratio that ensures that the aggregate and cement are sufficiently bonded together to handle the increased load on the pavement. Although no-fines concrete is a multipurpose material that can be used in various situations, sometimes it is not the best choice for specific applications. The design of the no-fine concrete pavement is significant for substructure of the pavement needs to pass water until it can penetrate the soil. So that is why the pavement structure is essential in the design, it can withstand the internal pressure caused by the water in the pavement without any damage to the pavement.

The use of no-fine concrete has various advantages today. The most significant benefit of no-fines concrete is that it performs better in thermal insulation than ordinary concrete. This is because the voids between the concrete are smaller for better thermal insulation. As a result, most no-fines concrete is used on exterior walls. Since no-fine aggregate or sand is used as a raw material in no-fine concrete, the amount of cement needed for coarse bond aggregate is reduced. Since there are no-fine aggregates during the mixing process, the compaction process of no-fine concrete does not require mechanical vibrators and can be thoroughly compacted by a simple compaction method. Compared to common weight concrete, the production cost of no-fine aggregates is relatively low because of the lower cement content used in the mixing process.

2.2.3 Foamed Concrete

The first foamed concrete was made in 1923 to act as an insulating material. After 100 years of development, today's foamed concrete has dramatically improved in the quality of foamed concrete. Foamed concrete is lightweight concrete with a dry density from 300 kg/m^3 to 1800 kg/m^3. Foamed concrete is lightweight concrete with many small voids to reduce the weight. Foamed concrete consists only of fine aggregate, cement, water and foam agent, appropriately mixed to form foamed concrete. Air bubbles are injected into the mixture using adequate manufactured foam to provide foamed concrete its characteristics. The foamed concrete is described as a mixture involving at least 20 % foam that is mechanically condensed into the cement. Compared with other types of lightweight concrete, foamed concrete is popular to use because of its excellent properties such as high insulation properties, fire resistance properties and low cost.

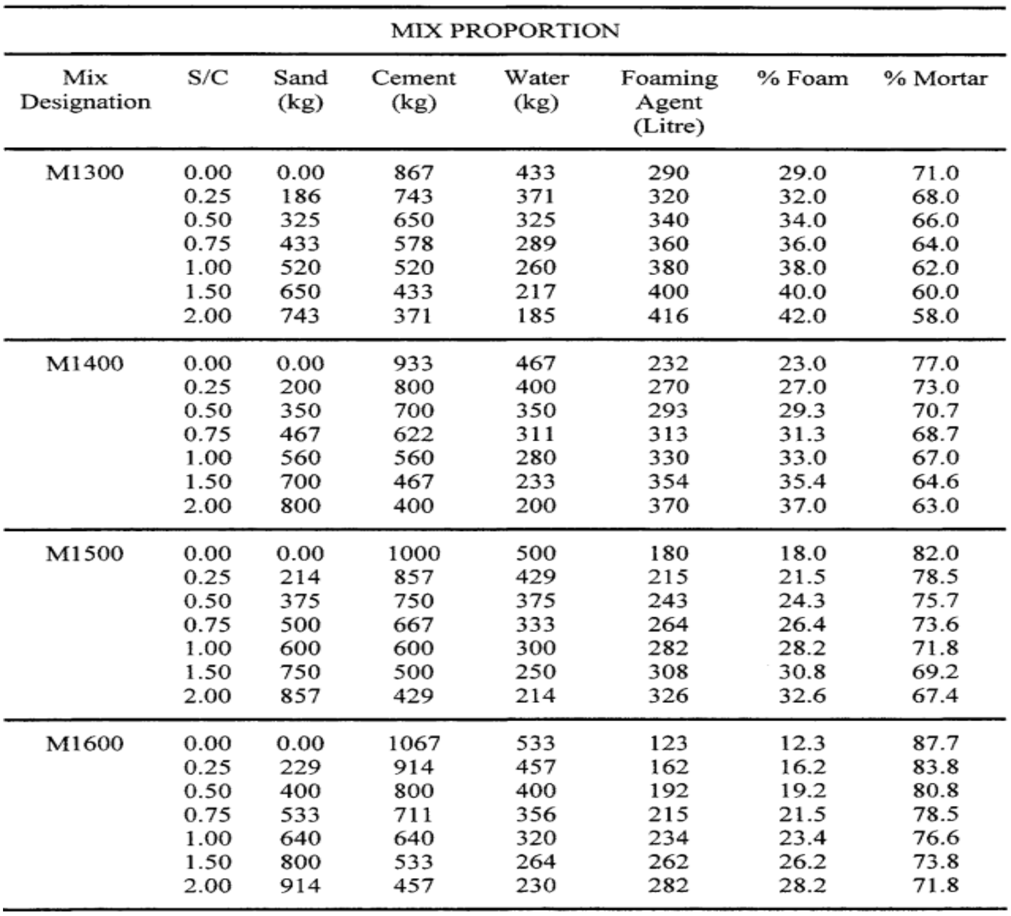
When preparing foamed concrete, there are two ways to form foamed concrete. The first technique uses a chemical process to inject the gas into the mixture while it is in plastic condition. In the second method, the air mixes with a stable foam or whips the air with an air-entraining agent. The first approach is frequently utilized in the prefabricated concrete industry, where precast components are inoculated to produce concrete with high tensile strength and minimum drying shrinkage. Meanwhile, the second approach is in-situ concrete, which is typically used for roofing slab insulation or piping covering.

Foamed concrete has its advantages and disadvantages to the environment. Compared with ordinary concrete, foamed concrete provides lower thermal conductivity and higher sound insulation performance. Foamed concrete has high freeze-thaw durability because it has many tiny pores inside the concrete (Tikalsky, Pospisil and Donald, 2004). In cold weather, not much external moisture penetrates the concrete, causing less moisture to freeze inside the concrete. Therefore, concrete is not easy to crack due to freezing and thawing (Tikalsky, Pospisil and Donald, 2004). Furthermore, foamed concrete has a lower density than clay bricks, making it easier and more cost-effective to transport. In other words, as the density of foamed concrete decreases, the factors affecting the compressive strength and flexural strength also decrease. Compared to clay bricks, foamed concrete requires more care to avoid breakage due to its brittleness (Saurabh and Sherin, 2018).

2.3 Density of Lightweight Foamed Concrete

It is mentioned in the article that M1300, M1400, M1500 and M1600 is produced from a sequence of four different densities of foamed concrete, specifically 1300 kg/m^3, 1400 kg/m^3, 1500 kg/m^3 and 1600 kg/m^3 each (Hamidah, et al., 2005). Table 2.1 shows the fundamental mix proportions for creating 1.00 m^3 from each foamed concrete sample density with one to one sand-cement (S/C) ratio. The proportions of the mortar mixture and injection of the amount of foam were estimated using an in-house spreadsheet tool and the outcomes are displayed in Table 2.1. The generated calculation table can also determine the mix ratio of any set density, S/C ratio and W/C ratio. The following S/C were used which are 0.0, 0.25, 0.5, 0.75, 1.0, 1.5 and 2.0. The W/C ratio was maintained constant at 0.56 in maximum. Therefore, the ideal density for the mixing ratio is 1400 kg/m^3, which can be viewed in Table 2.1 to obtain 1400 kg/m^3.

Table 2.1: Mix Proportion for Different Density (Hamidah, et al., 2005).



MIX PROPORTION							
Mix Designation	S/C	Sand (kg)	Cement (kg)	Water (kg)	Foaming Agent (Litre)	% Foam	% Mortar
M1300	0.00	0.00	867	433	290	29.0	71.0
	0.25	186	743	371	320	32.0	68.0
	0.50	325	650	325	340	34.0	66.0
	0.75	433	578	289	360	36.0	64.0
	1.00	520	520	260	380	38.0	62.0
	1.50	650	433	217	400	40.0	60.0
	2.00	743	371	185	416	42.0	58.0
M1400	0.00	0.00	933	467	232	23.0	77.0
	0.25	200	800	400	270	27.0	73.0
	0.50	350	700	350	293	29.3	70.7
	0.75	467	622	311	313	31.3	68.7
	1.00	560	560	280	330	33.0	67.0
	1.50	700	467	233	354	35.4	64.6
	2.00	800	400	200	370	37.0	63.0
M1500	0.00	0.00	1000	500	180	18.0	82.0
	0.25	214	857	429	215	21.5	78.5
	0.50	375	750	375	243	24.3	75.7
	0.75	500	667	333	264	26.4	73.6
	1.00	600	600	300	282	28.2	71.8
	1.50	750	500	250	308	30.8	69.2
	2.00	857	429	214	326	32.6	67.4
M1600	0.00	0.00	1067	533	123	12.3	87.7
	0.25	229	914	457	162	16.2	83.8
	0.50	400	800	400	192	19.2	80.8
	0.75	533	711	356	215	21.5	78.5
	1.00	640	640	320	234	23.4	76.6
	1.50	800	533	264	262	26.2	73.8
	2.00	914	457	230	282	28.2	71.8

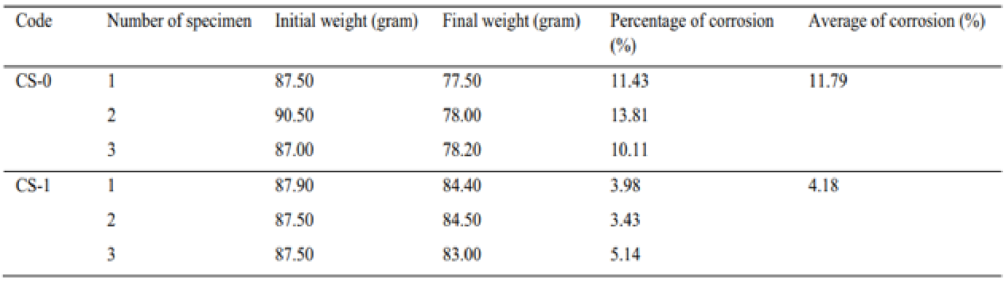
2.4 Water Repellent Agent

In the market, there are several types of water repellent agents applied in building materials including CS, Zinc Stearate, Silane and others. The water repellent is a treatment agent that coats the surface with a nanoparticle compound that imparts excellent water repellence to the material. Water repellents agent are included in the concrete mix and transferred into the pore space from the surface (Wittmann and Zurich, 2011). In addition, to further improve water repellence and durability, the main purpose is to recognise how the water repellent regularly binds and stabilises on the surface at the molecular level. Furthermore, the function of the water repellent agent does not inhibit capillary water absorption for hydration in the cementing process. Conversely, water repellents form a hydrophobic layer on the surface of the microspores to prevent fluid absorption by the capillary.

2.4.1 Calcium Stearate (CS)

CS act as a water repellent agent utilised in this study. CS is considered a physiologically safe chemical that is insoluble in most solvents. Furthermore, Maryoto (2017) mentioned that the CS repel moisture on the steel surface through polar carboxylate groups and blocks the pore to resist corrosion, thereby forming insoluble hydrophobic salts on the steel surface. Table 2.2 illustrates the percentage of corrosion in the reinforcement bar with the presence of CS. Erosion of CS in bars using 0 kg of CS reduced the final average weight to 11.79 % (Maryoto, 2017). In the experiments, it has been mentioned that CS can protect the concrete away from corrosion because chloride ions penetrate to prevent water from passing through the micro rods. Therefore, it can be demonstrated that CS has the function of repelling water to reduce the corrosion that occurs throughout the rod. When 1 kg of CS was applied to the rod, the final mean mass was reduced to 4.18 %. Hence throughout the experiment, the presence of CS can prevent the corrosion of reinforcement bars that consists in the reinforced lightweight concrete to improve the mechanical properties of the building.

Table 2.2: Percentage of Corrosion in Rebar with Presence of Calcium Sterate (Maryoto, 2017).



Code	Number of specimen	Initial weight (gram)	Final weight (gram)	Percentage of corrosion (%)	Average of corrosion (%)
CS-0	1	87.50	77.50	11.43	11.79
	2	90.50	78.00	13.81	
	3	87.00	78.20	10.11	
CS-1	1	87.90	84.40	3.98	4.18
	2	87.50	84.50	3.43	
	3	87.50	83.00	5.14	

2.5 Pre-Foam Method

A foam generator and concrete mixer are necessary equipment for foamed concrete production. The pre-foam method is used in the production of LWFC. This method involves producing base mix and pre-formed foam independently, then only mixing both of the components afterwards. Before mixing with the base mix, the foam must be firm and stable to withstand the forces created throughout the mixing process until the foamed concrete reaches its initial stage. After the foamed concrete has finished the initial stage, a solid matrix-like structure will be formed between the tiny bubbles to ensure sufficient air bubble separation. The quality of LWFC produced by the pre-foam method largely depended on the foam and mortar mixing procedure. Foams contain a dozen to several thousand pores in the total volume of lightweight concrete. Pores in concrete significantly influence its mechanical characteristics, which decrease mechanical characteristics as porosity increases (Kurpinska and Ferenc, 2017). Therefore, increase the amount of cement used in lightweight concrete to produce hydraulic silica gel to improve the strength behaviour.

2.6 Compressive Strength Test (CST)

The CST for lightweight concrete is the most important step in producing concrete cubes. The primary function of CST is to determine a limited state of compressive stress on concrete that causes the materials to fail in a ductile manner (Dundu, 2012). In addition, many external factors would affect the strength of concrete, including surrounding temperature, moisture content, curing period and aggregate types (Khoury, 1992). Therefore, extensive testing is required to design with high compressive strength to investigate which standards can perform with the appropriate concrete for the site. Typically, residential concrete compressive strength requirements for commercial projects range from 2,500 psi to 4,000 psi or higher in different applications. The compressive strengths of concrete are often considerably higher than tensile strength. This is because concrete composition favours compressive force rather than tensile strength.

2.6.1 Compressive Strength Difference in Structural and Non-structural in Lightweight Concrete

The lightweight aggregate concrete can be divided into structural and non-structural types and different types of aggregate involved can be used in different applications. The lightweight concrete should achieve a compressive strength of at least 17 MPa and an optimum density of 1840 kg/m^3 in twenty-eight (28) days. In addition, the acceptable practical density should vary from 1400 kg/m^3 to 1840 kg/m^3 for lightweight structural concrete (Hedjazi, 2019). Compared to the lightweight structural concrete, non-structural lightweight concrete forms a mixture with lower densities and more air voids inside the cement paste (Hedjazi, 2019). At the same density as structural lightweight concrete, non-structural lightweight concrete has compressive strength properties of less than 17 MPa (Bedekovic, et al., 2019). This is because the non-structural lightweight concrete has more air voids inside the concrete. Since there are more voids between the concrete, the voids cannot provide any support for the concrete for greater compressive strength. The way of determining the strength of concrete depends on the size, shape, texture, quality and strength of aggregates (Musa and Saim, 2017). There are two types of lightweight aggregates suitable for both forms of lightweight concrete including (1) natural aggregates and (2) processed aggregates. Natural aggregates are used in lightweight structural concrete, whereas processed aggregates are much more suitable to be used in non-structural lightweight concrete. The main difference between natural aggregates and processed aggregates is the mortar bond to the surface of the different types of aggregates. The processed aggregates have a lighter density and more pores in the aggregate. Therefore, this is why the compressive strength of non-structural lightweight concrete is lower than that of lightweight structural concrete.

2.6.2 Effect of Various Degrees of Temperature on the Lightweight Concrete

Bingol and Gul (2004) reported that the compressive strength of each mixed group of the lightweight concrete declined as the temperature increased. However, there is no substantial strength loss between 150 °C and 300 °C. Across all of the mixed groups, 750 °C is the optimal temperature at which all groups considerably reduce their initial strength as shows in Figure 2.2. The heating period seems to influence the strength loss, but the higher temperature is a more critical factor in terms of reduction in strength. The cement component in the mixture would absorb water to form a calcium silicate hydrate bond (C-

S-H). The C-S-H bond creates a gel texture with the aggregate and hardens to form compressive strength. The C-S-H has a primary hydration product that contributes to the concrete's strength, cohesion and adhesion. At 300 °C, the water absorbed from the production of gel and the chemically mixed water in the hydration begin to evaporate. Meanwhile, the water in the capillary voids would evaporate at approximately 100 °C (Yazicioglu, et al., 2018). As a result, shrinkage would present and build-up of steam pressure in the concrete, causing the concrete cracks and split. Therefore, it is essential to control the temperature of the concrete to have better compressive strength throughout the working process.

The temperature during concrete manufacture and application would significantly affect its curing time, which ultimately affects the final strength of the concrete. The optimum temperature for pouring concrete is between 4 °C - 16 °C. Therefore, many mass concrete works use cold water through mixing to control the temperature of the concrete and minimise the risk of cracking and damage. When concrete reaches its intended strength within twenty-eight (28) days, the concrete may expand and contract depending on the ambient temperature (Cruz and Gillen, 1980). Besides, the aggregates account for the production of concrete should approximately 70 % to 80 % of the volume of concrete. The aggregates essentially influence the ratio of development in the higher temperatures on the concrete that cause concrete to expand, leading to cracks.

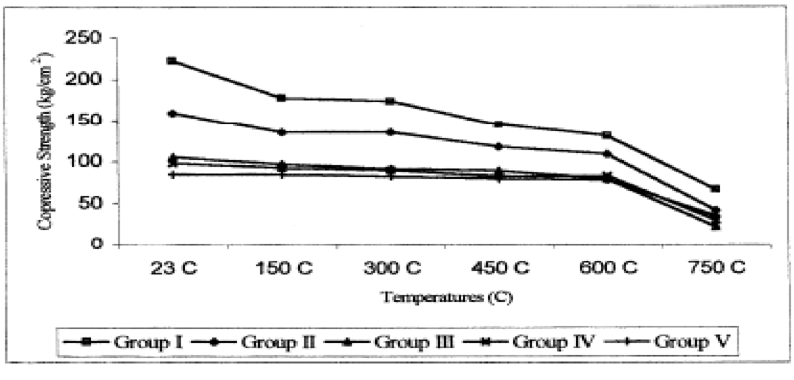
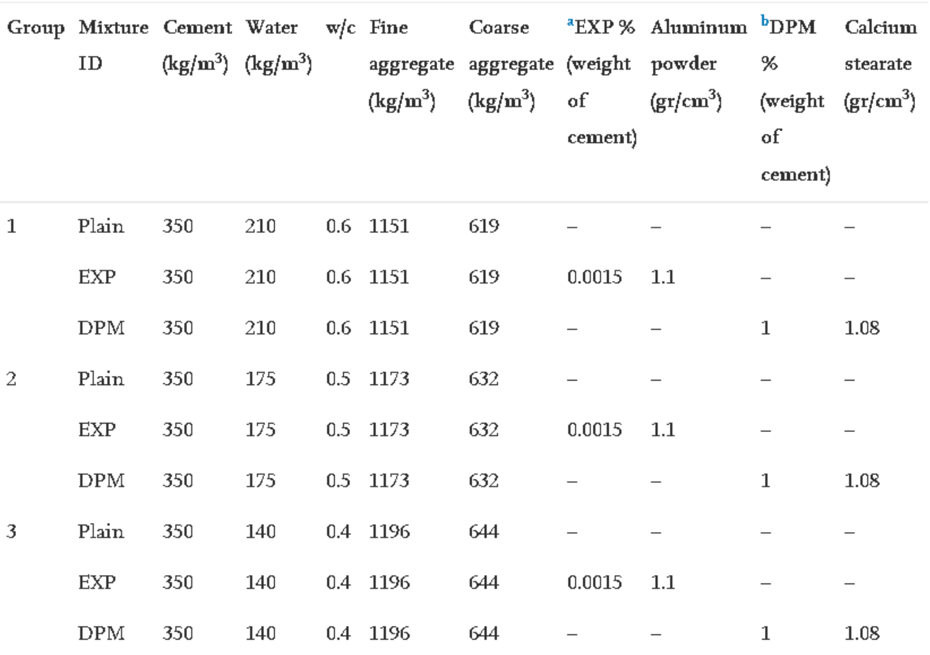


Figure 2.2: Residual Compressive Strength of Concrete Specimens After Exposure to Elevated Temperatures (Bingol and Gul, 2004).

2.6.3 Effect of Calcium Stearate in Compressive Strength

Concrete drying shrinkage is one of the most severe issues in the structure, resulting in multiple cracks on the concrete surface. In environments with low relative humidity, water evaporation through the capillary pores of the hydrated cement paste is the main issue of drying shrinkage. There are two methods suggested to minimise crack formation caused by drying shrinkage: (1) evaluating the evaporation of moisture from the concrete surface and (2) selecting the correct additives to prevent cracking. The first approach necessitates the monitoring of curing conditions and water management, while the second approach necessitates the implementation of effective chemical admixtures in this study. The second approach investigated which chemical admixtures could provide high compressive strength. Table 2.3 shows that nine assorted designs are divided into three groups used to analyse the influence of CS and aluminium powder on the characteristics of fresh and cured concrete.

Table 2.3: Mixture Proportion (Azarhomayun, et al., 2022).



Group	Mixture ID	Cement (kg/m^3)	Water (kg/m^3)	w/c	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	[a]EXP % (weight of cement)	Aluminum powder (gr/cm^3)	[b]DPM % (weight of cement)	Calcium stearate (gr/cm^3)
1	Plain	350	210	0.6	1151	619	–	–	–	–
	EXP	350	210	0.6	1151	619	0.0015	1.1	–	–
	DPM	350	210	0.6	1151	619	–	–	1	1.08
2	Plain	350	175	0.5	1173	632	–	–	–	–
	EXP	350	175	0.5	1173	632	0.0015	1.1	–	–
	DPM	350	175	0.5	1173	632	–	–	1	1.08
3	Plain	350	140	0.4	1196	644	–	–	–	–
	EXP	350	140	0.4	1196	644	0.0015	1.1	–	–
	DPM	350	140	0.4	1196	644	–	–	1	1.08

CS was combined with C-S-H to create a water repellent waxy material that presents in a gel form. The water repellent resulted in a less compact, lightweight and more stable combination. The ratio of CS added to the lightweight concrete is vital as it would significantly affect the compressive strength of concrete. This is because CS is a water repellent agent that blocks the absorption of water in the voids. Therefore, the higher the CS amount the lower the W/C ratio required. As a result, Figure 2.3 demonstrates that the CS's material has a more significant impact on the reduction of compressive strength by raising the W/C ratio. Furthermore, CS inhibits cement paste and aggregate bonding throughout the interfacial transition zone, increasing air percentage and reducing density (Azarhomayun, et al., 2022). In Figure 2.3, EXP demonstrates Expansive admixtures and DPM indicates Damp Proofing Material.

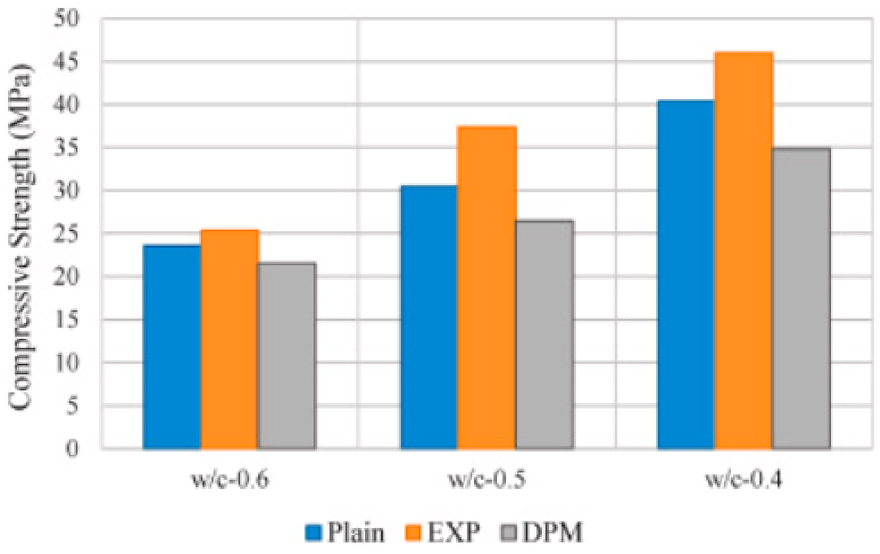


Figure 2.3: Compressive Strength of Concrete at 28 Days with Various Water to Cement Ratio (Azarhomayun, et al., 2022).

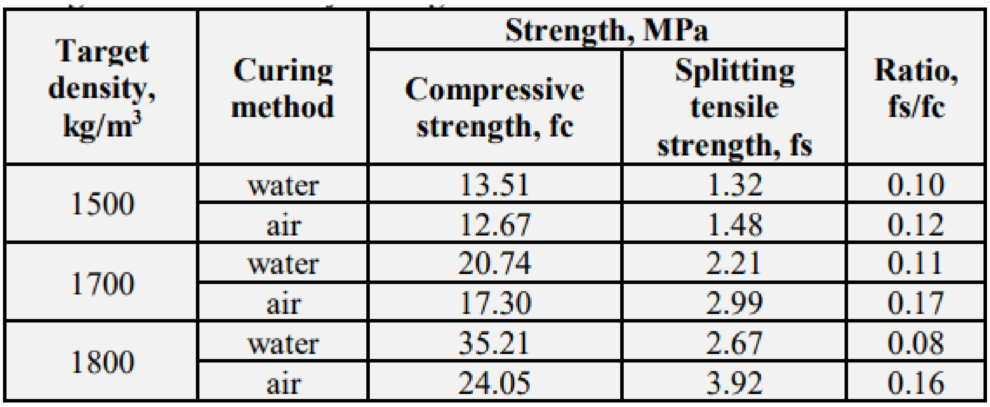
2.7 Splitting Tensile Strength Test (STST)

Tensile strength is a fundamental property of cylinder concrete when structural stress causes tensile cracking of concrete at the vertical diameter. Concrete's tensile strength is usually lower than its compressive strength. Commonly, the tensile strength of concrete is approximated to be around 10 % of compressive strength. This is because the brittle quality of the concrete makes it particularly weak under stress. Furthermore, indirect methods are used to identify the tensile strength as direct methods are challenging to obtain accurate results (Sutan and Meganathan, 2003). The main problems with direct tensile strength include increased bending stress caused to eccentricity or displacement of the load and stress concentrations at the loaded grips.

2.7.1 Effect of Curing Method on Splitting Tensile Test of Lightweight Foamed Concrete

For LWFC samples immersed in air and water in the tank, the split tensile strength improved with increasing density after curing for twenty-eight (28) days. Table 2.4 shows the splitting tensile strength of LWFC immersed in the air rises dramatically with the unit weight compared to water cured LWFC cured. In splitting tensile strengths, the most incredible value for 1800 kg/m^3 air-cured, whereas the lowest value for 1500 kg/m^3 water cured was 3.92 MPa and 1.32 MPa respectively. The recorded value is above the minimum value of 0.17 MPa according to ASTM C869-91 for LWFC. Kado, et al. (2018) further mentioned that the LWFC STST varies from 8 % to 17 % of the CST after twenty-eight (28) days of water and air-curing.

Table 2.4: Curing Methods Affect Splitting Tensile and Compressive Strength and Lightweight Foamed Concrete (Kado, et al., 2018).



Target density, kg/m^3	**Curing method**	**Strength, MPa**		**Ratio, fs/fc**
		Compressive strength, fc	**Splitting tensile strength, fs**	
1500	water	13.51	1.32	0.10
	air	12.67	1.48	0.12
1700	water	20.74	2.21	0.11
	air	17.30	2.99	0.17
1800	water	35.21	2.67	0.08
	air	24.05	3.92	0.16

2.7.2 Effect of Water to Cement Ratio on Splitting Tensile Strength Test

The W/C ratio has a significant impact on concrete's splitting tensile strength. The test operates for the W/C ratio varies from 0.50 to 1.20 and Cement to Sand ratio varies from 1:03 to 1:07 (Singh, Thammishetti and Munjal, 2015). According to the observations, increasing the W/C ratio and Cement to Sand ratio lowers splitting tensile strength values while improving workability. The variation coefficient and concrete splitting tensile strength data are demonstrates in Figure 2.4. The cylinder's splitting tensile strength was tested and the cylinder breaking in half indicated that the specimen had failed at its maximum splitting tensile strength. After twenty-eight (28) days of casting, check the splitting tensile strength data. Splitting tensile strength has been shown to decrease as water content rises.

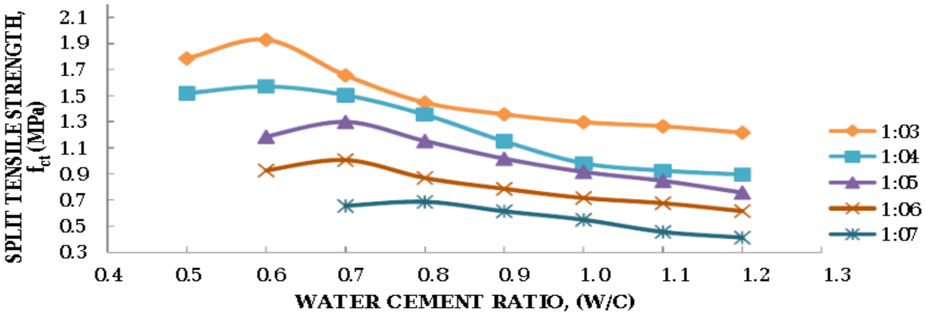


Figure 2.4: Variation of Splitting Tensile Strength with Water to Cement Ratio at 28 Days (Singh, Thammishetti and Munjal, 2015).

2.8 Flexural Strength Test (FST)

FST is frequently performed to assess the material's flexural modulus or elastic strength. FST assesses a concrete beam's or slab's capacity to resist flexural failure. The FST analyses the amount of force required to fracture a beam under three-point stress. This data is frequently used to select materials for parts that can resist pressures without bending. A modulus of rupture in MPa or psi represents the results of a concrete flexural test. The stress versus strain deformation curve slope determines the flexural modulus. The numbers can be used to assess the strength of the sample to withstand bending or bending forces. Furthermore, a lower modulus of rupture was observed when larger concrete specimens were studied.

2.8.1 Effect of Temperature on Flexural Strength of Lightweight Concrete

Flexural strength for lightweight concrete decreased with the increase in temperature, as shown in Figure 2.5 for all densities of lightweight concrete. At temperatures of 20 °C, 100 °C, 200 °C, 300 °C, 400 °C, 500 °C and 600 °C, the flexural strength of lightweight concrete could be investigated. At temperatures over 65 °C, all of the first heating series resulted in delayed crystalline production, which caused detrimental tensile stresses in the rectangular concrete (Soleimanzadeh and Othuman, 2012). Moreover, changes in physical and chemical properties and small volume changes due to the evaporation process of the free moisture present in the concrete mass would cause shrinkage at the temperature of around 93 °C to 200 °C. At 200 °C, the flexural strength of the rectangular concrete would be decreased by about 15 % of its original value when the temperature is increased. Dehydration causes both the C-S-H bond and sulfoaluminate components to decompose between 200 °C and 300 °C and microscopic cracks on the surface begin to appear. Besides, the flexural strength of all the rectangular concrete in different densities would be dropped around 25 % of the actual temperature at 300 °C. In addition, the flexural strength for rectangular concrete was about 65 % of the initial value at 400 °C. Meanwhile, calcium hydroxide dehydrates at a temperature of 500 °C, which may lead to deep cracks, which eventually break entirely in the bending test (Soleimanzadeh and Othuman, 2012). Last but not least, at 600 °C, the flexural strength drops to 40 % of its original value.

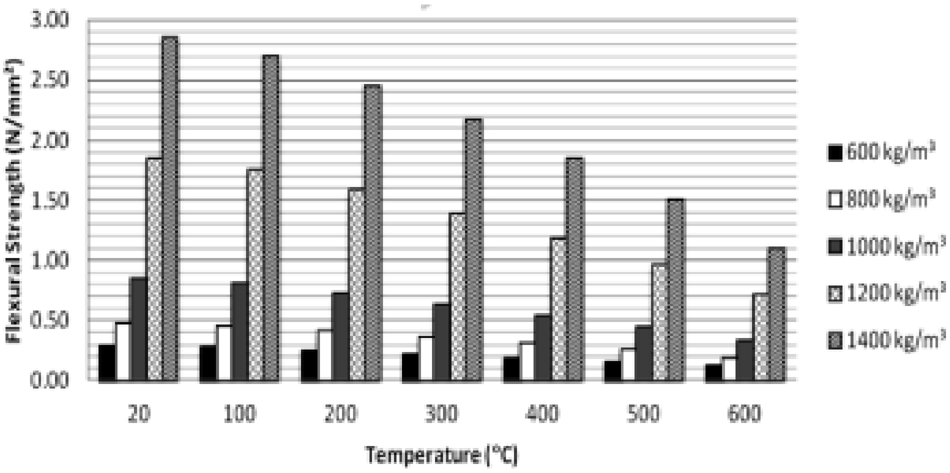


Figure 2.5: Flexural Strength of Lightweight Concrete with Different Temperature (Soleimanzadeh and Othuman, 2012).

2.9 Summary

In short, “Lightweight Aggregate Concrete”, “Non-fines Concrete” and LWFC are the three categories of lightweight concrete. Today, LWFC is used frequently because of their lightweight, which reduces the overall dead load of the building and reduces the overall construction cost. The pre-formed technique is the method selected to produce LWFC in this study. There are two processes in the pre-formed method. Firstly, the cement is mixed with sand and water to form Mixture 1 and the second process is that the foaming agent is mixed with water to create foam. After that, Mixture 1 and the prepared foam are then combined and mixed thoroughly to form LWFC.

In addition, investigations on the performance of water repellent additives in the presence of LWFC have been studied and discussed. CS will be applied as a water repellent agent in this study. The CS can reduce water absorption by blocking the fluid movement within the concrete. Based on the existing experiments, the strength performance of concrete with water repellent is lower than that of concrete without water repellent agents due to hydrophobic characteristics, which may slow the process of cement hydration. Several strength performance tests, including CST, STT and FST would be performed in 1400 kg/m^3 of LWFC concrete density; these tests are used to determine the appropriate amount of CS.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

The focus of this study's procedures and methods, including processing ingredients to manufacture LWFC with a unit weight of 1400 kg/m^3. First, the materials and moulds were collected and prepared in detail and continue with the mix proportion, mixing and testing procedure for LWFC specimens. The strength performance and desired density of LWFC mixed with CS and W/C ratio are the main areas of investigation for determining the appropriate mix proportions. Figure 3.1 are shows the flow chart of the project work scope for a study on the strength performance of 1400 kg/m^3 LWFC with CS.

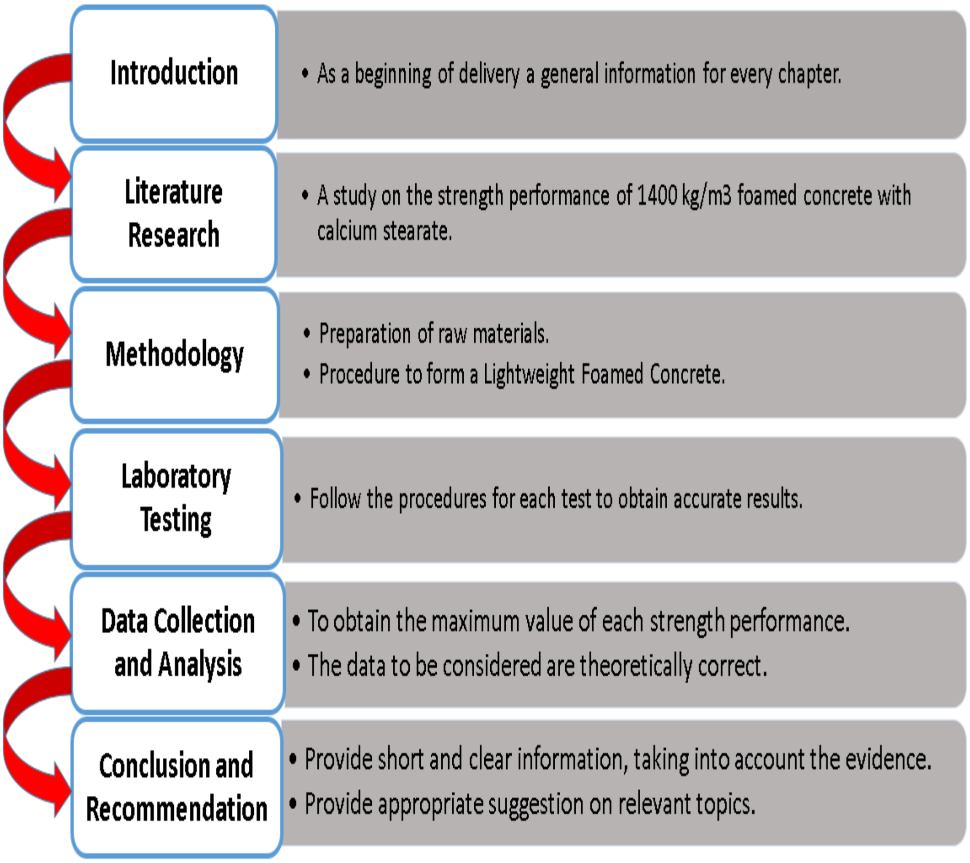


Figure 3.1: Flow Chart of Project Work Scope.

3.2 Raw Materials

Ordinary Portland Cement (OPC), fine aggregates, water, foam and calcium stearate (CS) were the essential components of LWFC. After that, all raw materials were mixed to produce LWFC specimens with a unit weight of around 1400 $kg/m^3 \pm 50\ kg/m^3$. The sub-section below describes each raw material used in detail.

3.2.1 Ordinary Portland Cement (OPC)

Cement is also known as OPC, manufactured by Yeoh Tiong Lay Sdn Bhd with 52.5 N. According to ASTM C150 (2005), the OPC employed in this study corresponded with Type I Portland Cement. Table 3.1 listed the composition of OPC used. The OPC is sieved through a 600 μm sieve and collected in an airtight package before mixing with the concrete. This process is to avoid moisture air in the OPC that may influence the formation of calcium silicate hydrate (C-S-H) gel. Figure 3.2 shows a picture of OPC with Orang Kuat brand from YTL Sdn Bhd.

Figure 3.2: Ordinary Portland Cement, ‘Orang Kuat’ brand from YTL Sdn Bhd.

Table 3.1: General Composition of Ordinary Portland Cement Used (Ahmad, 2015).

Constituent	Ordinary Portland Cement % by Weight
Lime (CaO)	64.64
Silica (SiO_2)	21.28
Alumina (Al_2O_3)	5.60
Iron Oxide (Fe_2O_3)	3.36
Magnesia (MgO)	2.06
Sulphur Trioxide (SO_3)	2.14
N_2O	0.05
Loss of Ignition	0.64
Lime saturation factor	0.92
C_3S	52.82
C_2S	21.45
C_3A	9.16
C_4AF	10.2

3.2.2 Fine Aggregates

Fine sand was used as the aggregate in this study to manufacture of LWFC. According to ASTM C778 (2004) standard specification, graded sand must pass a 600 μm sieve and thus it only can be classified as the fine aggregate for use in LWFC. To ensure there is no extra water inside the sand, it is oven-dried for at least 24 hours at around 100 °C to 110 °C before the sieving test. Figure 3.3 shows a picture of fine aggregate pass through 600 μm of sieve plate.

Figure 3.3: Fine Aggregate Sieved with 600 μm.

3.2.3 Water

One of the most essential ingredients in the manufacture of LWFC is water. The water must be free of contaminants and have a pH of 7. Otherwise, water contains contaminants that may affect the hydration process and eventually affect the durability of the cement. According to ASTM C1602 (2006), potable and non-potable water can be used as mixed water. The concrete mix for LWFC was used with tap water. Since to satisfy the study's object, the maximum ratio of W/C is a constant used for the actual mix proportion after it has been determined in the trial mix proportion.

3.2.4 Foam

The main function of applying an air-entraining agent is to create many microscopic air bubbles within the concrete particles. A foaming agent creates LWFC with a unit weight of 1350 kg/m^3 to 1450 kg/m^3 in this investigation. The ratio of foam agent to water was about 1:20 and the density of the foam product is about 45 kg/m^3 at 0.45 MPa pressure mix in the machine foam generator. Figure 3.4 and Figure 3.5 demonstrates a picture of foam generator and the foam pressurised by foam generator.

Figure 3.4: Foam Generator.

Figure 3.5: Foam Generated by Foam Generator.

3.2.5 Calcium Stearate

The function of CS is to provide foamed concrete with hydrophobic characteristics, which reduce water absorption by blocking the fluid movement within the concrete. Furthermore, CS is considered a physiologically safe chemical that is insoluble in most solvents. The main ingredient in CS is soap scum mixed with water to form a white solid. The control mix has no water repellent add, but the following samples have CS ranging from 0.0 to 1.0 % by mass of cement for every 0.2 % increase in CS. Furthermore, CS has itself chemical formula of ($C_{36}H_{70}CaO_4$), M = 607.02 g/mol and contain manufacture CAS NO of [1592-23-0]. Table 3.2 demonstrates the detailed specification of CS, which clearly written on the content label. Figure 3.6 shows a picture of CS powder added into fresh concrete.

Table 3.2: Detailed Specification of Calcium Stearate.

Appearance	**Powder**
Ash (%, max)	10.5
Free Fatty Acid (%, max)	1.0
Melting Point (^{o}C)	150
Moisture (%, max)	4.0
Particle Size (% thru 200 mesh)	90
Specific Gravity (g/cm^3)	1.01

Figure 3.6: Calcium Stearate Powder.

3.3 Mould

There are two types of moulds available in the lab, which are plastic moulds and steel moulds. Therefore, Table 3.3 shows the three different shapes and size moulds were required for each mechanical test as according to ASTM standards and requirements.

Table 3.3: Different Sizes of Moulds Used in Different Mechanical Tests.

Mechanical Test	**Shape**	**Length (mm)**	**Width (mm)**	**Height (mm)**
Compressive Strength	Cube	100	100	100
Splitting Tensile Strength	Cylinder	-	100 (diameter)	200
Flexural Strength	Prism	160	40	40

The mould must be in a clean situation and ensure it is double checked before the concrete is poured into the concrete mould. This step is to confirm there is no residue is left inside the concrete mould. The next step was to apply a thin layer of oil to the mould's surface that is to allow easier in the process of removal of concrete cube after the it has hardened. Figure 3.7, Figure 3.8 and Figure 3.9 shows the cubical, cylindrical and prism steel mould with respective dimensions.

Figure 3.7: Cubical Steel Mould with 100 mm x 100 mm x 100 mm.

Figure 3.8: Cylindrical Steel Mould with 100 mm Diameter and 200 mm Height.

Figure 3.9: Prism Steel Mould with 40 mm Width x 40 mm Height x 160 mm Length.

3.4 Mix Proportions

The mix ratio of LWFC can be calculated according to the volume of 1 m^3. Table 3.4 shows the calculation of each component for mix proportion of LWFC.

Table 3.4: Basic Information for Mix Proportion of Lightweight Foamed Concrete.

Components	Density(kg/m^3)
Cement	3150
Sand	2600
Water	1000
Foam	40 - 50
Cement to Sand Ratio	1 : 1
Water to Cement Ratio	0.50 – 0.60
Foam Agent to Water Ratio	1 : 20
Calcium Stearate	0.0 % - 1.0 % of Cement Weight

3.5 Trial Mix

The cement to sand ratio is 1:1 while W/C ratio is increased from 0.50 to 0.60 with 0.02 increments until the W/C ratio reaches its maximum value. The density of the concrete mix was maintained at 1400 ± 50 kg/m^3 for the addition of pre-form dry stable foam. Table 3.5 shows the trial mix for respective mass in 0.0014 m^3 volume which included 40 % wastage in every different W/C ratio.

Table 3.5: Trial Mix for Respective Mass in 0.0014 m^3 with Different Water to Cement Ratio.

W/C ratio	Cement (kg)	Sand (kg)	Water (kg)	Foam (g)
0.50	2.30	2.30	1.150	73.96
0.52	2.30	2.30	1.196	73.96
0.54	2.30	2.30	1.242	73.96
0.56	2.30	2.30	1.288	73.96
0.58	2.30	2.30	1.334	73.96
0.60	2.30	2.30	1.380	73.96

3.6 Actual Mix

The cement to sand ratio is 1:1 and the amount of CS added was from 0.0 % to 1.0 % on cement weight. The mix proportions were remained constant with a C/S ratio of 1:1, while the W/C ratio reaches 0.54 as the maximum value.

Furthermore, the density of the concrete mix was maintained at 1400 ± 50 kg/m^3 for the addition of pre-form dry stable foam. Table 3.6 demonstrates the actual mix for respective mass in 0.0040 m^3 volume which included 40 % wastage with different amount of calcium stearate.

Table 3.6: Actual Mix for Respective Mass in 0.0040 m^3 Volume with Different Amount of Calcium Stearate.

CS (%)	**Cement (kg)**	**Sand (kg)**	**Water (kg)**	**Foam (g)**	**CS (g)**
0.0	20	20	10.80	627.20	0
0.2	20	20	10.80	627.20	40
0.4	20	20	10.80	627.20	80
0.6	20	20	10.80	627.20	120
0.8	20	20	10.80	627.20	160
1.0	20	20	10.80	627.20	200

3.7 Mixing Procedure

First, the materials were weighed in the appropriate amount according to the mix proportion of OPC and fine aggregate, then pour them into a concrete mixer for mixing. After the material was added to the first process in the production of LWFC is combining the cement with sand and water to make a mortar mixture (Mixture 1), water was weighted and properly added to the mixing bowl until the correct W/C ratio was achieved. While waiting for the mixture to complete, the foam was produced in the foam generator with a 1:20 ratio of a foaming agent to the water. The foaming agent and the quantity of CS were added to the wet mixture until the target density of 1400 kg/m^3 is reached. After all of the mixing process was complete, the LWFC was placed in the prepared mould, spread evenly and compacted. The fresh concrete was allowed to cure and hardened for 24 hours before being removed from its mould. After one day of hardening, the concrete cube immerses in water for the curing process and then waits for seven (7), twenty-eight (28) or fifty-six (56) days to perform the mechanical test. Figure 3.10 shows the flow of the mixing procedures of LWFC.

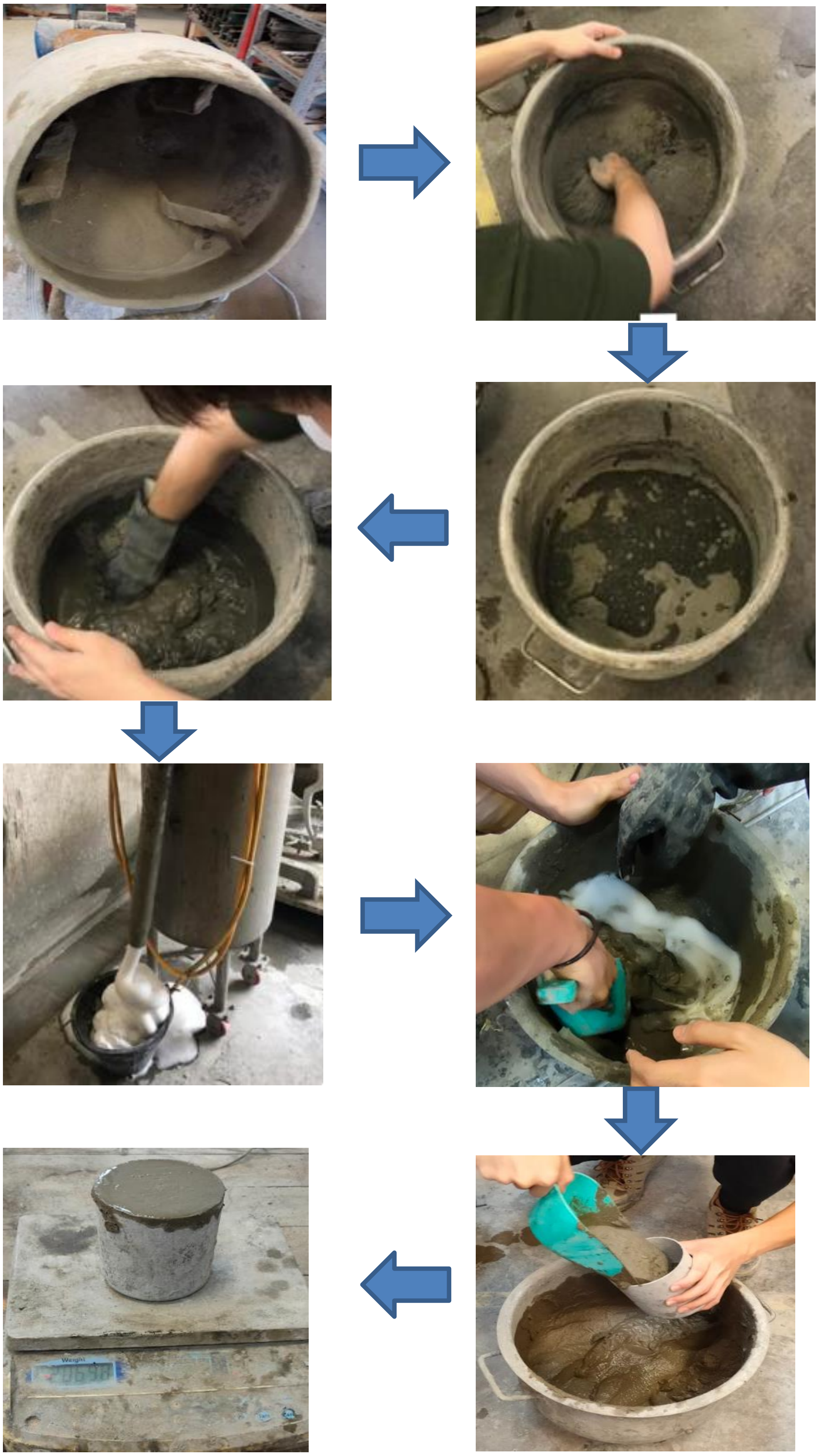


Figure 3.10: Flow of The Mixing Procedures of Lightweight Foamed Concrete.

3.8 Curing

Concrete specimens were then left to cure for 24 hours after pouring of concrete. After that, the concrete specimens were removing from the concrete mould and the water curing process starts. Those concrete samples were placed in a water basin for curing to improve the hydration process of the samples. A suitable temperature for the curing process was between 25 ^{o}C and 30 ^{o}C. All concrete samples were immersed in water basins and tested after seven (7), twenty-eight (28) and fifty-six (56) days. Figure 3.11 presents a picture of concrete samples were cured in water for seven (7), twenty-eight (28) and fifty-six (56) days.

Figure 3.11: Concrete Samples Cured in Water.

3.9 Fresh Density Test

A 1-litre capacity container was tared to zero on the weighing machine and fresh LWFC was applied. The empty container was removed from the weighing scale and filled with the new foamed concrete mix into the container. After that, lightly tap all sides of the container for consolidation purposes and excess LWFC in the container was removed. The whole container was placed on a calibrated weighing scale to determine its net weight. After that, the fresh concrete container was measured three times and the density was recorded and get the average density. The formula for calculating fresh density based on Equation 3.1:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \tag{3.1}$$

3.10 Inverted Slump Test

The slump test uses an ASTM C995-01 (2001) to determine the workability and consistency of concrete mixtures. First, the slump cone was placed on a flat surface. The slump cone was filled in three levels with freshly mixed concrete. Every new layer of the cement paste was placed inside the cone, it must be tapped uniformly until it has mixed evenly with the layer below it. Every layer was tapped around 25 times with a long metal rod of 16 mm diameter. Extra concrete must be removed from the top of the cone once the final layer is filled. Then immediately pull upward with both hands in a twisting motion. After then, the concrete is free to fall. The remaining height, known as the slump, was measured after the free fall. Figure 3.12 demonstrates inner and outer diameter after applied of inverted slump test.

Figure 3.12: Measured Inner and Outer Diameter After Inverted Slump Test.

3.11 Flow Table Test

The flow test was performed to measure the workability of mortar under ASTM C230 (ASTM 2008). The flow test evaluates how efficiently the mortar can be moved within flat steel plate. In this test, the fluidity or flowing property of the fresh concrete was used to determine how workable it is. The flow table test was performed before added of the foam. The fresh concrete was poured into the conical mould on the middle flat steel plate. The conical mould was removed that allow the fresh concrete free moveable on the steel plate. The flow test evaluates how well high or low workable concrete can be performed before it slumps. It provides insight into the consistency and cohesion of the concrete's quality. Figure 3.13 presents a flow table test to obtain how many drops of fresh concrete.

Figure 3.13: Flow Table Test.

3.12 Consistency and Stability

The fresh and hardened concrete densities can be obtained and calculated in order to figure out the value of consistency and stability of the concrete mixture. When the ratio between the fresh density and the hardened density is close to one mean the concrete mixture is considered to be stable. Equation 3.2 was used to calculate the LWFC mixture's consistency and Equation 3.3 was used to determine the mixture's stability.

$$\text{Consistency} = \frac{\text{Fresh Concrete}}{\text{Targeted Density}} \tag{3.2}$$

$$\text{Stability} = \frac{\text{Fresh Density}}{\text{Hardened Density}} \tag{3.3}$$

3.13 Strength Performance

3.13.1 Hardened Density

Laboratory tests were conducted to determine the strength performance of the LWFC after the samples have been cured for the mentioned testing days. The concrete samples were placed on a calibrated weighing scale and make sure the weighing scale was zero to determine the net weight for each sample, which is used to calculate the hardened density of the concrete. A dry cloth removes moisture from the concrete surface for all samples.

3.13.2 Compressive Strength Test (CST) (BS EN 12390-3)

A testing machine conducts the compressive strength under BS EN 12390-3 (BSI, 2002) as shown in Figure 3.14. A uniform velocity of 0.02 mm/s was applied to foamed concrete samples, which are cubic form with the scales of 100 mm x 100 mm x 100 mm until the concrete cube fails. Before performing the CST, the concrete cubes were taken out from the water basin and ensure that the cubes were dry thoroughly. The concrete cubes were measured and recorded before performing the testing. Then, placed the concrete cube in the centre of the compressor and a smooth surface of the concrete cube was set on the top and bottom of the compressor plate to make sure the load can be utterly separate throughout the concrete cube. The maximum reading from the machine was recorded. The methods were repeated for the next two concrete cubes to achieve the results. An average of compressive strength was calculated. The compressive strength calculation for LWFC is shows in Equation 3.4.

$$\text{Compressive Strength, F} = \frac{\text{Load (P)}}{\text{Cross Sectional Area (A)}} \qquad (3.4)$$

Figure 3.14: Compressive Strength Test with Cube Sample.

3.13.3 Splitting Tensile Strength Test (STST) (ASTM C469)

The STST was conducted using testing equipment under ASTM C496 (2002) as shown in Figure 3.15. The procedure was almost similar to the compression test, but a cylindrical sample was chosen rather than a cube concrete. The cylindrical samples were removed from the water basin and allow concrete fully dries before starting the test. The mean of three cylinders evaluates the splitting tensile strength for an individual LWFC mixture. Draw a diameter line with the same axis at both ends of the samples. The specimen was placed horizontally into the testing machine with thin strips of plywood on the top and bottom to ensure uniform stress distribution throughout the specimen. The specimen was continually loaded until failure occurs. The maximum force applied to the specimen before collapse was displayed on the machine's screen. Equation 3.5 is used to record and apply to tensile strength split calculations.

$$\text{Splitting Tensile Strength, T} = \frac{2 \times \text{Load (P)}}{\pi \times \text{Length (L)} \times \text{Diameter(D)}} \tag{3.5}$$

Figure 3.15: Splitting Tensile Strength Test with Cylinder Sample.

3.13.4 Flexural Strength Test (FST) (ASTM C292)

The ASTM C292 standards (2002) assess the FST, commonly known as the modulus of rupture as shown in Figure 3.16. A prism concrete with measurements of 40 mm by 40 mm by 160 mm was subjected to a centre-point loading with a steady loading rate of 0.1 mm/min until it fractures. Before FST, the prism concrete was removed from the water basin and allow the sample to dry sufficiently to ensure no excess water on the concrete. A 10 mm offset was marked down on both sides of the prism concrete before placing it on the support block. For the remaining two samples, calculated and recorded the mean of the three samples. Equation 3.6 was used to determine the prism specimen's flexural strength:

$$\text{Flexural Strength, R} = \frac{3 \times \text{Load (P)} \times \text{Length (L)}}{2 \times \text{Width (b)} \times \text{Depth (d)}^2} \qquad (3.6)$$

Figure 3.16: Flexural Strength Test with Prism Sample.

3.14 Summary

To produce LWFC with the desired density of 1400 kg/m^3. The five essential raw materials for the manufacturing of LWFC are (1) OPC, (2) fine aggregate, (3) water, (4) CS and (5) foam. To make the dry mix, it was vital to combine the raw materials (1) and (2) in the quantities stated in the concrete mixture. After the dry mix is prepared, water was added to make a mortar with a W/C ratio of about 0.50 to 0.60 until reaching the maximum point on the W/C ratio. The pre-forming process was used to create the foam, mixed with mortar to make LWFC with a unit weight of 1400 kg/m^3 with a tolerance of 50 kg/m^3. The cement mortars were produced in moulds of various sizes for various tests. After casting, all samples were dried for 24 hours and then subjected to seven (7), twenty-eight (28) and fifty-six (56) water curing programs in water basin. All samples performed specific mechanical properties under their respective procedures to obtain higher strength performance of LWFC. Figure 3.17 shows the procedure of obtain strength performance result for LWFC.

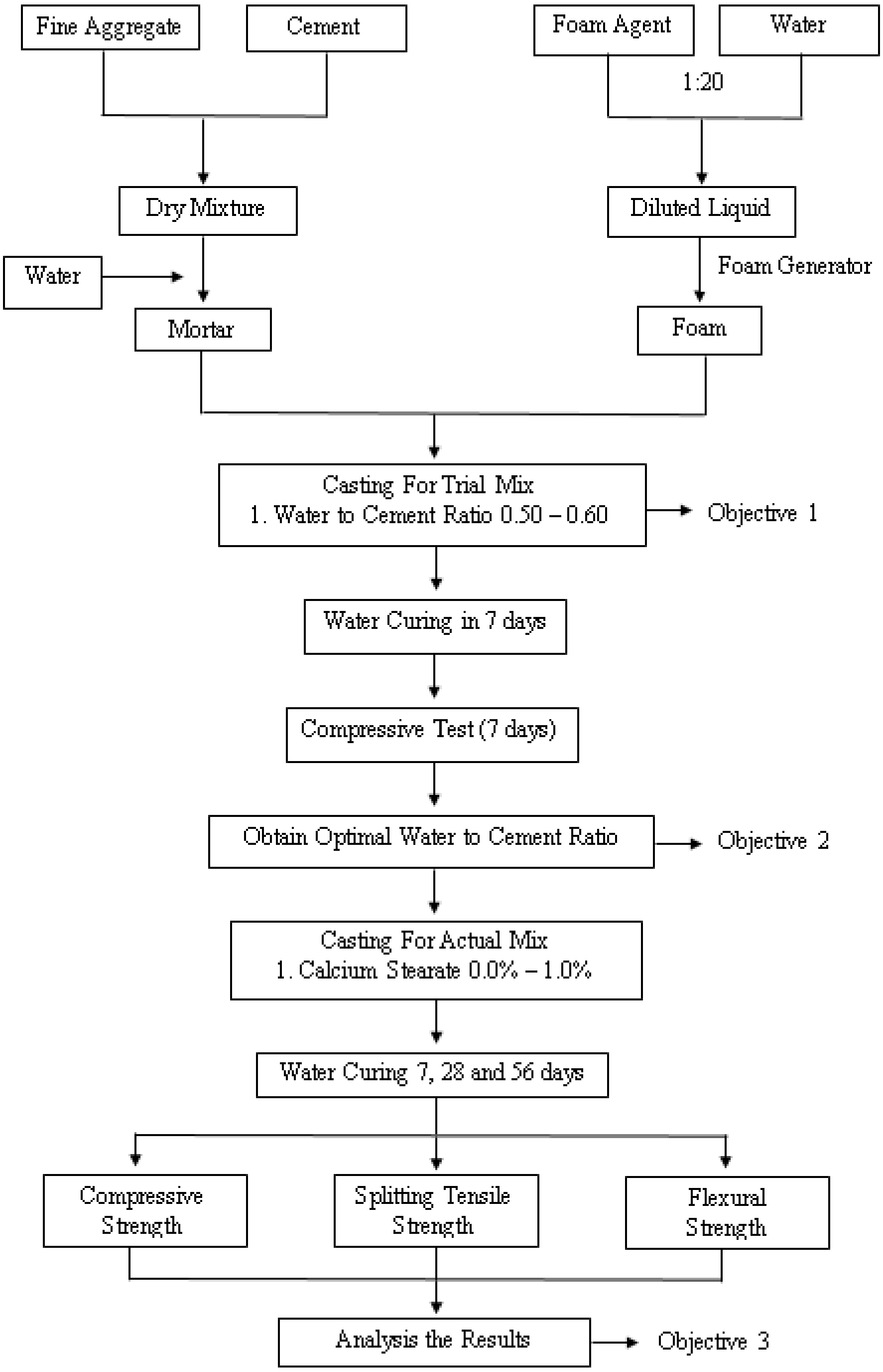


Figure 3.17: Procedure of Obtain Strength Performance Result for Lightweight Foamed Concrete.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The experiment results are discussed in this chapter and further describe the changes in strength performance and engineering performance with the viability amount of CS added between 0.0 % to 1.0 % into the LWFC. The findings from trial mixes to manufacture the LWFC with a relative density varies from 1350 kg/m^3 to 1450 kg/m^3 and a constant W/C ratio of 0.54. After that, the three fundamental strength performance experiments: (1) compressive strength test (CST), (2) splitting tensile strength test (STST) and (3) flexural strength test (FST), were conducted. Before the test, the cube, cylinder and prism specimens were immersed in a water tank for seven (7), twenty-eight (28) and fifty-six (56) days accordingly.

4.2 Trial Mix

The optimal amount of the W/C ratio between 0.50 and 0.60 was identified during the trial mix-cube specimens. All fresh and dry concrete cube density readings were measured and analysed to determine their workability, consistency and stability. The fresh concrete cube density was measured before being placed into the water tank meanwhile, the dry concrete cube density was measured after the oven dry process. The concrete cube was placed in the tank for seven days before proceeding to the compression test. After that, all the cube's compressive strengths were obtained and the W/C ratio was selected for the actual experiment with its optimal compressive strength. Based on the density of the concrete cube, the average compressive strength result was computed to evaluate the concrete strength performance. Table 4.1 summarises the entire trial mix results.

Table 4.1: Summary of Trial Mix Results.

W/C Ratio	**Flow Table Test (mm)**	**Fresh Density (kg/m^3)**	**Dry Density (kg/m^3)**	**Consistency**	**Stability**	**Compressive Strength (MPa)**
0.50	9	1390	1238	0.99	1.12	6.69
0.52	23	1430	1365	1.02	1.05	7.65
0.54	18	1410	1350	1.01	1.04	8.80
0.56	16	1401	1338	1.00	1.05	7.45
0.58	15	1351	1244	0.97	1.09	6.72
0.60	17	1355	1259	0.97	1.08	5.52

Based on the results tabulated in Table 4.1, the average flow table test considerably increases when the W/C ratio is between 0.50 and 0.52 and somewhat declines between 0.54 and 0.60. In contrast, the W/C ratio of 0.52 shows lower workability than other W/C ratios. Theoretically, the higher the W/C ratio used to mix the concrete, the fewer drops are necessary when mixed with the same amount of cement and sand.

Additionally, based on Table 4.1 the consistency and stability values are identical and the lowest difference at W/C ratios of 0.52 and 0.54, with a 0.03 difference. Conversely, the consistency and stability values of freshly mixed and hardened concrete differed the most at 0.13 in the concrete specimens with the W/C ratio of 0.50. All consistency data obtained were in the range of 0.96 to 1.04 when the density was 1350 kg/m^3 to 1450 kg/m^3. Ideally, both consistency and stability values have to obtain 1.0, the concrete cube specimens are categorised as favourable. This is because the hardened, fresh and targeted densities are in the ideal weight of 1400 kg/m^3. However, due to some external factors, both consistency and stability values are difficult to equal to 1.0. The external factors can be due to the casting environment and water curing temperature, poor mixing with cement and sand, bubbles disappearing when the mixture is dipped into the mould and partial cement hydration when the package is opened.

Moreover, Table 4.1 compares of 7-days LWFC's average compressive strength with W/C ratios ranging from 0.50 to 0.60. After calculation, the average maximum strength value of 8.80 MPa was obtained in the 7-days specimen with 0.54 W/C ratio. Meanwhile, in the 7-days specimen with 0.60 W/C ratio has acquired the average minimum strength value of 5.52 MPa. The average compressive strength variation of maximum and minimum values varied by around 59.5 %.

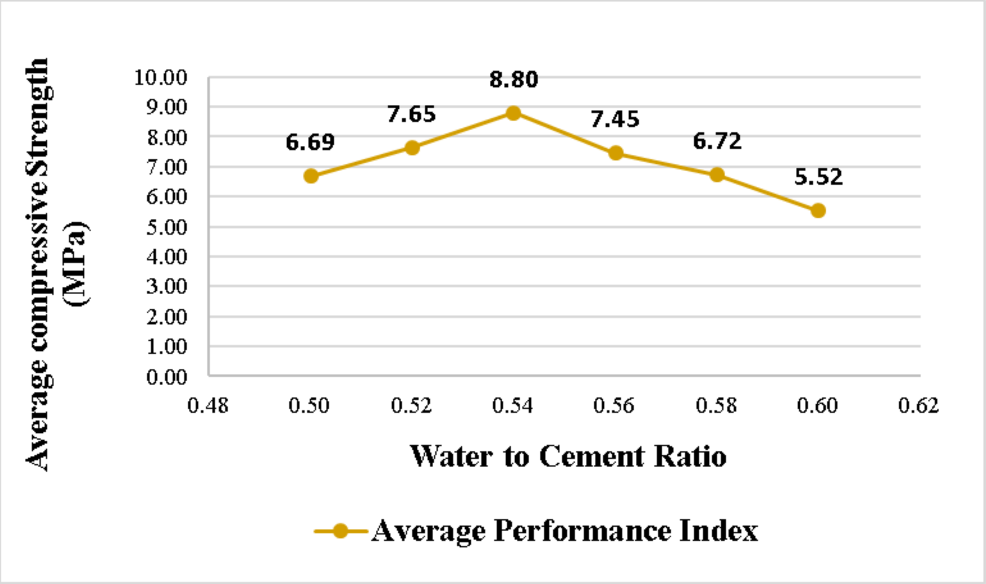


Figure 4.1: Graph of Water to Cement Ratio Versus Average Compressive Strength.

Figure 4.1 demonstrates a line graph of the LWFC's average compressive strength with W/C ratios ranging from 0.50 to 0.60. The average compressive strength enabled for the assessment of concrete strength depending on the density of the concrete. The concrete cubes with the 0.54 W/C ratio have the highest compressive strength value of 8.80 MPa. Therefore, this graph shows that a concrete cube with 0.54 W/C ratios was recommended to conducting a further experiment.

In short, based on the results gathered and compared, it was concluded that 0.54 was the appropriate W/C ratio for the actual mixture. This was made possible by having the best overall workability, consistency, stability and compressive strength. In the second part of this study, foamed concrete samples were casted using CS with the optimal W/C ratio was determined to be used of 0.54.

4.3 Mix Proportion

Table 4.2 tabulated the changing in the mix proportion when the amount of CS added to the LWFC was increased to produce LWFC with a density range of 1350 kg/m^3 to 1450 kg/m^3. The percentage of each raw material, theoretical and actual foam added and flow table test was introduced in Table 4.2 in terms of density and from 0.0 % to 1.0 % of the CS was added into each batch of fresh concrete mixture, with an increment of 0.2 %.

Table 4.2: Mix Proportion with Respective Mass in 0.0040 m^3 Volume with Changing the Amount of Calcium Stearate.

CS (%)	**Cement (kg)**	**Sand (kg)**	**Water (kg)**	**CS (g)**	**Theoretical Foam (g)**	**Actual Foam (g)**	**Flow Table Test (drops)**
0.0	20	20	10.80	0	421.80	520	22
0.2	20	20	10.80	40	421.80	535	20
0.4	20	20	10.80	80	421.80	547	18
0.6	20	20	10.80	120	421.80	560	17
0.8	20	20	10.80	160	421.80	585	15
1.0	20	20	10.80	200	421.80	600	14

4.3.1 Comparison of Theoretical Foam and Actual Foam

Table 4.2 shows that the actual foam added is higher than the theoretical foam calculated. This is due to the uncontrollable conditions and causes the foam to become unstable throughout the mixing process of fresh concrete. The highest percentage difference between theoretical foam and actual foam CS was 1.0 %, a rise of about 42.2 %, while the lowest percentage difference for CS was 0.0 %, an increase of approximately 23.2 %.

The differences in the addition of foam can be explained in two parts. First, part of the foam that was added to fresh concrete during the mixing process may have burst when it was stirred into the mortar mixture. The exothermic reaction that occurs during the hydration process will release a lot of heat and the temperature difference will also cause the foam to become unstable. Additionally, the first batch of foam is always regarded as unstable foam since the unstable form is produced in the foam generator before the pressure is reached. The foam bursts on its own when exposed to ambient temperature over a lengthy amount of time.

4.3.2 Flow Table Test

According to the recorded data presents in Table 4.2, the value of the drops in the flow table test decreased as the CS percentage increased. The flow table test for fresh concrete provides the lowest drops at 1.0 % CS with 14 drops and the highest drops at 0.0 % CS with a value of 22 drops. Furthermore, the 0.4 % of CS, which contributes 18 drops to the flow table test, is the midpoint between the highest and lowest number of drops. According to Naseroleslami and Chari (2019), the irregular forms of the CS particles cause a decreasing in the workability of concrete. Therefore, it is a similar trend of workability for the LWFC, with a higher amount of CS added, the lower the workability is obtained.

4.4 Strength Performance

This study included three primary tests in determining the mechanical characteristics of LWFC with a different portion of CS added. The tests include the CST, STST and FST. A total of 18 sets of the desired density of the fresh concrete mix were casted with differing quantities of powdered CS added ranging from 0.0 % to 1.0 % and each group having 3 specimens were then proceeded to perform each strength performance test. The average value was determined throughout the experiment to validate the result's accuracy and consistency. Table 4.3 tabulates the consistency and stability values of fresh and hardened concrete in control of CS.

Table 4.3: The Consistency and Stability Values of Fresh and Hardened Concrete in Control of Calcium Stearate.

CS (%)	**Fresh Density (kg)**	**Dry Density (kg)**	**Consistency**	**Stability**
0.0	1438.92	1382.81	1.028	1.041
0.2	1439.21	1386.51	1.028	1.038
0.4	1445.21	1396.84	1.032	1.035
0.6	1440.38	1387.04	1.029	1.038
0.8	1442.62	1391.58	1.030	1.037
1.0	1443.78	1393.90	1.031	1.036

4.4.1 Stability and Consistency

As mentioned before, the most ideal specimen would have good quality specimen values on the hardened, fresh and targeted densities; hence, the computed ideal consistency and stability values for the hardened concrete specimen are equal to 1.0. However, external factors that create uncontrollable and unstable changes throughout the experiment make it challenging to obtain the most ideal consistency and stability values.

In addition, the external factors met in the trial mix also recur in the actual mix. For example, the inconsistent values are affected by the surrounding casting and water curing temperatures, poor cement and sand mixing, bubbles disappearing when the mixture is dipped into the mould and partial cement hydration when the package is opened. Indeed, all of the consistent statistics for CS levels between 0.0 % and 1.0 % fell between 0.96 and 1.04 are within the range of 0.93 to 1.07. The lowest consistency value of 1.028 was recorded in the concrete specimens with 0.0 % CS and 0.2 % CS, meanwhile, the greatest consistency value was 1.032 in the concrete specimens with 0.4 % CS.

Additionally, the stability value that the experiment yielded ranged from 0.93 to 1.07. Although the overall trend of stability values indicates a decrease between CS 0.0 % and 1.0 % from 1.041 to 1.036, however there is a slight increase to 1.038 found in the concrete specimen with 0.6 % CS. This is due to some uncontrollable changes in the concrete density.

4.4.2 Compressive Strength

The CST is the most influential examination in building construction as it is essential to assess the quality and grade of concrete used for the building. In this study, 54 concrete cube samples sized (100 x 100 x 100) mm each were casted and assessed for compressive strength. The concrete cube samples were categorised into 6 groups of different percentages of CS added which are 0.0 % of CS, 0.2 % of CS, 0.4 % of CS, 0.6 % of CS, 0.8 % of CS and 1.0 % of CS. For each set, three cube samples were examined to allow for the calculation of the average compressive strength value. In addition, by dividing the maximum pressure (P) on the contact of the cube surface (A), the compressive strength was calculated. Figure 4.2 presents the obtained average result of the CST on 7-days, 28-days and 56-days with different percentages of CS added into LWFC.

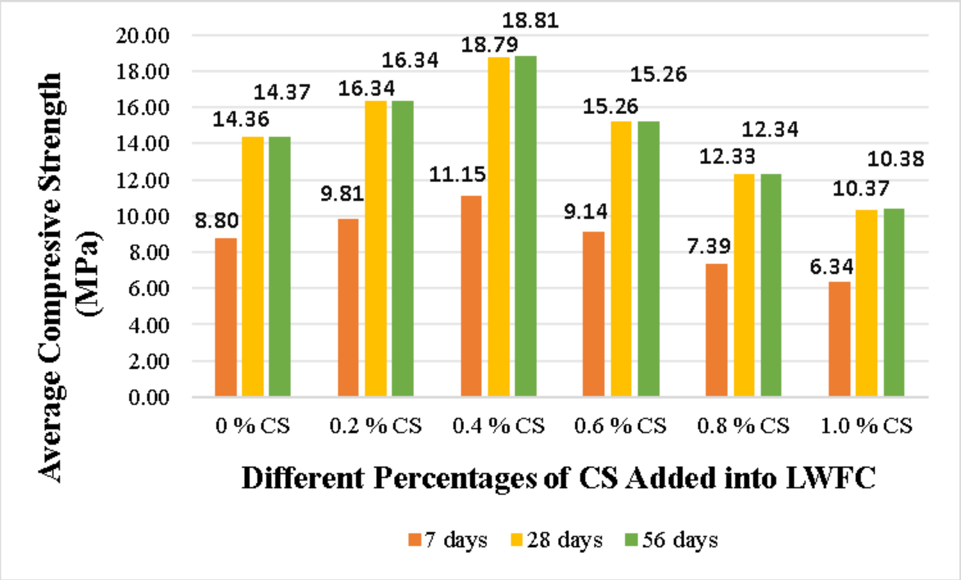


Figure 4.2: The Average Result of Compressive Strength Test in 7, 28 and 56 Days with Different Percentages of Calcium Stearate Added into Lightweight Foamed Concrete.

According to Figure 4.2, the compressive strength in 7-days is presents in a positive skewed bell-shaped. First of all, the specimens with CS 0.0 % have 8.80 MPa and it rises slowly to reach the maximum strength when the CS proportion was 0.4 %, then the strength significantly drops afterwards as the CS proportion increases. The maximum compressive strength with a CS proportion of 0.4 % has an increment of 26.70 % compared to the specimens with no CS. After that, in the specimen with the highest proportion of CS (1.0 %), the compressive strength was dropped to the lowest value (6.34 MPa). This can be explained by the process of CS starting to repel water into freshly poured concrete, which finally results in improper cement paste and fine aggregate bonding. Therefore, the applied pressures may not be distributed evenly, which could result in the development of cracks (Sofi, 2018).

Moreover, the compressive strength value for the 28-days specimen and the addition of CS to LWFC increased the compressive strength even more. Figure 4.2 demonstrates that compressive strength has a tendency to rise at its maximum and subsequently fall. For the 28-days specimen, the maximum compressive strength was also retained at specimens with 0.4 % of CS, contributing to 18.79 MPa. Meanwhile, the minimum compressive strength was maintained at specimens with 1.0 % of CS, providing about 10.4 MPa. The LWFC became denser as the C-S-H gel developed much more rigid as compared to specimens in 7-days. At later ages, the rigid C-S-H gel produced enhances the interfacial interactions between the aggregates and pastes (Karim, 2011).

Furthermore, the overall compressive strength value was slightly higher in the 56-days specimens compared to the 28-days specimens, as shown in Figure 4.2. The compressive strengths for the same proportion of CS added (CS 0.4 %) for 56-days and 28-days were 18.81 MPa and 18.79 MPa, respectively. In other words, the LWFC was considered a completely rigid structure after 28-days, while the presence of CS as a retarder decreased the compressive strength in the initial state.

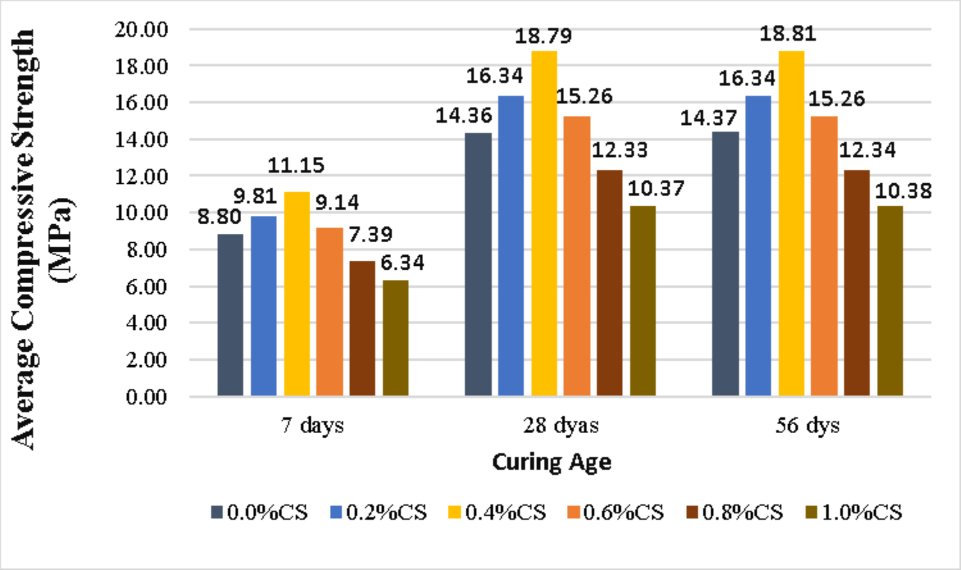


Figure 4.3: Average Compressive Strength in 7, 28 and 56 Days with Each Proportion of Calcium Stearate Added.

Besides, Figure 4.3 demonstrates the average compressive strength in 7, 28 and 56-days with each proportion of CS added. There is a similar trend for all curing ages with an upward and downward sloping bar chart, with 0.4 % of CS added representing the maximum compressive strength and 1.0 % representing the lowest. After a 7-days test, the compressive strength of specimens continued to increase. In comparison to the compressive strength of the previous 7-days, the overall compressive strength improved from 7-days to 28-days increasing in the range of 63 % to 69 %. In addition, the overall compressive strength at 56-days slightly increased by 0.00 to 0.03 MPa. Compared to 28-days compressive strength, the highest gain at 56-days was only a 3 % increase at 0.4 % CS addition.

4.4.3 Splitting Tensile Test

Other than the compressive strength, splitting tensile strength is also one of the most significant characteristics that might affect a concrete structure's performance and fracture size. As a result of being brittle, concrete can fail under tension and cannot withstand the load directly. Additionally, cracking would happen when the applied splitting tensile forces are greater than the concrete's tensile strength. In this research, 54 cylindrical concrete samples with dimensions of H = 200 mm and d = 100 mm were cast to perform STST. The cylindrical samples were also categorised into 6 groups with different percentages of CS added. For each set, three cylindrical samples were examined to allow for the calculation of the average splitting tensile strength. Figure 4.4 demonstrates the obtained average result of the STST in 7-days, 28-days and 56-days with different percentages of CS added into LWFC.

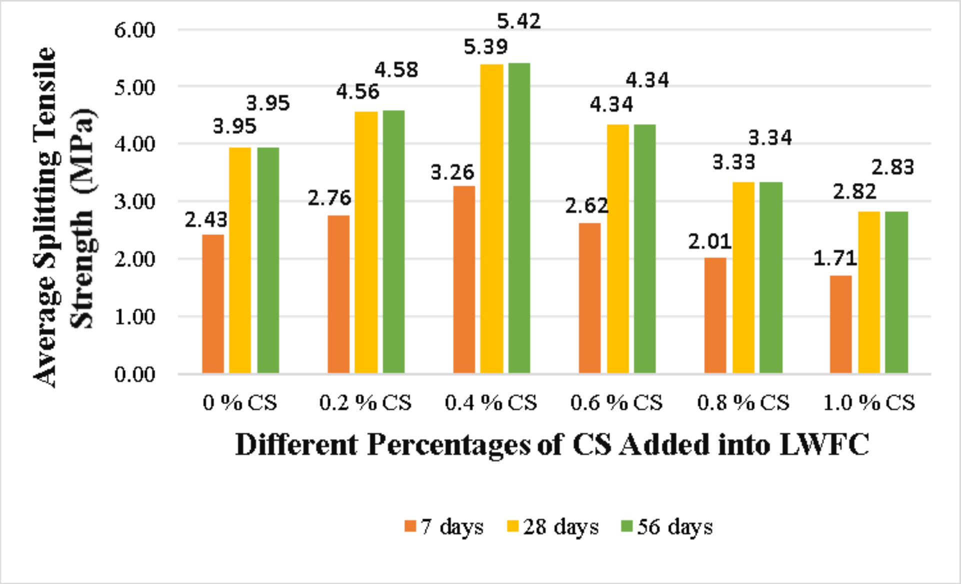


Figure 4.4: The Average Result of Splitting Tensile Strength Test in 7, 28 and 56 Days with Different Percentages of Calcium Stearate Added into Lightweight Foamed Concrete.

According to Figure 4.4, a positive skewed bell-shaped was shown in 7-days cylindrical specimens. At first, the specimens with CS 0.0 % have 2.43 MPa and it rises slowly to 2.76 MPa when 0.2 % of CS is added to the specimens. After that, the splitting tensile strength reaches its highest value when 0.4 % of CS is added to the cylindrical specimens and hits the maximum strength of 3.26 MPa and then the strength drops afterwards as the CS proportion increases.

It is possible for LWFC with numerous gaps to effectively absorb tensile stresses because of their irregular form and rough surface of fine aggregate, which increases the splitting tensile strength (Grinys, et al., 2012). This can be further explained when the CS powders are combined with cement paste, adhesion is improved compared to when regular aggregate is combined with the cement matrix, which is the cause of this rise in strength. Nonetheless, once the CS powders are added over their maximum amount, which is from 0.6 %

onward, a considerable reduction in splitting tensile strength will happen. Therefore, when 0.4 % of CS is added to the cylindrical specimens, the splitting tensile strength of LWFC reaches a maximum of 3.26 MPa and then drops to a minimum of 1.71 MPa at 1.0 % with a 52.45 % difference from the average splitting tensile test.

Moreover, LWFC with 0.4 % CS was observed to have the highest splitting tensile strength trend when compared to the other CS percentage differences. The splitting tensile strength peaked at 3.26 MPa during the first seven days of curing age and sharply climbed to 5.39 MPa during the following 28-days. However, there was a decline of approximately 47.7 % between the splitting tensile strength of 0.4 % CS and 1.0 % CS, which was the largest percentage difference. The splitting tensile strength is about 52.3 % of its compressive strength in 0.4 % of CS. After that, the splitting tensile strength slightly increased to 5.42 MPa after 56-days with 0.4 % of CS added to the LWFC. This resulted in the formation of a rigid C-S-H gel between cement and the fine aggregate when cement was fully hydrated by water.

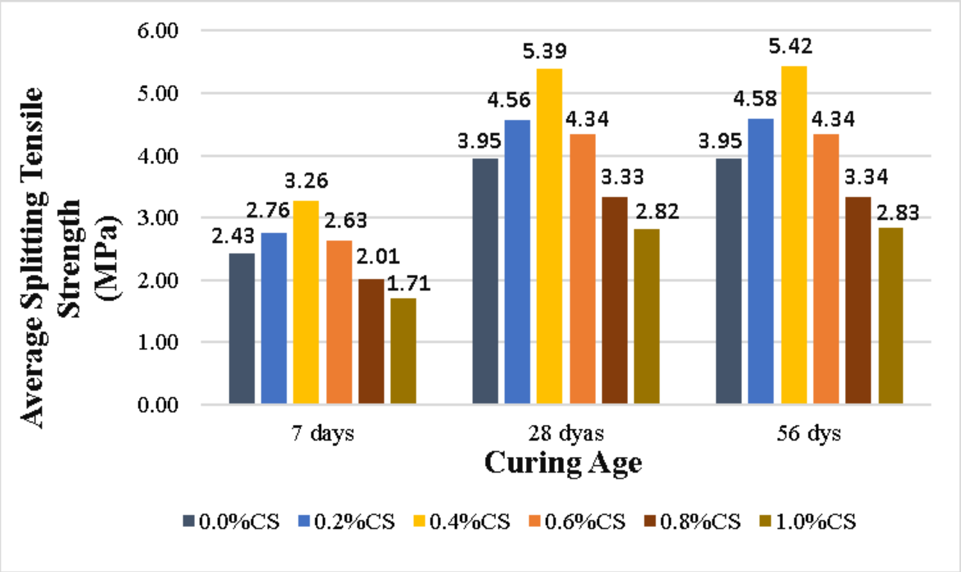


Figure 4.5: Average Splitting Tensile Strength in 7, 28 and 56 Days with Each Proportion of Calcium Stearate Added.

The splitting tensile test was carried upward in excess of the strength of seven days after twenty-eight days of splitting. Figure 4.5 shows the overall splitting tensile strength increased by 62 % to 66 % when the splitting tensile strength increased from 7-days to 28-days. The stronger C-S-H gel formed within the fine aggregate and cement is the reason for the splitting tensile strength increases. As a result, the testing device requires increased strength to break the concrete. The overall increasing trend for the 56-days STST was an increase of 0.00 to 0.03 MPa in the CS added between 0.0 % to 1.0 %. The highest average splitting tensile strength was 0.4 % of CS added with 5.42 MPa and the lowest was 1.0 % CS added with 3.95 MPa in 56-days STST.

4.4.4 Flexural Strength

The highest bending force that concrete can withstand before yielding is known as the flexural strength of concrete. A method known as the three-point flexural test was used to obtain the flexural strength value. A concrete prism will simultaneously provide compression at the top and tension at the bottom during a three-point load transmitted to the middle of the structure. When the prism is unable to withstand the tension pressures, the elongation action taken on by the bending will cause the prism to break. So, the bottom would experience cracks. For the FST in this study, 54 concrete prism samples with dimensions of 40mm x 40mm x 160mm were cast. The prism samples were also categorised into 6 groups with different percentages of CS added. For each set, three prism samples were examined to allow for the calculation of the average flexural strength. Figure 4.6 presents the result of flexural strength in 7, 28 and 56-days.

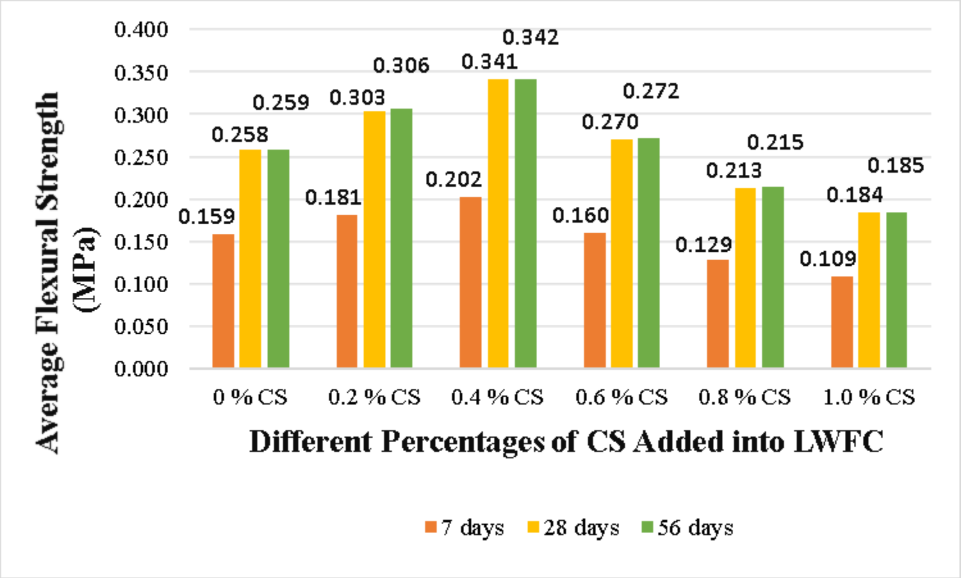


Figure 4.6: The Average Result of Flexural Strength Test in 7, 28 and 56 Days with Different Percentages of Calcium Stearate Added into Lightweight Foamed Concrete.

Figure 4.6 clearly illustrates the up-and-down curve in flexural strength as the percentage of CS rises. The maximum flexural strength was recorded at 0.202 MPa with 0.4 % CS in 7-days. After that, it starts to decline to 0.109 MPa for the prisms specimen with 1.0 % of CS in 7-days flexural strength. As 1.0 % of CS is introduced, flexural strength is significantly reduced by 53.96 % compared to the maximum flexural strength, LWFC.

Flexural strength development generally follows the same pattern as compressive and splitting tensile strengths. LWFC blended with CS exhibited higher flexural strength compared to the LWFC without CS. In the 28-days chart, flexural strength trends ranged from 0.258 MPa at 0.0 % CS to a maximum of 0.341 MPa at 0.4 % CS and drop to 0.184 MPa at 1.0 % CS. At 28-days, the flexural strength of 0.0 % CS was 24.34 % lower than that of 0.4 % CS. However, the flexural strength of 1.0 % CS was 46.04 % lower than that of 0.4 % CS at 28-days.

The flexural strength starts at 0.259 MPa with 0.0 % CS addition, increases to the highest value of 0.342 MPa with 0.4 % CS addition and then drops to 0.185 MPa with 1.0 % CS addition. This is related to the long-term negative effects of applying too much CS, which can cause internal concrete cracks and reduce ultimate flexural strength.

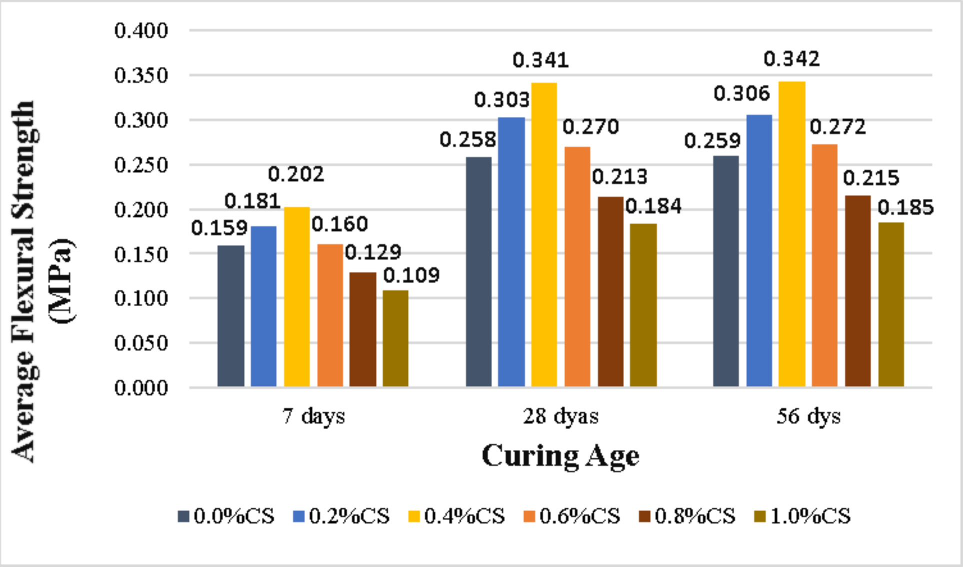


Figure 4.7: Average Flexural Strength in 7, 28 and 56 Days with Each Proportion of Calcium Stearate Added.

There are similar trends of compressive strength and splitting tensile strength. In Figure 4.7, the overall flexural strength increased from 7-days to 28-days by 62 % to 69 % compared to the flexural strength of the prior 7-days. The increase in flexural strength is due to the more complex C-S-H gel produced within the fine aggregate and cement. Therefore, the testing machine requires more strength to crack the concrete. Additionally, the overall flexural strength had only marginally risen from 0.000 to 0.003 MPa at 56-days. The highest gain at 56-days was just a 3 % rise at 0.2 % CS addition compared to 28-days compressive strength, while 0.6 % of CS has remained constant compared to 28-days flexural strength.

4.5 Summary

First of all, the mix proportions of the trial mix results indicated that 0.54 was the ideal W/C ratio to be used for the actual mix design. The result of the trial mix was determined after evaluating their entire stability, consistency and compressive strengths, this was concluded.

In the actual mix, all of the LWFC specimens were prepared within the desired density range of 1350 kg/m^3 to 1450 kg/m^3 with the calculated mix proportion. The study of the strength performance test was evaluated, recorded and analysed. It was concluded that the results of this study show that adding of CS into the LWFC has the potential to raise the strength performance. Overall, the study revealed a consistent pattern for strength performance on days 7, 28 and 56.

Furthermore, there are three different types of strength performance tests which are compressive, splitting tensile and flexural. According to the strength performance test results, additional of different quantities of CS to LWFC specimen can have an effect on the strength behaviour. In fact, the minimal CS addition produced the highest mechanical test result compared to the original LWFC. This is due to the fact that CS serves as a water reducting agent and has the ability to remove extra water from the concrete mixture. In turn, a higher CS addition will prevent the concrete from hydrating completely, resulting in less rigid C-S-H gel that eventually has a lower strength performance.

Moreover, the strength performance of LWFC reaches its maximum value when 0.4 % CS is added to the specimen. Also, as the amount of CS added is increased further, the strength performance decreases after 7, 28 and 56-days of water curing. The decrease in strength performance was caused due to the long-term negative effects of adding too much CS. The maximum compressive strength is 11.15 MPa for 7-days, 18.79 MPa for 28-days and 18.81 MPa for 56-days. 3.26 MPa for 7-days, 5.39 MPa for 28-days and 5.42 MPa for 56-days are the maximum splitting tensile strengths. For the last one the maximum splitting tensile strength obtained 0.202 MPa for 7-days, 0.341 MPa for 28-days and 0.342 MPa for 56-days.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The research outcomes, which relate to the corresponding objective that is stated in the introductory chapter of this study can be formed based on the laboratory data.

The first objective of this study is to develop and maintain a density of 1400 ± 50 kg/m^3 for all LWFC specimens during the trial mix and actual mix. The set of densities in each of the three strength performance tests for LWFC was completed throughout the trial and the mix.

The second objective of this study is to acquire the maximum water-cement ratio of foamed concrete with CS. According to the results, the LWFC with the 0.54 W/C ratio had the greatest compressive strength value, which reached 6.52 MPa. In relation to LWFC with an increasing W/C ratio, the compressive strength demonstrates a declining trend as a result of LWFC with a 0.54 W/C ratio providing the most effective C-S-H gel.

The third objective was to investigate the impact of CS on the mechanical characteristics of LWFC. In consequence, 0.4 % of CS has the most outstanding strength performance. First of all, the optimal compressive strength was obtained in the 28-days cube specimen which is 18.79 MPa. Meanwhile, the optimal splitting tensile test was recorded as 5.39 MPa in the 28-days cylinder specimen; 0.341 MPa was the optimal flexural strength in the 28-days prism specimen.

5.2 Recommendations of Future Work

There are limited studies on the research about LWFC integrated with CS in the field of civil construction, but it is an important topic with lots of potential for future research. For further advancements, it is necessary to take into account the ensuing factors connected to the integration of CS in LWFC:

1. The engineering properties of LWFC in terms of strength behaviour and physical strength were adjusted for LWFC mixes with various water repellent contents and curing circumstances.

2. Instead of focusing on mechanical properties, investigate how different concentrations of a different water-reducing chemical in LWFC affect other performance parameters such as sound insulation, thermal conductivity, impact and water absorption.
3. To better understand the negative impacts of CS overdose in LWFC, higher levels of CS must be incorporated into LWFC's engineering properties.
4. To conduct the microstructure analysis of LWFC with CS amount for a better understanding of its microstructure characterization.

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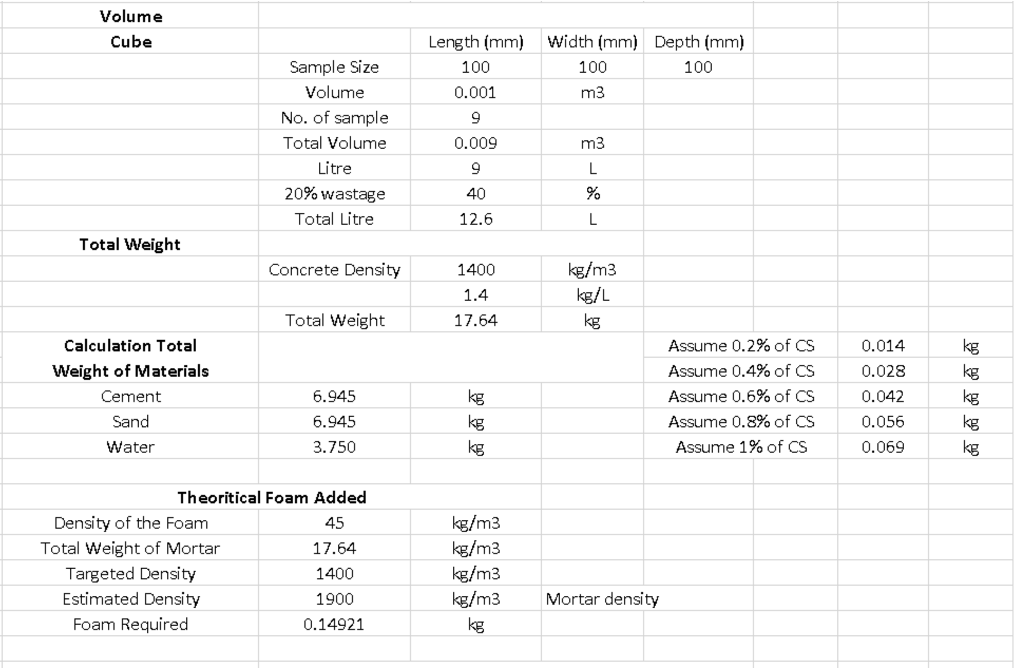
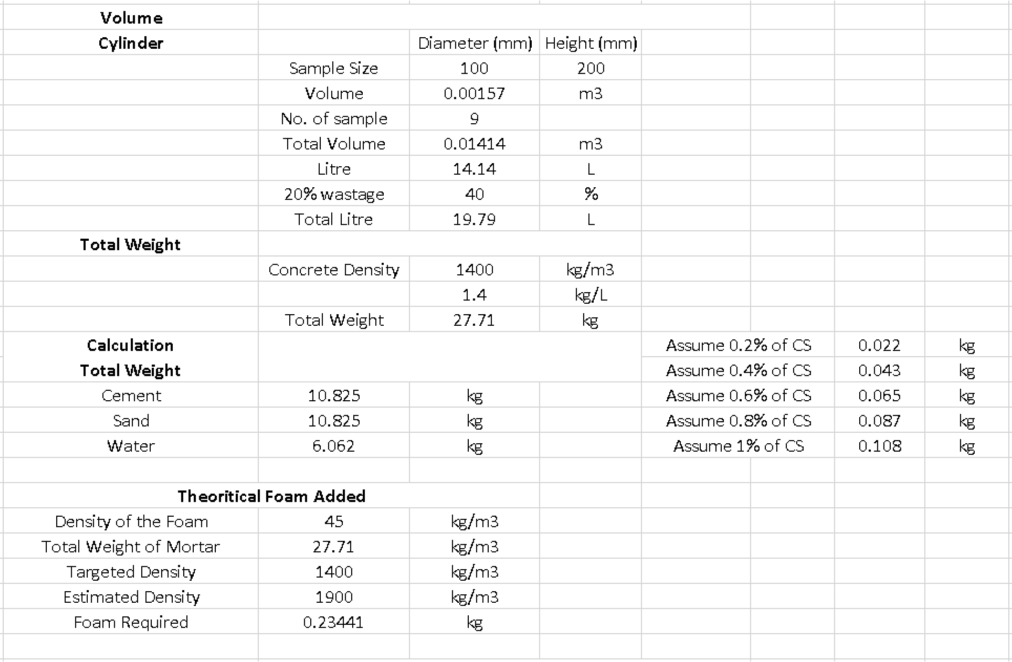
APPENDICES

Appendix A: Mix Proportion Calculation of Cube.



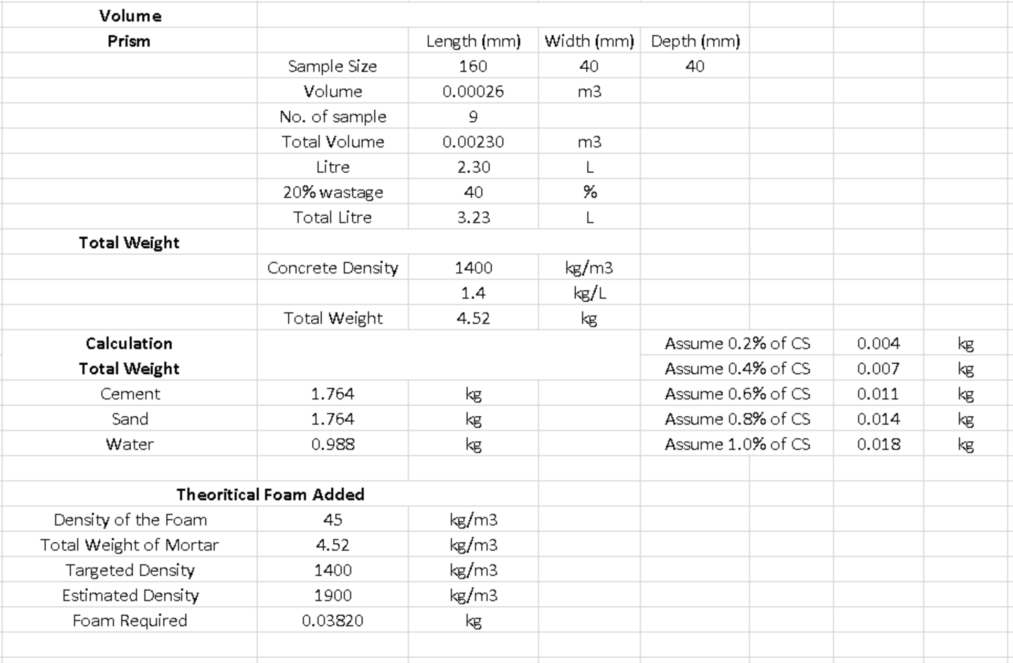
Volume							
Cube		Length (mm)	Width (mm)	Depth (mm)			
	Sample Size	100	100	100			
	Volume	0.001	m3				
	No. of sample	9					
	Total Volume	0.009	m3				
	Litre	9	L				
	20% wastage	40	%				
	Total Litre	12.6	L				
Total Weight							
	Concrete Density	1400	kg/m3				
		1.4	kg/L				
	Total Weight	17.64	kg				
Calculation Total				Assume 0.2% of CS		0.014	kg
Weight of Materials				Assume 0.4% of CS		0.028	kg
Cement	6.945	kg		Assume 0.6% of CS		0.042	kg
Sand	6.945	kg		Assume 0.8% of CS		0.056	kg
Water	3.750	kg		Assume 1% of CS		0.069	kg
Theoritical Foam Added							
Density of the Foam	45	kg/m3					
Total Weight of Mortar	17.64	kg/m3					
Targeted Density	1400	kg/m3					
Estimated Density	1900	kg/m3	Mortar density				
Foam Required	0.14921	kg					

Appendix B: Mix Proportion Calculation of Cylinder.



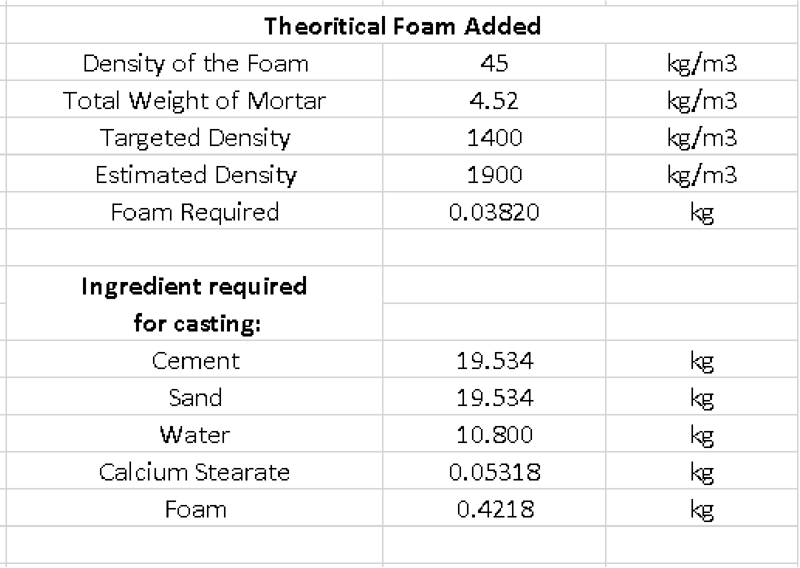
Volume							
Cylinder		Diameter (mm)	Height (mm)				
	Sample Size	100	200				
	Volume	0.00157	m3				
	No. of sample	9					
	Total Volume	0.01414	m3				
	Litre	14.14	L				
	20% wastage	40	%				
	Total Litre	19.79	L				
Total Weight							
	Concrete Density	1400	kg/m3				
		1.4	kg/L				
	Total Weight	27.71	kg				
Calculation				Assume 0.2% of CS		0.022	kg
Total Weight				Assume 0.4% of CS		0.043	kg
Cement	10.825	kg		Assume 0.6% of CS		0.065	kg
Sand	10.825	kg		Assume 0.8% of CS		0.087	kg
Water	6.062	kg		Assume 1% of CS		0.108	kg
Theoritical Foam Added							
Density of the Foam	45	kg/m3					
Total Weight of Mortar	27.71	kg/m3					
Targeted Density	1400	kg/m3					
Estimated Density	1900	kg/m3					
Foam Required	0.23441	kg					

Appendix C: Mix Proportion Calculation of Prism.



Volume							
Prism		Length (mm)	Width (mm)	Depth (mm)			
	Sample Size	160	40	40			
	Volume	0.00026	m3				
	No. of sample	9					
	Total Volume	0.00230	m3				
	Litre	2.30	L				
	20% wastage	40	%				
	Total Litre	3.23	L				
Total Weight							
	Concrete Density	1400	kg/m3				
		1.4	kg/L				
	Total Weight	4.52	kg				
Calculation				Assume 0.2% of CS		0.004	kg
Total Weight				Assume 0.4% of CS		0.007	kg
Cement	1.764	kg		Assume 0.6% of CS		0.011	kg
Sand	1.764	kg		Assume 0.8% of CS		0.014	kg
Water	0.988	kg		Assume 1.0% of CS		0.018	kg
Theoritical Foam Added							
Density of the Foam	45	kg/m3					
Total Weight of Mortar	4.52	kg/m3					
Targeted Density	1400	kg/m3					
Estimated Density	1900	kg/m3					
Foam Required	0.03820	kg					

Appendix D: Summary of the Calculation of Materials.



Theoritical Foam Added		
Density of the Foam	45	kg/m3
Total Weight of Mortar	4.52	kg/m3
Targeted Density	1400	kg/m3
Estimated Density	1900	kg/m3
Foam Required	0.03820	kg
Ingredient required for casting:		
Cement	19.534	kg
Sand	19.534	kg
Water	10.800	kg
Calcium Stearate	0.05318	kg
Foam	0.4218	kg