A STUDY OF THERMAL AND ACOUSTIC PERFORMANCES OF CRUMB RUBBER LIGHTWEIGHT FOAMED CONCRETE WITH DENSITY OF 1050 KG/M^3 - 1150 KG/M^3

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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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April 2020

DECLARATION

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

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"A STUDY OF THERMAL AND ACOUSTIC PERFORMANCE OF CRUMB RUBBER LIGHTWEIGHT FOAMED CONCRETE WITH DENSITY OF 1050 - 1150 KG/M^3"** was prepared by **CHANG JUN MING** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

In this new century, green technology design was started to lead the world towards a better future. Majority of the green technology researches are mainly focusing on the construction field as well. Due to the accumulation of the massive amount of waste rubber tyres at various landfills over the past few decades, waste tyres are recycled and converted to crumb rubber (CR) which can be used as the concrete additives. Thus, this study aims to produce crumb rubber lightweight foamed concrete (CRLWC) with a fresh concrete density ranging from 1050 kg/m^3 to 1150 kg/m3. The objective of this study is to determine the optimal mix proportion of granular and powdered CRLWC that exhibit the most favourable thermal and sound insulating properties. There are two experiments, namely thermal conductivity test and acoustic performance test were conducted in this study. For thermal conductivity test, one specimen of each mix proportion was tested. For acoustic performance test, a total of two specimens were used to test for the sound absorption coefficient of the CRLWC in the frequency range from 100 Hz to 5000 Hz. The result showed that the addition of powdered crumb rubber in LWC provides the lowest thermal conductivity with a value of 0.2288 W·K^{-1}·m^{-1} as compared with the control sample (0.3490 W·K^{-1}·m^{-1}). Also, the control sample has a better acoustic performance than concrete with the inclusion of CR due to higher void content in the control sample. The absorption coefficient was reduced by 40 % to 60 % in a frequency ranging from 100 Hz to 630 Hz. In conclusion, the participation of CR in LWC can improve the thermal conductivity, but for acoustic performance, the addition of crumb rubber in LWC will be lower the absorption coefficient of LWC.

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LIST OF SYMBOLS / ABBREVIATIONS

A	area, m^2
b	width of specimen, mm
d	diameter of specimen, mm
f	compression strength, MPa
l	length of specimen, mm
P	maximum load carried by specimen, N
R	flexural strength, MPa
T	splitting tensile strength, MPa

ASTM	American Society for Testing and Materials
C-S-H	calcium silicate hydrate
W/C	water to cement ratio
LWC	lightweight foamed concrete
CRLWC	crumb rubber lightweight foamed concrete
OPC	ordinary portland cement

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Concrete is the main component in the construction of building structures that made up from cement, aggregates and water. In building construction, concrete is used in the construction of beams, columns, slabs, foundations, retaining wall and other load-bearing elements. Concrete is a suitable material in the construction field because it has a remarkable mechanical compressive strength, excellent durability, good fire resistance and longer design life. Generally, concrete is composed of cement, fine aggregates, coarse aggregates and water. Concrete is able to be further improved by adding additives such as air-entraining agents and superplasticizer into the mixing proportion. Additives are added to overcome some problems or to meet the desired properties of the concrete.

Lightweight Concrete is concrete that has added foam agents or replacing lightweight aggregates into the plain concrete. There is a total of three types of lightweight concrete which are Lightweight Aggregate Concrete (LWAC), No-Fine Concrete (NFC) and Aerated Concrete. Lightweight concrete has a low density compared to the plain concrete. Due to its low density, the strength of lightweight concrete is much lower. Thus, lightweight concrete is not encouraged to be used in heavy construction or load-bearing applications. Improving the concrete grade and incorporation of additives in the concrete are the common ways to enhance the strength properties of the foamed concrete.

A large amount of waste rubber tyres have been accumulated in various landfills over the past few decades. Thus, as an environmentally friendly and sustainable management of these waste rubber tyres, they are recycled and converted to crumb rubber which can be used as the concrete additives. The inclusion of crumb rubber can enhance the properties of the concrete. This is an innovative idea for the future since it is environmentally friendly and economical. On top of that, lightweight foam concrete that contains crumb rubber is mainly applied in the fabrication of precast partition wall because it has superb thermal and acoustic insulating properties.

1.2 Problem Statement

According to the journal of Camille (2013), the amount of waste tyres that are accumulated in the world each year is over 400 million in the United States and the European Union. In order to get rid of the waste tyres, the inexpensive and easiest way to decompose the waste tyre is open burning. However, burning of the tyres will release harmful and poisonous gases which will pollute the air condition. Thus, burning used tyre is prohibited in some countries such as Malaysia. Other than burning, there is another most popular method which is to pile those waste tyres in landfill or placed in a dump (basically piled in a large hole in the ground). Nevertheless, these dumps may lead to great breeding of mosquitoes and it will become a dangerous health hazard. Moreover, the waste tyre can also be utilised as fuel, pigment soot in bitumen paste and more. Furthermore, the tyre processing factory is believed to be the source of toxic pollutants found in Sungai Kim Kim (Rizalman, 2019). A total of sixteen schools have been instructed to close for a few days following back-to-back incidences of pupils falling ill due to the suspected air pollution (Amanina Suhaini, 2019).

In recent year, people are seeking for an environmentally friendly product that can be used in the construction field. Besides, Malaysia is a tropical country and the weather can reach up to 35 ^{o}C during the afternoon. In order to achieve customer desire which is quiet and chill place to stay, a structure in building that able to encounter Malaysia hot weather and able to absorb noise is highly preferable. Hence, concrete with the inclusion of crumb rubber is strongly recommended to reduce waste in the environment and solve Malaysian's problem.

1.3 Aim and Objectives

The aim of this study is to produce crumb rubber lightweight foamed concrete (CRLWC) with a fresh concrete density ranging from 1050 kg/m^3 to 1150 kg/m^3. The objectives are:

1. To study the effect of crumb rubber replacement proportion of 0 % to 80 % with an interval of 10 % on the thermal conductivity of crumb rubber lightweight foamed concrete.

2. To verify the influence of crumb rubber replacement proportion of 0 % to 80 % with an interval of 10 % on the sound absorption coefficient of crumb rubber lightweight foamed concrete from 100 Hz to 5000 Hz.
3. To determine the optimal mix proportion of both granular and powdered crumb rubber lightweight foamed concretes that depict the most favourable thermal and sound insulating properties.

1.4 Scope of the Study

The purpose of this study is to analyse the engineering properties of the CRLFC in term of thermal conductivity and acoustic performances. In these tests, there are a total of seventeen sets of specimens to be tested. These seventeen specimens were categorized into 9 main mixing proportion which are 0 %, 10 %, 20 %, 30 %, 40 %, 50 %, 60 %, 70 % and 80 % replacement of crumb rubber as fine aggregates. Among these nine mixing proportion, there are another two types of crumb rubber which are granular and powdered crumb rubber. The water to cement ratio throughout this study is 0.6. The density of the mix concrete will be fall between 1050 kg/m^3 to 1150 kg/m^3. Foam added in concrete by preforming method is used to reduce the density of concrete towards desired density. As the scope of this project is only cover on crumb rubber lightweight foamed concrete.

For thermal conductivity test, thermal conductivity machine used to test the thermal insulation properties of concrete specimen. The sizing of specimen for thermal conductivity machine is 300 mm x 300 mm x 50 mm panel. According to the standard for impedance tube sound absorption testing, the sizing of specimen specified into 30 mm and 60 mm diameter with 20 mm height. In thermal conductivity and acoustic performance assessment test, the panel and cylindrical specimens were moist-cured for 28 days at certain temperature and humidity. The specimens were oven-dried at 85 ^{o}C temperature for 24 hours. There is one specimen per mix proportion for thermal conductivity test and two specimens per mix proportion for acoustic performance test to get an average result.

1.5 Significant of Study

Throughout the years, waste tyres have been considered as one of the major impacts on the environment. In order to overcome this global environmental issue, this study is focusing on how to reuse the waste material into something useful. This application of waste tyres in construction can also be related in Green Building Index standard. In this study will promote the use of crumb rubber to replace the fine aggregates in lightweight foamed concrete at definite proportions. By employing crumb rubber as the fine aggregate in the lightweight foamed concrete, will bring out some benefits such as improve better thermal insulation, sound insulation and so on. Furthermore, this environmental friendly concrete can be adopted in the construction of precast wall panel segments instead of a conventional brick wall. The purpose of this study is to ascertain the thermal conductivity and acoustic performance of crumb rubber lightweight foamed concrete and its eligibility for various civil applications.

Other than that, the addition of crumb rubber in lightweight foamed concrete able to reduce the construction time in constructing wall instead of using brick. As compare with brick wall, the construction process for rubberised lightweight foamed concrete is in casting way which taking less construction time. The rubberized foamed concrete also able to reduce the loading that acting on the supporting member and provides an economical design structure.

1.6 Layout of Report

In this project, there are fivechapters consist in this report:

Chapter 1 discuss the introduction of the study of the project, statement of the problem that has been facing before we start this project, objectives, scopes of this project, study’s significance and report layout.

Chapter 2 is a literature review for this whole project. This chapter will discuss into more detail about the properties and application of lightweight concrete, crumb rubber and both. All of the information was based on the study, articles and research paper of professionals.

Chapter 3 discuss the methodology used in this project study. This includes the procedures and way of getting the mix proportion, the preparation of resources, mixing process and test methods involved.

Chapter 4 discuss the results tested of different mixture specimens of the lightweight foamed concrete (LWC). Next, to decide the optimum rubber particle ratio for the mix proportion. Throughout the chapter, the thermal conductivity test and acoustic insulation test of mixing concrete specimens were discussed based on the results acquired from the experiment testing.

Chapter 5 will conclude the whole experiment project with the results obtained in the laboratory experiment. The conclusion is made based on the objective to be accomplished. On top of that, this chapter will be discussed several recommendations for future study of this experiment.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

There were several types of concrete and each of them has their own properties and applications. First, Normal Strength Concrete is the most commonly used in and its basic ingredients are mixing with cement, aggregate and water, which will give normal strength around 10 MPa to 40 MPa. The initial setting time is in the range of 30 minutes to 90 minutes (depends on the cement properties and weather condition). Plain Concrete is the main constituents of this type of concrete are similar to Normal Strength Concrete (cement, aggregate, water) and its used mix design is 1:2:4. This type of concrete was used in the construction of the building and also pavement. It is not advisable to use in an area where there is a high demand for tensile strength. Next, High-Density Concrete (a.k.a Heavyweight Concrete), the density of this concrete is much higher than normal-weight concrete due to existent of heavyweight aggregates (Barytes). The density of this type of concrete is around 3000 kg/m^3 – 4000 kg/m^3. This type of concrete usually constructed in the construction of atomic or radiation power plants because the heavyweight concrete is able to make the structure to resist radiations. Then, High-Strength Concrete has a strength higher than 40 MPa. To achieve desire high strength, the water-cement ratio has to set lower than 0.35. Hence, it will affect the workability to reduce. Calcium hydroxide crystal that was used during hydration for forming the strength properties is reduced by the incorporation of silica fume. High-Performance Concrete is known as a high strength concrete. However, not all high-performance concretes are high strength concrete. There are several standards that conform to the high-performance concrete which are gaining strength in the primary stage, settlement of the concrete is easy, permeability and density factors, durable concrete, environmental concerns, toughness and life term mechanical properties and heat of hydration.

2.2 Literature Review

Lightweight Concrete was first founded by the Romans in 2nd century. The density of lightweight concrete is from 300 kg/m^3 – 1840 kg/m^3 (Newman and Choo, 2003). It is actually lighter than the normal weight or plain concrete. Pumice which is the most common type of aggregate, has been used to construct "The Pantheon". In the following time, use of lightweight concrete has been widely spread throughout the world. (Kamsiah, 2004).

Lightweight concrete can be categories into three groups which are No-Fines Concrete (NFC), Lightweight Aggregate Concrete (LWAC) and Aerated Concrete. In Figure 2.1 below shows, the microstructures among the lightweight concrete. These three groups of concretes have different materials and their own purpose. In the following topic will further define those types of concrete.

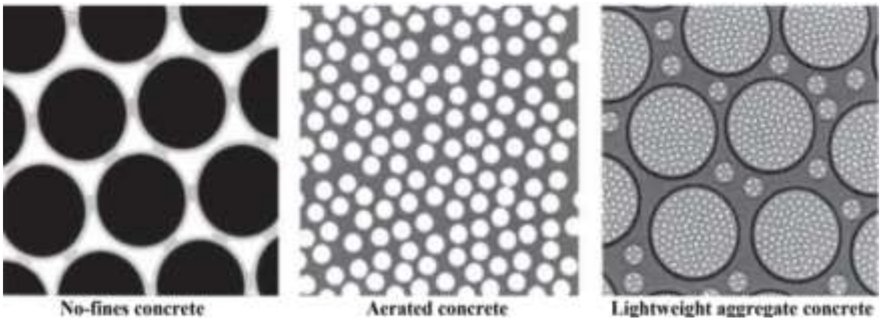

Figure 2.1: Basic Microstructure of Lightweight Concrete (Newman and Choo, 2003).

2.2.1 No-Fines Concrete (NFC)

The concrete mix of NFC is without the presence of fine aggregates, and it only consists of course aggregates, cement and water. To produce this type of concrete, the size of course aggregate shall be passing through the sieve size of 20 mm and retained on 10 mm size. Thus, water can actually sip through the No-Fine Concrete due to its large void. No-Fines concrete was used in the construction of external loading bearing load and small retaining wall. Other than that, it also can be used as a damp proof material. (Suryakanta, 2016)

No-Fines Concrete has a low drying shrinkage compare to plain or normal weight concrete. Besides, the movement of water is negligible due to its capillary. Amount of cement used in the concrete mix is low does not contain fine aggregates or sand (large surface area).

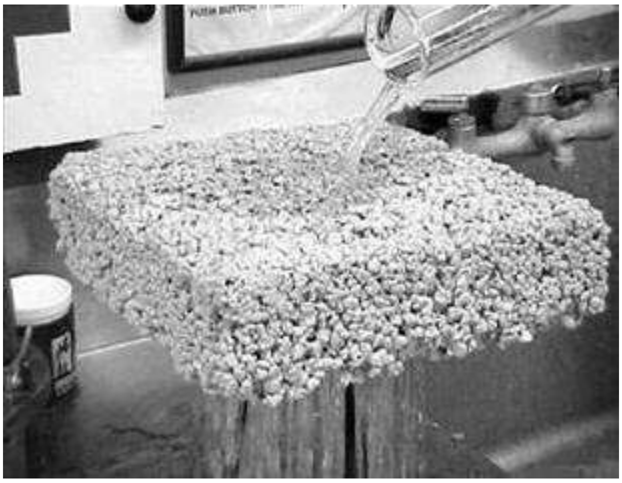

Figure 2.2: No-Fines Concrete (Saadiqbal, 2016).

2.2.2 Lightweight Aggregate Concrete

Lightweight aggregates concrete contains lightweight aggregates, cement and water. Recently, lightweight aggregates were produced in a very wide range of density from 50 kg/m^3 perlite to 1000 kg/m^3 for clinkers. With these aggregates, lightweight aggregates concrete will able to sustain a compressive strength of 80 MPa with a size of 15 cm cube. Figure 2.4 shows the graph of compressive strength compared with other lightweight concretes. The strength is highest among the other lightweight concrete is because the bond between the aggregates and matrix is much stronger than in normal-weight concrete. This reason why because cement pastes were able to sip through the aggregates due to their porous properties. (Satish and Leif, 2002).

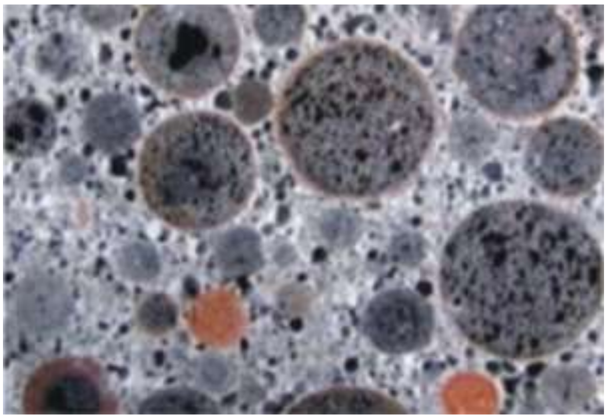

Figure 2.3: Cut Section of Lightweight Aggregate Concrete (Pelcon, 2016).

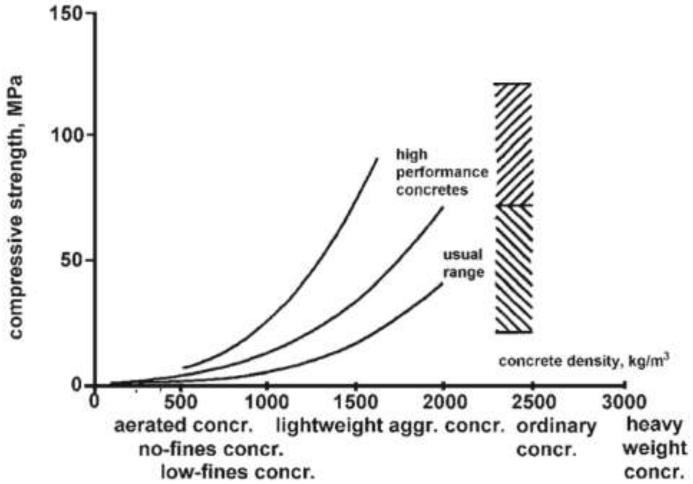

Figure 2.4: Graph of Compressive Strength against Concrete Density (Satish and Leif, 2002).

2.2.3 Lightweight Foamed Concrete (LWC)

Aerated Concrete, including Autoclaved Aerated Concrete (AAC) and Lightweight Foamed Concrete (LWC). The difference between AAC and LWC is one is adding expansion agent into the concrete mix and another one is adding a stable foam agent. The foaming agent was defined as an air-entraining admixture. By adding foam into the concrete mix, it will affect the density of the fresh concrete to decrease and make the concrete more workable. Besides, the foamed bubbles are the main substance to make cellular structure in concrete (Zulkarnian and Ramli, 2011). The density of LWC can be varied from range 400 kg/m^3 to 1600 kg/m^3 and for compressive strength from 1 MPa to 15 MPa (British Concrete Association, 1994).

LWC can be defined as Cellular Concrete with random air-void which formed from mixed foam agents in mortar. LWC has been recognised as concrete that has low viscosity, low cement and aggregate usage, and great thermal insulation. Foam concrete was also being considered as a cost-effective in production of large-scale, lightweight construction materials and components (Mugahed Amran, 2015). Foam concrete can be acquired for application of structural members, partitions, insulations and roofing. A lot of features such as the selection of foaming agents and materials, proportion of materials, mixture design tactics and also the performance of fresh and hardened concrete were depended by the production of Lightweight Foamed Concrete (Ramamurthy, 2009).

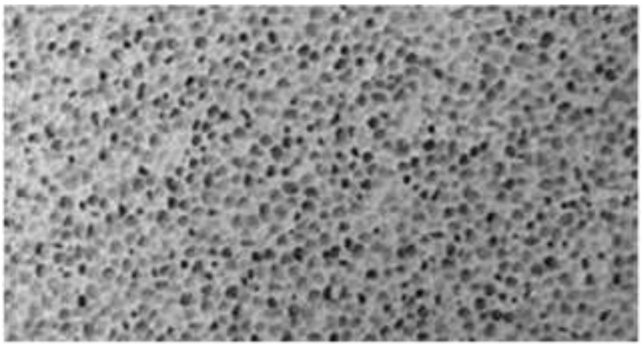

Figure 2.5: Cellular Structure in Lightweight Foamed Concrete (Arjun, 2016).

2.2.3.1 Advantages of Lightweight Foamed Concrete

LWC (a.k.a Cellular Lightweight Concrete [CLC]) has a lighter weight and thus it has a positive impact on the weight management of building materials and craning work. So, it can be reduced the bearing load acting on the building structure as the dead load was already reduced. On the other hand, for normal concrete that already sets into a form is very dense and makes it more difficult to work. Lightweight concrete has a higher fire resistance due to the air voids in its structure are liable to fire breakout. Besides, the lightweight concrete wall is non-combustible and can endure fire breakout for a few hours due to its irrespective of density range. CLC is a good thermal insulator and acoustical insulator due to high porous structure. Thus, the building is able to maintain in lower temperature than outdoor temperature (especially in hot weather country) since LWC able to prevent the hot temperature from penetrating through the wall into the indoor of the building. Even though at this low density has no structural reliability in term of strength, but CLC is substantially diminished cost of construction and is also termite proof and have higher freeze-thaw resistant too (Shaik, 2016).

2.2.4 Functional Properties of Lightweight Foam Concrete

Throughout this sub-topic will further explain the functional properties of lightweight foamed concrete. Functional properties are an actual behaviour of foam concrete towards acoustic and thermal insulation and fire resistance.

2.2.4.1 Acoustic Insulation Resistance

Lightweight Foamed Concrete (LWC) does not have any significant sound insulation characteristic. As comparing with high dense concrete, LWC is less effective in blocking the transmission of sound. This is because the transmission loss of the sound depends on the mass law (Ramamurthy, 2009). The frequency of sound reflection hypothetically depends on the bulk density and thickness of the wall as according to the theory of solid wall sound resistance. Thus, the higher the density of the wall, the more sound would be reflected. LWC able to absorb sound instead of reflecting it. Foam concrete or cellular wall capable of transmitting the frequency of sound up to value of 3 % higher than normal-weight concrete wall due to its cellular microstructure properties. The inclusion of foam amount, content, size and distribution of pores and also its uniformity can influence the acoustic insulation of foam concrete (Mugahed Amran, 2015).

2.2.4.2 Thermal Conductivity

Lightweight Foamed Concrete (LWC) has an excellent thermal insulating property due to its cellular microstructure. Foam concrete and normal weight concrete has a thermal conductivity up to value of 0.66 W/mK and 1.6 W/mK at a density of 1600 kg/m^3 and 2200 kg/m^3. It is shown that the thermal conductivity of foam concrete is lower than plain concrete by 59 %. The thermal conductivity insulation reacts inversely proportional to density volume. According to the study, the degree of thermal insulation of foam concrete was also depended on mixture composition such as the mineral admixture and the aggregate types (Mugahed Amran, 2015). Alternating foam ratio will cause changes in density and has a huge influence on insulation capacity (Ramamurthy, 2009).

2.2.4.3 Fire Resistance

The heat was able to transfer through the porous materials by radiations while in the high temperature. Since the foam concrete has low thermal conductivity, it may result in well fire resistance compared to plain concrete (Ramamurthy, 2009). As the density is lower, it able to withstand fire longer time. Concrete with a density of 950 kg/m^3 can withstand fire for 3.5 hours whereas density with 1200 kg/m^3 can withstand fire with only 2 hours. Other than density, the cement composition will also affect the behaviour of foam concrete at the high temperature too.

2.3 Crumb Rubber Lightweight Foamed Concrete (CRLWC)

The LWC with the additive of crumb rubber is called as Crumb Rubber Lightweight Foamed Concrete. The mixing content of Crumb Rubber with Lightweight Foam concrete is almost similar to foam concrete but have extra was material which is crumb rubber. The density of crumb rubber lightweight foam concrete in this research is from the range of 1050 kg/m^3 to 1150 kg/m^3. With this range of density, it cannot be fulfilling the structural material standard. However, the properties of crumb rubber lightweight foamed concrete such as thermal and acoustic insulation has been determined and that insulation may be applicable and useful to those non-structural elements such as the wall of the library, cinema and more.

The participate of crumb rubber foam concrete may affect the properties such as enhanced the strength of concrete and reducing the fire resistance of concrete. A certain amount of crumb rubber can reduce the degradation rate of compressive strength after concrete exposed in high temperature, but excessive of crumb rubber will decrease the concrete strength significantly on unheated concrete (Guo et al., 2014).

2.4 Classification of Rubber

There are many types of rubber that can be applied into construction materials or element. In this project, crumb rubber is one of those rubber that will be introduced into this topic. The various types of rubber can be classified as mechanical grinding, shredded rubber tires, crumb rubber, and ground rubber tire respectively.

2.4.1 Mechanical Grinding

Mechanical grinding of rubber will produce tyre chips called as edger chips. Edger Chips usually used to replace coarse aggregate. Edges chips after manufactured will be then completely rinsed until removed the foreign substance such as soil, and organic material by using a high-speed nozzle. This is because the foreign substance of waste tyres such as soil and organic material will lower down the strength of the concrete (Eldin and Senouci, 1994). The size of the edger chip will be at range 0.75 mm to 1.5 mm due to the mechanical grinding limitation.

The rubberized concrete provides adequate workability because rubber was impermeable substance. Therefore, as the rubber aggregate size increase will cause the workability of the concrete mix to be very hard to work. Besides, the compressive and tensile strength of edger chips concrete is lower than the crumb rubber concrete. Figure 2.6 shows the compressive and tensile strength of edger chips concrete and crumb rubber concrete, respectively. Group code 1 represents the aggregate replaced by edger chips, and group code 2 represents the aggregate replaced by crumb rubber (Eldin and Senouci, 1994).

Group code (1)	Percent of rubber aggregate (2)	Percent volume of rubber in concrete mass (3)	Compressive strength (4)	Tensile strength (5)
1	25	10.25	19.2	2.2
1	50	20.50	11.6	1.5
1	75	30.75	8.2	1.2
1	100	41.00	6.0	0.8
2	25	5.75	23.4	2.8
2	50	11.50	19.2	2.4
2	75	17.25	14.7	2.0
2	100	23.00	12.4	1.7

Figure 2.6: Table of Compressive and Tensile Strengths of Concrete Specimens (Eldin and Senouci, 1994).

2.4.2 Ground Rubber

The size of the ground rubber is smaller compare with mechanical grinding as the size range from 0.475 mm to 0.075 mm. The workability will reduce during the concrete mix with the ground rubber because the friction between the particle of rubbers and cementitious are affecting the workability of concrete. Therefore, super-plasticizer will be added into the mixture in order to control the workability of concrete (Thomas, 2016).

The flexural strength of rubberized concrete will decrease up to 37 % by adding the ground rubber tire. This is because the strength of concrete depends on the density of concrete. The density of the concrete will reduce by adding the ground rubber tire. The ground rubber tyre can lower the density of concrete so can produce the lightweight concrete for some special purpose (Thomas and Gupta, 2016).

2.4.3 Shredded Rubber Tyres

Shredded rubber tires have the less than 1 mm size and contain approximately 20 % of polypropylene fibre. The density of shredded rubber tires is around 430 kg/m^3 (Benazzouk et al., 2006). The size of distribution and the grade of the rubber aggregated are all base on the ASTM C33 (Eldin and Senouci, 1994). The shredded rubber tires mixing with the concrete will also affect the workability too. Hence, more water will be needed for the concrete mix to increase the workability and it might be affecting the strength of concrete (Toutanji, 1996).

2.4.4 Crumb Rubber (CR)

CR is a product made by re-processing or grinding disposed of waste tyres. During the process of shredding, steel debris found in the steel-belted tyres will be removed and makes CR. There are few mechanical methods to scrap apart the tyres into CR which are through the cracker mill, micro mill and granulator method. CR is a fine rubber particle with a range from 0.075 mm to 4.75 mm. During the concrete mix, CR would replace some portion of the aggregates in the concrete mix (Camille, 2012).

2.5 Application of Crumb Rubber

In the last 20 years, civil construction decided to use crumb rubber as part of the construction materials to reduce pollution toward the environment. From that time onwards, waste tyres will ground into small particles to use in asphalt pavement, tuber sheets or raw material of concrete mixtures (Sukontasukkul, 2009).

One of the crumb rubber application is used in asphalt pavement. Crumb rubber is first applied as asphalt pavement since 1960. Technology nowadays can modify the properties of crumb rubber in asphalt to meet the application-specific requirements. One of the specific requirements according to Strategic Highway Research Program (SHRP) is the viscosity in 135 ºC should less than 3 Pas so that pump-ability and constructability of the binder were better based on the lower viscosity. Hence, the crumb rubber used in the asphalt pavement was modified base on the requirement (Bahia and Davies, 1991).

Figure 2.7: Rubberized Asphalt Pavement (ADOT, 2017).

Next application of crumb rubber is to modify the concrete properties by adding it into the concrete mix. In this project, crumb rubber is going to add into the foam concrete mix to form a crumb rubber lightweight foamed concrete. The future application is to produce a wall panel using crumb rubber lightweight foamed concrete.

2.6 Acoustic Properties of Rubberized Concrete

The absorption of the coefficient was also known as the level of sound absorption where a hyperdense material can deflect mostly all of the sound away and gives the value of zero absorption coefficient. A concrete containing crumb rubber (CR) able to give value from range 0.3 to 0.7 which categories as a good absorber of sound. Besides, CR that added into concrete mix will produce a lighter, flexible and more durable concrete. CR is a material that replaced 20% of fine aggregates. The level of absorption coefficient increases when concretes were added or mixed with larger volume and larger size of crumb rubber (Nial, 2014).

Table 2.1: Table of Common Construction Materials' Average Absorption Coefficients (Nial, 2014).

Material	Sound absorption co-efficient
Concrete	0.02–0.06
Unpainted blockwork	0.02–0.05
Hardwood	0.3

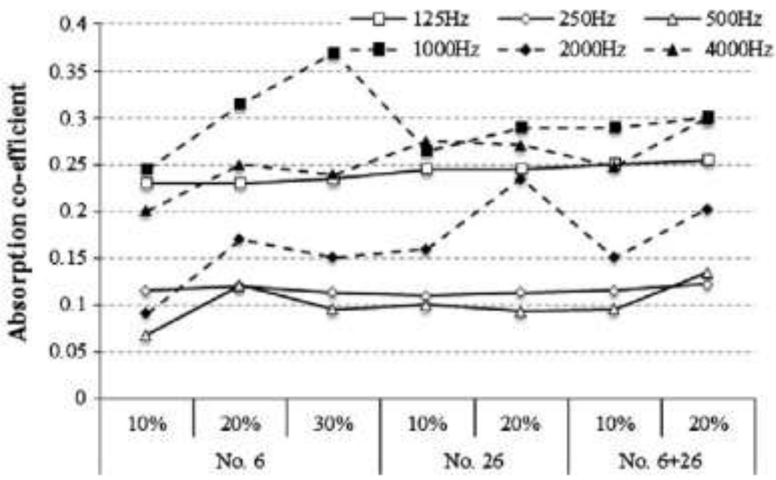

Figure 2.8: Absorption Coefficient with Crumb Rubber size and Replacement (Nial, 2014).

2.7 Thermal Properties of Rubberized Concrete

An ability for a material to conduct heat is called thermal conductivity (k). A great heat conductor will give a high value of k whereas a good heat insulator will give low values of k. There are several features that can affect the thermal conductivity of a certain material which are moisture content, density and temperature. According to the study, the value of k is directly proportional to the density of the material. Thus, while replacing CR as aggregates in concrete, the density of concrete will decrease and cause the thermal conductivity level of concrete to decrease.

Concrete type	*k* (W/m K)
PC	0.531
6CR10	0.443
6CR20	0.295
6CR30	0.241
26CR10	0.290
26CR20	0.275
26CR30	0.267
626CR10	0.313
626CR20	0.304
626CR30	0.296

Figure 2.9: Table of Average Conductivity of Crumb Rubber Concrete.
(Sukontasukkul. 2009)

2.7.1 Ordinary Portland Cement (OPC)

Most of the cement still using in the construction market was OPC. It can use in any condition as long as there is no sulphates exposure occur. This cement was classified as Type 1 OPC according to reference ASTM C150 standard.

Table 2.2: Compound Composition in OPC (Nevile, 2010).

Component	Content, %
C_3S	42 – 67
C_2S	8 – 31
C_3A	5 – 14
C_4AF	6 - 12

2.7.2 Aggregate

Aggregates are produced from gravel and sand. Aggregate is also known as one of the most important civil construction material. For the mixing of concrete, there are two types of aggregates which are fine aggregate and coarse aggregate for casting concrete. The size of the aggregates may affect the properties of a concrete. Particles size of fine aggregates should be less than 4.75 mm. From ASTM C33 mentioned that the fine modulus for fine aggregate has to be maintained in the range between 2.3 to 3.1.

2.7.3 Foam

The foaming agent can be split into two main groups which are natural foaming agents and synthetic foaming agents. , The natural foaming agent, is ordinarily used in industry and are a tannic extract from the leather industry. While synthetic foaming agents are produced according to technical requirement and will have a longer working life. To determine the production of foam agent, it is necessary to depend on the production capacity, regional condition and also the concrete mix production method (MD Jalal, 2017).

The main requirement of foam is capable of remaining stable and not collapsing for the period of placement, pumping and curing. According to the journal, it stated that the density of the foam is around 110 kg/m^3 (MD Jalal, 2017). Thus, during the concrete mix with foam was added along, the density will be decrease depends on how much volume that has been added into the concrete mix.

2.8 Summary

They are three types of lightweight concrete which are No-Fine Concrete (NFC), Lightweight Aggregate Concrete (LWAC) and Aerated Concrete. Lightweight Foamed Concrete (LWC) is under the category of Aerated Concrete. LWC is made up of mortar mix with foam agents whereas Autoclaved Aerated Concrete is adding expansion agent instead of foam agent. According to journals, the properties of LWC has a low density compared with normal weight or plain concretes. So as due to its low density, the compressive, splitting and tensile strength of foamed concrete are very low. Foam agent is the main material that will affect the concrete to decrease its own density. How low is the concrete mix will be depending on how much foam was added into the concrete mix. Due to the additive of foam agent, the microstructure of foam concrete is in cellular shape. Thus, LWC is also called Cellular Lightweight Concrete (CLC). With the cellular microstructure, foam concrete is a good thermal and acoustic insulator. Lastly, CLC has a very high fire resistance too, as depending on the concrete density.

According to the problem, statement has been mention in chapter 1, crumb rubber is going to be used in LWC to provide an environmentally friendly concrete structure. Other than that, with reusing waste material such as waste tyres, it able to reduce the cost of construction too. Besides that, properties of the LWC will be enhanced too while adding in crumb rubber into the mixing foam concrete. After adding in the crumb rubber into LWC, it would be called as Crumb Rubber Lightweight Foamed Concrete (CRLWC). CRLWC strength will be higher compare with LWC. Other than that, it will be better for sound insulation too. Hence, it can be applying for the partition of wall panel for better sound absorption environment such as the library.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Throughout this topic will be briefed on methodology and testing requirements on thermal conductivity and acoustic performance of crumb rubber lightweight foamed concrete (CRLWC). Preparation of materials and requirement of steps will be discussed at the sub-topic below.

3.2 Raw Materials

Raw materials used in the production of CRLWC include crumb rubber, fine aggregate, foam, water and Ordinary Portland Cement.

3.2.1 Ordinary Portland Cement (OPC)

Brand of OPC that was used in this experiment is "Orang Kuat"; the product from YTL supplier in Malaysia. Before the cement was used in the mixing, it was sieved through a 600 μm tube to make sure they remove the hydrated cement particles. This cement was used throughout the project in order to standardize the result.

Figure 3.1: "Orang Kuat" OPC (Tan, 2016).

3.2.2 Fine Aggregate

Throughout the project, fine aggregates according to the standard specification of ASTM C33 which the particle size of the fine aggregate is within 75 µm (No. 200 sieve) and pass through 4.5 mm (No. 4 Mesh). Thus, the size of the fine aggregates used in this project should be sieved through 600 µm sieve. Before the fine aggregates were used, they were oven-dried at the temperature at around 100 °C for twenty-four hours to ensure the fine aggregates were in dry condition. The dried fine aggregates were then put into the container and stored well.

3.2.3 Foaming Agent (FA)

Pre-form foaming method was performed in this project. The foaming agent standard has been stated on ASTM C796-97. SikaAER@ - 50/50 is the foaming agent used in this project. This type of foaming agent was able to provide stable foam to the concrete mix and therefore, the inaccurate result could be avoided. A foam with a density of 45 ± 5 kg/m^3 that yielding the volume of 800 litres was formed by mixing the diluted foam agent and 20 litres of tap water per litre of foam agent in foam generator. The first batch of foam was discarded before start to mix with concrete due to unstable foam which will affect the density of concrete.

Figure 3.2: SikaAER@ - 50/50, FA (Kelvin, 2019).

Figure 3.3: Foam Generator.

3.2.4 Crumb Rubber (CR)

The sizes of CR employed in this study are 1 mm to 4 mm (granular CR) and below 40 Mesh (powdered CR). The CR was manufactured from the waste tyre and the usage of this CR was to replace the fine aggregate in the ratio of 0 % to 80 % with an increment interval of 10 %.

3.2.5 Water

According to ASTM C1602, tap water is used in the concrete mixing purpose. The water-cement ratio for this project is specified in the ratio of 0.6 as this project is to compare the result of different type of CR and CR proportion under the same water to cement ratio.

3.3 Specimen Designation

Thermal conductivity test and acoustic performance test were carried out in this project. The mixture specimen will be classified into a different ratio of crumb rubber replacement as fine aggregates (0 % to 80 % with an increment interval of 10 %) and different type of crumb rubber. The designation and number of the specimen of each mix proportion of crumb rubber lightweight foamed concrete were stated in Tables 3.1 and 3.2. The control sample (LWC-G0) in this study denotes lightweight foamed concrete without the inclusion of any types of crumb rubber. LWC-G10 represents granular crumb rubber lightweight foamed concrete with a crumb rubber replacement level of 10 %. On the contrary, LWC-P70 indicates powdered crumb rubber lightweight foamed concrete with a crumb rubber replacement level of 70 %.

Table 3.1: Thermal Conductivity Test Specimens.

Designation	W/C	Size of Specimen (mm)	Quantity
LWC-G0	0.6	300 x 300 x 50	1
LWC-G10	0.6	300 x 300 x 50	1
LWC-G20	0.6	300 x 300 x 50	1
LWC-G30	0.6	300 x 300 x 50	1
LWC-G40	0.6	300 x 300 x 50	1
LWC-G50	0.6	300 x 300 x 50	1
LWC-G60	0.6	300 x 300 x 50	1
LWC-G70	0.6	300 x 300 x 50	1
LWC-G80	0.6	300 x 300 x 50	1
LWC-P10[3]	0.6	300 x 300 x 50	1
LWC-P20	0.6	300 x 300 x 50	1
LWC-P30	0.6	300 x 300 x 50	1
LWC-P40	0.6	300 x 300 x 50	1
LWC-P50	0.6	300 x 300 x 50	1
LWC-P60	0.6	300 x 300 x 50	1
LWC-P70	0.6	300 x 300 x 50	1
LWC-P80	0.6	300 x 300 x 50	1

Note:

W/C = Water to Cement Ratio.

LWC-G10 = Lightweight Foamed Concrete with the replacement of 10 % Granular Crumb Rubber.

LWC-P10 = Lightweight Foamed Concrete with the replacement of 10 % Powdered Crumb Rubber.

Table 3.2: Acoustic Performance Test Specimens.

Concrete Specimen	W/C	Quantity of Specimen	
		Diameter 60mm	Diameter 30mm
LWC-G0	0.6	2	2
LWC-G10	0.6	2	2
LWC-G20	0.6	2	2
LWC-G30	0.6	2	2
LWC-G40	0.6	2	2
LWC-G50	0.6	2	2
LWC-G60	0.6	2	2
LWC-G70	0.6	2	2
LWC-G80	0.6	2	2
LWC-P10[3]	0.6	2	2
LWC-P20	0.6	2	2
LWC-P30	0.6	2	2
LWC-P40	0.6	2	2
LWC-P50	0.6	2	2
LWC-P60	0.6	2	2
LWC-P70	0.6	2	2
LWC-P80	0.6	2	2

Note:

W/C = Water to Cement Ratio.

LWC-G10 = Lightweight Foamed Concrete with the replacement of 10 % Granular Crumb Rubber.

LWC-P10 = Lightweight Foamed Concrete with the replacement of 10 % Powdered Crumb Rubber.

3.3.1 Mixing Procedure

The amount of crumb rubber to be added into the concrete has been calculated prior to the commencement of concrete casting works. The replacement of crumb rubber is according to the requirement of specimens.

Ordinary Portland Cement, aggregates, water, crumb rubber were weighed according to the calculated amount. Next, cement, aggregates and crumb rubber were poured into the mixer and mixed uniformly. After that, tap water was poured into the mixer and start to mix to form mortar. Then, the fresh density of the aqueous mortar was used to calculate the amount of foam to be added to the mortar to reach a density of 1050 kg/m^3 to 1150 kg/m^3.

3.3.2 Casting and Curing Condition

When the concrete mix had achieved the desired density, which was within 1050 kg/m^3 to 1150 kg/m^3, the concrete mix was cast in different types of moulds for different tests. For acoustic performance test, the sizes of moulds are 60 mm (d) x 20 mm (h) and 30 mm (d) x 20 mm (h). On the contrary, for a thermal conductivity test, the mould size is 300 mm x 300 mm x 50 mm. Before pouring the fresh concrete into the mould, a layer of oil was applied to the internal surface of the mould in order to ease the demoulding work afterwards. Next, the mould was tapped simultaneously after the concrete mix was poured in order to remove unstable foam in the specimen. Then, the concrete mix was let dry for 24 hours to set into harden concrete.

After 24 hours, the concrete specimens were demoulded and water curing was conducted on them. The curing process is a process which incubates the concrete specimen into the water tank. During the curing process, the temperature of the water was maintained within the range of 25 ^oC to 28 ^oC. After the curing process of 28 days, the concrete specimens were removed from the water tank, and the oven-dried for another 24 hours to remove excess moisture content.

Figure 3.4: Curing Process.

3.4 Laboratory Test

In this study, two different tests were conducted on the concrete specimens of each mix proportion, namely thermal conductivity and sound absorption tests. For thermal conductivity the thermal insulation properties of the concrete specimen was tested by thermal insulation measurement machine. For acoustic performance test, the sound absorption coefficient of the concrete specimen at a frequency between 100 Hz to 5000 Hz was tested by using impedance tube.

3.4.1 Thermal Conductivity

According to ASTM C177, thermal transmission properties and steady-state heat flux (SSHF) measurement were conducted. The concrete specimen with the dimensions of 300 mm x 300 mm x 50 mm was set up between two plates which are hot plate were cold plate assemblies. This test was started by raising the temperature of the hot plate and chilling the cold plate at the temperatures of 40 ^{o}C and 24 ^{o}C, respectively. Simultaneously, the temperature changes in both hot and cold plate assemblies were measured and recorded in every hour. The process of heating up was continued until the SSHF state was attained. This experiment test took around 20 hours to complete.

Figure 3.5: Thermal Transmission Properties Testing Machine.

3.4.2 Acoustic Performance

The acoustic performance test was carried out to determine the coefficient of sound absorption and impedance of the concrete sample. This test was executed using impedance tube as specified in (ISO 10534-1, 1996). Two different sizes of specimens in the form of the dish were prepared for this test. Two specimens with diameters of 30 mm and 60 mm will be using two different frequency ranges comprising high-frequency range and the low-frequency range. The ratio between the maximum and minimum sound pressure was measured when the standing wave was produced in the tube. Then, the absorption coefficient of the test sample for 0^o incident sound wave was tabulated from the collected data.

Figure 3.6: Impedance Tube to Access the Acoustic Performance of Material.

3.5 Summary

There are a total of seventeen sets of mix proportion in this project. These seventeen sets of mix proportion specimen are classifying into a different ratio of crumb rubber replacement as fine aggregates (0 % to 80 % with increment interval of 10 %) and different type of crumb rubber which are granular crumb rubber and powdered crumb rubber. The size of granular crumb rubber is with 1 mm to 4 mm whereas powdered crumb rubber is below 40 Mesh. In this project, the water to cement ratio is fixed at 0.6 to achieve the objective in this research.

The concrete materials are cement, water, fine aggregates, crumb rubber and foam. The casting of concrete is starting with a dry mix which is mixing the crumb rubber, cement and fine aggregates. Next step will be wet mix by adding water and start to mix until cluster concrete disappeared. The foam was added at last until it reaches the density of 1050 kg/m^3 – 1150 kg/m^3. The foam used in this project is the pre-forming method.

Each set of concrete mix contain one panel mould and two types of cylindrical mould. The size of panel mould is 300 mm x 300 mm x 50 mm whereas cylindrical mould is 30 mm and 60 mm in diameter and both with 20 mm height. The concrete panel is used for thermal conductivity test and the cylindrical specimen is for the acoustic performance test. The size of the concrete specimen is cast according to the standard of the machine that use to test the result for this research.

In a nutshell, the concrete mix was let dry for 24 hours to set into harden concrete. After 24 hours, the concrete specimens were demoulded and water curing was conducted on them. The curing process is a process which incubates the concrete specimen into the water tank. During the curing process, the temperature of the water was maintained within the range of 25 ^{o}C to 28 ^{o}C. After the curing process of 28 days, the concrete specimens were removed from the water tank, and the oven-dried for another 24 hours to remove excess moisture content. Hence, the concrete specimens are ready to be tested.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Throughout this chapter will be discussing the result of a thermal conductivity test and acoustic performance test on the crumb rubber lightweight foamed concrete (CRLWC). There are several types of specimens tested according to the test standard. In this project, there are total of one experiment testing in thermal conductivity and three experiments testing in the acoustic performance test. In a thermal conductivity test, thermal conductivity measurement machine was used to determine the thermal conductivity of LWC. On the contrary, the impedance tube was used to test the acoustic performance of the concrete specimen. There are total of three ranges to test for acoustic performance which is 60 mm of specimen diameter in a wide range, 60 mm of specimen diameter in the normal range and 30 mm of specimen diameter in the normal range. Each range was tested in different frequency and those frequencies has been combined at the end of the result.

4.2 Mixed Proportion of Concrete Specimen

In order to achieve the desired density of 1050 kg/m^3 to1150 kg/m^3 in this study, the mix proportion of every type of concrete mixture was calculated and tabulated in Table 4.1. Table 4.1 shows the mix proportion of cement, sand, water, crumb rubber and foam in the unit of weight per cubic meter (kg/m^3) of each designation.

Table 4.1: Mix proportion of each designation.

Concrete Specimen	Material (kg/m^3)					
	Cement	Sand	Water	Crumb Rubber		Foam
				Granular	Powder	
LFC-0	415.07	415.07	249.04	0.00	0.00	20.82
LFC-G10	424.85	382.36	254.91	17.64	0.00	20.25
LFC-G20	435.10	348.08	261.06	36.12	0.00	19.65
LFC-G30	445.85	312.10	267.51	55.52	0.00	19.02
LFC-G40	457.15	274.29	274.29	75.90	0.00	18.36
LFC-G50	469.04	234.52	281.42	97.35	0.00	17.67
LFC-G60	481.56	192.62	288.94	119.94	0.00	16.94
LFC-G70	494.77	148.43	296.86	143.76	0.00	16.17
LFC-G80	508.73	101.75	305.24	168.94	0.00	15.36
LFC-P10	424.85	382.36	254.91	0.00	17.64	20.25
LFC-P20	435.10	348.08	261.06	0.00	36.12	19.65
LFC-P30	445.85	312.10	267.51	0.00	55.52	19.02
LFC-P40	457.15	274.29	274.29	0.00	75.90	18.36
LFC-P50	469.04	234.52	281.42	0.00	97.35	17.67
LFC-P60	481.56	192.62	288.94	0.00	119.94	16.94
LFC-P70	494.77	148.43	296.86	0.00	143.76	16.17
LFC-P80	508.73	101.75	305.24	0.00	168.94	15.36

Note:

LWC-G10 = Lightweight Concrete with replacement of 10 % Granular Crumb Rubber

LWC-P10 = Lightweight Concrete with replacement of 10 % Powdered Crumb Rubber

4.3 Thermal Conductivity Test

The thermal conductivity test experiment was conducted by using a thermal conductivity measurement machine. Granular crumb rubber lightweight foamed concrete and powdered crumb rubber lightweight foamed concrete specimens were tested for at least 20 hours and the thermal conductivity value of each hour was recorded.

4.3.1 Thermal Conductivity of Granular Crumb Rubber Lightweight Foamed Concrete

Table 4.2 indicates the thermal conductivity result of granular crumb rubber lightweight foamed concrete specimens. The volume of foam and crumb rubber proportion in the concrete was stated down for a further explanation.

Table 4.2: Thermal Conductivity of Granular Crumb Rubber Lightweight Foamed Concrete specimens

Specimens	**Density (kg/m^3)**	**Percentage Volume of Foam (%)**	**Percentage Volume of Crumb Rubber (%)**	**Thermal Conductivity, k ($W \cdot K^{-1} \cdot m^{-1}$)**
CS	1103	46	0.0	0.3490
G10	1046	48	0.9	0.2963
G20	1105	43	1.9	0.2533
G30	1059	43	3.0	0.2406
G40	1128	41	4.0	0.2395
G50	1129	38	5.6	0.2455
G60	1091	38	6.8	0.2448
G70	1055	39	8.1	0.2511
G80	1092	35	10.2	0.2622

Note:

CS = Control Sample

G10 = Lightweight Foamed Concrete with 10% volume replacement of sand by Granular Crumb Rubber

Figure 4.1 shows the graph of the thermal conductivity of granular CRLWC. According to the graph in Figure 4.1, the increment in the percentage content of crumb rubber in concrete is able to reduce the thermal conductivity of concrete. Above 40 % of crumb rubber replacement level, the thermal conductivity of the concrete increases gently. This shows that there are several factors affecting the thermal conductivity which are the density of CRLWC and the crumb rubber proportion. Figure 4.1 shows that 40 % of granular crumb rubber replacement gives the optimum result, which has the lowest k value of 0.2395 $W{\cdot}K^{-1}{\cdot}m^{-1}$. The thermal conductivity reduction for an increment of crumb rubber from 30 % to 40 % is about 2 % to 5 % (Fadiel et al., 2014). There is only a small decrement from G30 to G40 due to the difference in the density of concrete. According to Table 4.2, the density of G40 is greater than that of G30. This is due to the higher volume of foam in G30 and this leads to lower the density of concrete G30. With a higher quantity of foamed in concrete, it will make the concrete to have greater void content. It is known that void content has the tendency of reducing the thermal conductivity of the concrete. As compared with control sample which has greater void content than other concrete samples, it has the highest thermal conductivity. This is because the addition of crumb rubber reduces the thermal conductivity by reducing the void content in concrete. While adding in the granular crumb rubber into the concrete, the particle of crumb rubber will have occupied the void space in the LWC. There are two related factors that affect thermal conductivity which is the increase in air content and low thermal conductivity properties of rubber (Fadiel et al., 2014). The increment in thermal conductivity value from G30 onwards is less than 1%. This can be explained according to Table 4.2. From G30 onwards, the foam volume starts to decrease, whereas the crumb rubber proportion increases simultaneously. Hence, this shows the thermal conductivity factors are countering each other and making the trend line stable.

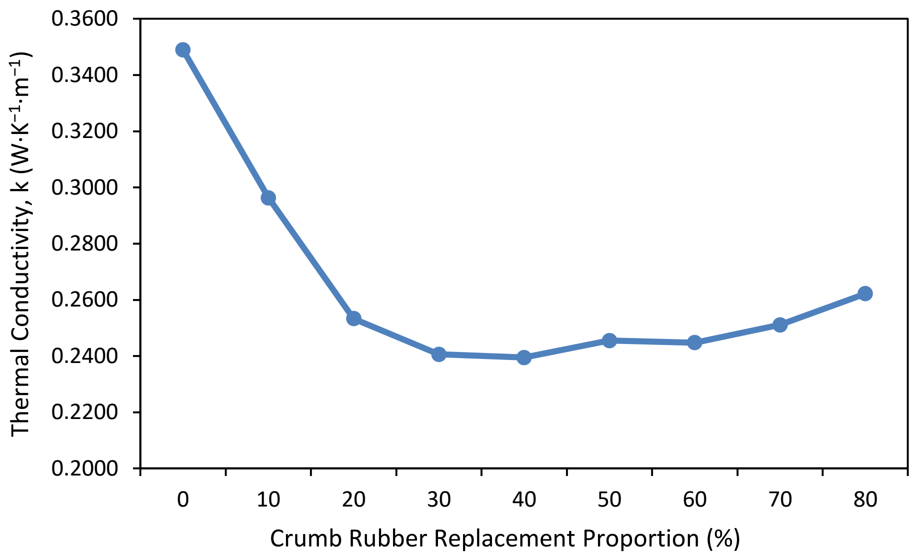

Figure 4.1: Thermal Conductivity Graph of Granular Crumb Rubber Lightweight Foamed Concrete.

4.3.2 Thermal Conductivity of Powdered Crumb Rubber Lightweight Foamed Concrete

Table 4.3 indicates the thermal conductivity result of powdered crumb rubber lightweight foamed concrete specimens. The volume of foam and crumb rubber proportion in the concrete was stated down for a further explanation.

Table 4.3: Thermal Conductivity of Powdered Crumb Rubber Lightweight Foamed Concrete.

Specimens	**Density (kg/m^3)**	**Percentage Volume of Foam (%)**	**Percentage Volume of Crumb Rubber (%)**	**Thermal Conductivity, k ($W \cdot K^{-1} \cdot m^{-1}$)**
CS	1103	46	0.0	0.3490
P10	1083	46	0.9	0.3410
P20	1166	40	2.0	0.3255
P30	1030	46	2.8	0.3193
P40	1036	44	3.9	0.3155
P50	1042	43	5.2	0.3022
P60	1066	40	6.7	0.2805
P70	1044	39	8.0	0.2456
P80	1045	38	9.7	0.2288

Note:

CS = Control Sample

P10 = Lightweight Foamed Concrete with 10% volume replacement of sand by Powdered Crumb Rubber

Figure 4.2 shows the graph of the thermal conductivity of powdered CRLWC. According to the trend in Figure 4.2, the thermal conductivity of concrete reduces with the increase in the crumb rubber proportion. Crumb rubber is one of the factors that contribute to the decline in thermal conductivity. The lower thermal conductivity of concrete is mainly due to the addition of crumb rubber in the lightweight foamed concrete which has the thermal conductivity value of 0.15 to 0.25 $W \cdot K^{-1} \cdot m^{-1}$ which is lower than sand or fine aggregates whose thermal conductivity value is around 1.5 $W \cdot K^{-1} \cdot m^{-1}$ (Abdel Kader et al., 2012). Thus, P80 has the lowest thermal conductivity value of 0.2288 $W \cdot K^{-1} \cdot m^{-1}$ among the powdered CRLWC specimens. This is because the crumb rubber proportion of P80 is the highest among other concrete mix specimens. Other than that, the density of specimens from P30 onwards is lower than that of the control sample, P10 and P20. This shows that density acts as another significant factor affecting the thermal conductivity of a concrete specimen.

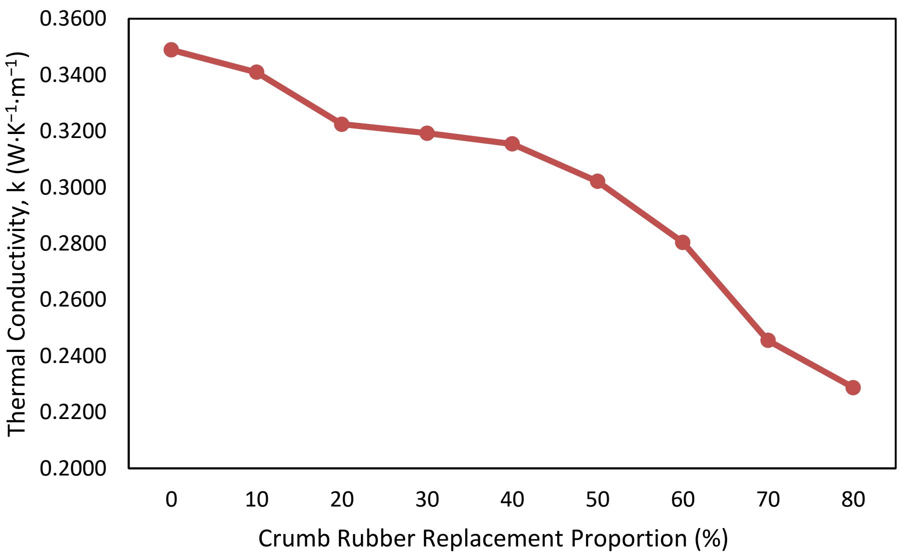

Figure 4.2: Thermal Conductivity Graph of Powdered Crumb Rubber Lightweight Foamed Concrete.

4.3.3 Discussion on Overall Concrete Specimens in Thermal Conductivity

Figure 4.3 shows the comparison graph between granular and powdered crumb rubber lightweight foamed concretes. The thermal conductivity value of powdered crumb rubber lightweight foamed concrete is gradually decreases with the crumb rubber proportion. On the other hand, the graph of granular crumb rubber lightweight foamed concrete shows a sudden decrease from control sample with a value of 0.3490 $W \cdot K^{-1} \cdot m^{-1}$, towards G40 which shows a value of 0.2395 $W \cdot K^{-1} \cdot m^{-1}$ and then the value was rebounded towards G80. This shows that the trend line for granular CRLWC was presented the optimum crumb rubber proportion, which is G40 whereas powdered crumb rubber curve does not. The difference between the granular and powdered crumb rubbers is the size of the crumb rubber particle. The particle size of crumb rubber acts as a main factor that causes the difference between them. The size of rubber particles could affect the reduction of thermal conductivity. In rubberized concrete, a large particle of crumb rubber tends to reduce thermal conductivity due to large particle which has greater surface compare with smaller particle. The large surface of large rubber particles tends to entrap air due to the nature of rubber. So, plain concrete with the addition of large crumb rubber particles has a higher thermal conductivity value compared to concrete containing small crumb rubber particles. This can be explained due to large particle entraps more air than a small particle in plain concrete (Fadiel et al., 2014). Oppositely in foamed concrete, the addition of large particle crumb rubber is reducing air void in foamed concrete. For small size crumb rubber, other than not reducing the air voids in concrete, it still can fill up the capillaries in the concrete to reduce the absorption of water.

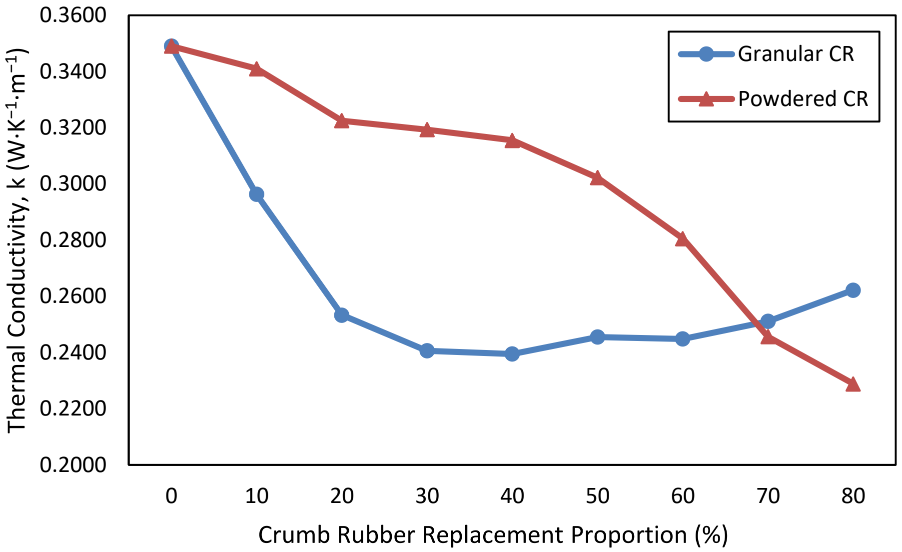

Figure 4.3: Thermal Conductivity Graph of Granular and Powdered Crumb Rubber Lightweight Foamed Concrete.

Table 4.4: Thermal Conductivity Reduction Efficiency.

Specimens	**Thermal Conductivity, K ($W \cdot K^{-1} \cdot m^{-1}$)**	**Reduction Efficiency (%)**
Control Sample	0.3490	-
G10[1]	0.2963	15.1
G20	0.2533	27.4
G30	0.2406	31.1
G40	0.2395	31.4
G50	0.2455	29.7
G60	0.2448	29.9
G70	0.2511	28.1
G80	0.2622	24.9
P10[2]	0.3410	2.3
P20	0.3255	7.6
P30	0.3193	8.5
P40	0.3155	9.6
P50	0.3022	13.4
P60	0.2805	19.6
P70	0.2456	29.6
P80	0.2288	34.4

Note:

G10 = Lightweight Foamed Concrete with 10% volume replacement of sand by Granular Crumb Rubber

P10 = Lightweight Foamed Concrete with 10% volume replacement of sand by Powdered Crumb Rubber

Figure 4.4 shows the thermal conductivity reduction efficiency of granular and powdered crumb rubber lightweight foamed concretes. In overall, P80 has the highest thermal conductivity reduction efficiency with a value of 34.4 %. The overall thermal conductivity of concrete decreases as the fine aggregates replace with crumb rubber particles which have higher thermal conductivity (Fadiel et al., 2014). On the other hand, granular crumb rubber lightweight foamed concrete, G40 has the greatest thermal conductivity reduction efficiency value of 31.4 %.

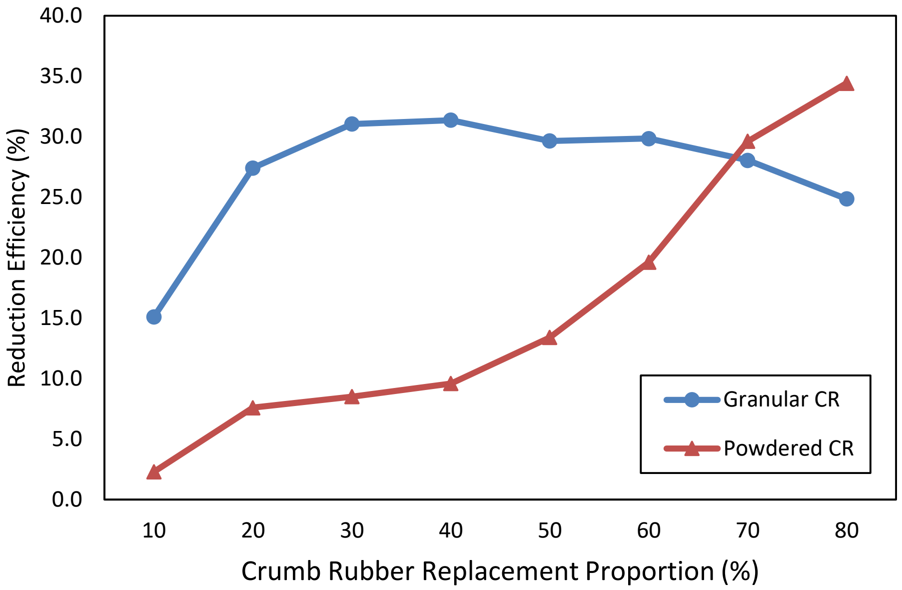

Figure 4.4: Thermal Conductivity Reduction Efficiency of Granular and Powdered Lightweight Foamed Concrete.

4.4 Acoustic Performance Test

The purpose of an acoustic performance test is to test the sound absorption of each crumb rubber lightweight concrete specimen. There are 3 steps in total, were carried out in order to receive the complete result from sound absorption test. First, the dish specimens having a diameter of 60 mm were tested in a normal spacing category whose frequency ranged from 400 Hz to 2500 Hz. Next, 60 mm diameter of the specimen was tested again in wide range spacing category whose frequency ranged from 100 Hz to 800 Hz. Lastly, 30 mm diameter of the specimen was tested in a normal spacing category whose frequency ranged from 1000 Hz to 5000 Hz. Eventually, those three tested results were recorded and combined.

4.4.1 Acoustic Performance of Granular Crumb Rubber LWC

Table 4.5 shows the sound absorption coefficient of granular crumb rubber lightweight foamed concrete.

Table 4.5: Absorption Coefficient of Granular Crumb Rubber Lightweight Foamed Concrete.

Frequency (Hz)	**Absorption Coefficient (%)**								
	CS[1]	**G10[2]**	**G20**	**G30**	**G40**	**G50**	**G60**	**G70**	**G80**
100	61	22	9	41	35	46	9	14	30
125	32	16	1	18	5	23	10	3	11
160	36	32	12	7	1	2	24	27	6
200	51	1	2	7	3	1	19	11	2
250	46	1	1	6	8	8	16	6	6
315	21	8	6	6	9	10	13	8	11
400	12	7	7	7	6	6	7	6	6
500	8	3	3	6	3	3	4	5	4
630	6	1	0	0	1	1	1	1	1
800	3	2	2	2	2	2	2	1	2
1000	9	7	8	9	8	8	9	7	8
1250	6	4	2	5	5	5	5	3	5
1600	8	9	5	6	4	5	6	3	5
2000	8	10	7	6	6	9	6	6	3
2500	14	17	9	9	9	11	10	6	5
3150	15	14	9	5	7	5	10	4	6
4000	26	10	10	4	9	8	12	6	10
5000	33	13	18	15	21	16	17	13	14

Note:

CS = Control Sample

G10 = Lightweight Foamed Concrete with 10% volume replacement of sand by Granular Crumb Rubber

Figure 4.5 illustrates the results of the sound absorption coefficient of granular crumb rubber lightweight foamed concrete. According to the trend in Figure 4.5, the sound absorption coefficient from 100 Hz to 250 Hz fluctuates. Above 315 Hz, the absorption coefficient of concrete specimens falls to the range of 1% to 21%. This shows that the concrete specimens are able to absorb sound from frequency 100 Hz to 315 Hz as the absorption coefficient is able to reach 46%.

At the frequency of 630 Hz, the absorption coefficient of the concrete specimen is the lowest which falls to nearly 0 %.

From Figure 4.5, the result trends are most likely the same. The most favourable absorption coefficient in overall granular CRLWC is G10 as a result is stable as compared to other mix proportion. G10 has the lowest proportion of crumb rubber among the other concrete mix. Factors that affect sound absorption coefficient is due to the density of concrete, void content in concrete and inclusion of crumb rubber in concrete. Since the density of every specimen is the same, density can be excluded out from factors that affecting the acoustic performance of concrete. In G10 have a lower volume of crumb rubber and a high volume of void content. As compare to G80, the absorption value seems to be lower. This is due to the crumb rubber particle that had occupied the space of void in foamed concrete. Formed concrete tends to absorb more sound and gave a higher sound absorption coefficient (Ramamurthy et al., 2009).

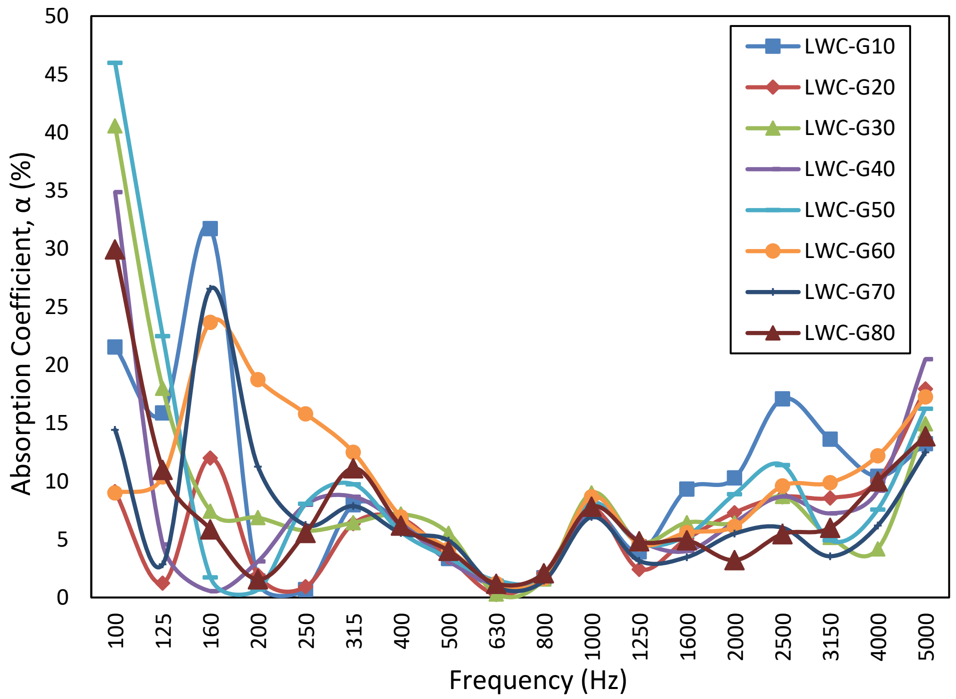

Figure 4.5: Granular Crumb Rubber Lightweight Foamed Concrete Results.

4.4.2 Acoustic Performance of Powdered Crumb Rubber LWC

Table 4.6 shows the sound absorption coefficient of powdered crumb rubber lightweight foamed concrete.

Table 4.6: Absorption Coefficient of Powdered Crumb Rubber Lightweight Foamed Concrete.

Frequency (Hz)	Absorption Coefficient (%)								
	CS[1]	**P10[2]**	**P20**	**P30**	**P40**	**P50**	**P60**	**P70**	**P80**
100	61	50	49	50	51	50	51	49	50
125	32	10	25	20	20	23	38	30	15
160	36	35	49	20	48	27	34	14	13
200	51	39	37	49	42	35	35	46	42
250	46	35	36	35	37	36	36	37	37
315	21	8	8	6	10	10	13	12	12
400	12	0	1	2	2	1	0	1	0
500	8	4	3	4	4	3	5	3	3
630	6	0	0	1	1	1	0	1	0
800	3	3	3	3	2	3	3	3	2
1000	9	9	8	9	9	8	8	9	8
1250	6	6	5	7	7	5	7	5	6
1600	8	7	7	10	10	5	9	7	7
2000	8	11	5	9	13	7	8	11	7
2500	14	15	8	11	13	3	13	16	12
3150	15	14	4	9	6	4	3	15	11
4000	26	18	15	12	4	5	13	14	12
5000	33	25	23	18	24	18	25	16	17

Note:

CS = Control Sample

P10 = Lightweight Foamed Concrete with 10% volume replacement of sand by Powdered Crumb Rubber

Figure 4.6 shows the sound absorption coefficient of powdered crumb rubber lightweight foamed concrete. According to the trend in Figure 4.6, the sound absorption from the frequency range of 100 Hz to 250 Hz is the highest, which gives a maximum value of 50 %. From 250 Hz onwards, the absorption coefficient is reduced for around 30 % which proves that the concrete specimens are inefficient in absorbing sound with a frequency higher than 250 Hz. Upon reaching 630 Hz, the absorption coefficient increases gradually until it reaches around 25% at a frequency of 5000 Hz.

Figure 4.6 illustrates the trend from frequency 100 Hz to 400 Hz is more stable than granular CRLWC shown in Figure 4.5. This result could be due to the size of crumb rubber. Comparing the same proportion of crumb rubber, powdered crumb rubber has less occupied the void content in foamed concrete compare to granular crumb rubber. This is due to the particle size of powdered crumb rubber is small enough to fill in the void capillary in foamed concrete. Therefore, the overall sound absorption coefficient for powdered CRLWC is higher than granular CRLWC can be explained.

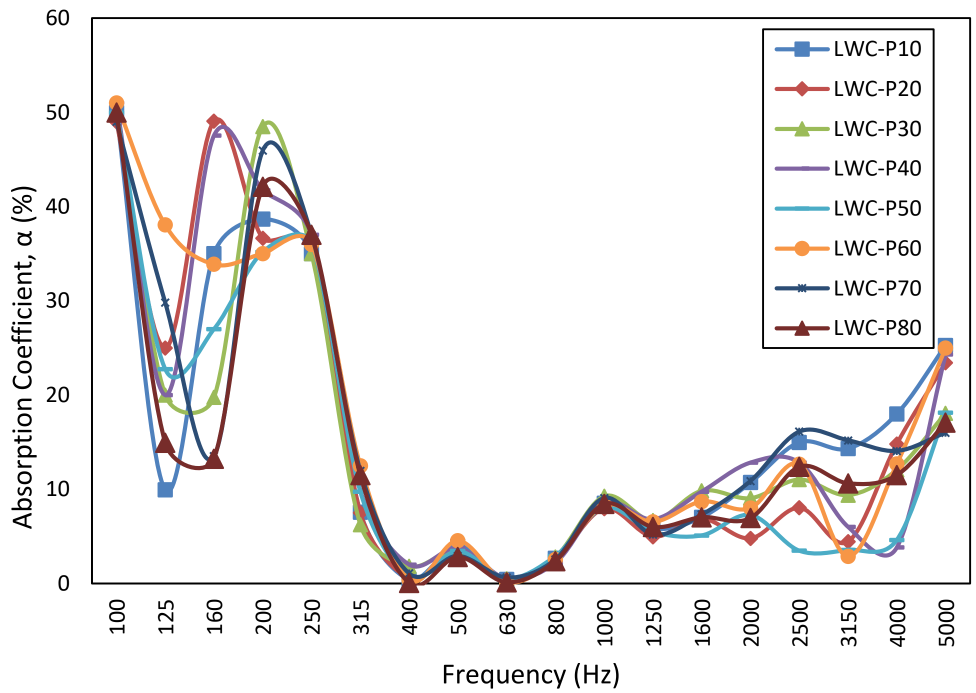

Figure 4.6: Powdered Crumb Rubber Lightweight Foamed Concrete Results.

4.4.3 Discussion on Concrete Specimens in Acoustic Performance

Figure 4.7 shows the trend of G10, P10 and a control sample. In the range around 100 Hz indicates all types of concrete having likely the same absorption coefficient. For low frequency, the sound insulation properties of concrete have a similar value, particularly at 63 Hz to 125 Hz (Holmes et al., 2014). From frequency range 800 Hz onwards, three of the concrete type has a similar trend line which is slowly increasing as the frequency raising.

According to the graph in Figure 4.7, the control sample of concrete specimen has the highest absorption coefficient followed by powdered CRLWC and granular CRLWC. This is due to the void content in the control sample is the highest among the others. Foamed concrete able to absorb more sound due to large existence the air void in concrete (Sukontasukkul, 2009). The addition of crumb rubber will affect a small reduction of void content in concrete (Holmes et al., 2014). The air void in the concrete tends to entrap the sound and causing the absorption coefficient value to increase. As comparing granular CRLWC and powdered CRLWC towards control sample, the addition of crumb rubber in concrete tends to reduce void content of concrete as crumb rubber is a non-porous material (Sukontasukkul, 2014). The absorption coefficient of granular CRLWC lower than powdered CRLWC is due to the size of the crumb rubber. In order to absorb more sound, larger surface area and heavier grade crumb rubber are the main factors to improve absorption coefficient of concrete (Holmes et al., 2014).

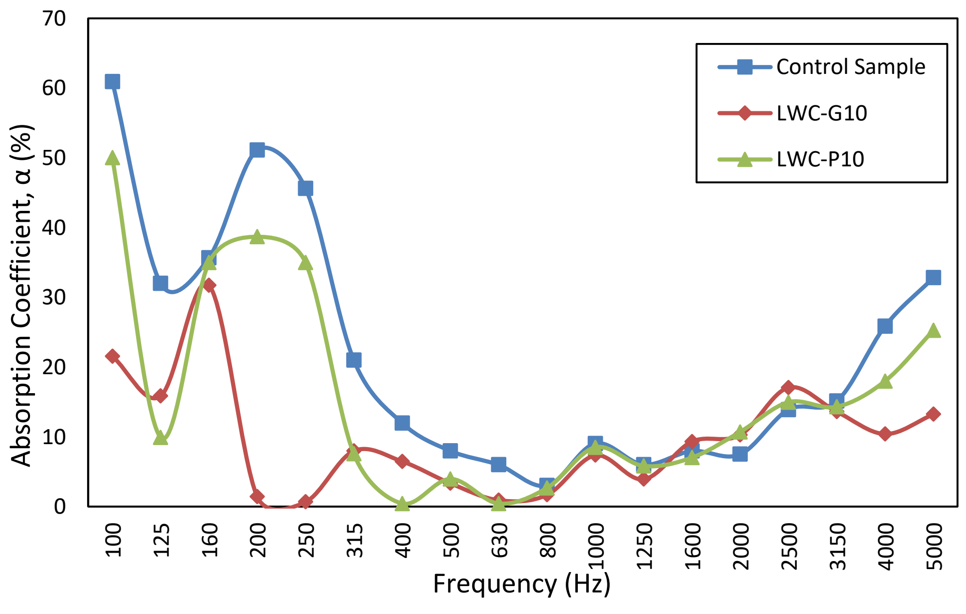

Figure 4.7: Overall Results of Acoustic Performance.

4.5 Summary

Throughout this chapter is discussing the thermal conductivity and the acoustic performance of powdered CRLWC and granular CRLWC. Majority of the concrete specimens have the densities ranging from 1050 kg/m^3 to 1150 kg/m^3. From a thermal conductivity test, powdered CRLWC is found to be better a thermal insulator than granular CRLWC. This is because the air void content in powdered CRLWC is greater than that in granular CRLWC. Higher air void content leads to lower thermal conductivity. The void content of granular CRLWC is lesser due to its larger crumb rubber particle size compared to that of powdered CRLWC. With larger particle size, it will occupy the void in foamed concrete and causing the void to decrease. Other than void, the existence of crumb rubber is able to reduce the thermal conductivity too. This is because the natural properties of rubber have lower thermal conductivity than sand. Next, the specimen depicting the best acoustic performance in this study is the control sample, followed by powdered CRLWC and granular CRLWC. This is because the void content in the control sample is the highest among the others. Foamed concrete is able to absorb more sound due to the existence of more air voids in concrete. In the comparison between the CRLWC and the conventional lightweight foamed concrete, the addition of crumb rubber in the concrete tends to reduce the void content of concrete as crumb rubber is a non-porous material.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

With the results from thermal conductivity and acoustic performance test were conducted, the discussion in Chapter 4 is supported by previous researches findings.

The aim of this study is to produce Crumb Rubber Lightweight Foamed Concrete (CRLFC) with the range of concrete density from 1050 kg/m^3 - 1150 kg/m^3 with water to cement ratio 0.6. This aim was achieved as the majority of the concrete samples were within the desired density range.

The first objective of this study is to investigate the effect of crumb rubber replacement proportion of 0 % to 80 % with an interval of 10 % on the thermal conductivity of crumb rubber lightweight foamed concrete. This objective has been achieved as a total of nine concrete specimens prepared in order to investigate the thermal conductivity and reduction efficiency on the different concrete mix. By plotting the result on the graph, the comparison has been made on the trend of CRLWC corresponding with the proportion of crumb rubber added. By increasing the powdered crumb rubber content in LWC, the thermal conductivity was reduced from 0.3490 $W \cdot K^{-1} \cdot m^{-1}$ to 0.2288 $W \cdot K^{-1} \cdot m^{-1}$ as compare to the control sample. This is due to the natural properties of crumb rubber has a lower thermal conductivity than fine aggregates. With increasing the crumb rubber proportion in LWC able to helps the concrete to become a better thermal insulating material.

The second objective is to verify the influence of crumb rubber replacement proportion of 0 % to 80 % with an interval of 10 % on the sound absorption coefficient of crumb rubber lightweight foamed concrete from 100 Hz to 5000 Hz. Thus, the objective has been achieved as a total of nine sets of the concrete mix were used to test for the acoustic performance test. By plotting the result of the graph, the comparison has been made on the trend of CRLWC corresponding with the proportion of crumb rubber added. By increasing the powdered crumb rubber content in LWC, the overall sound absorption coefficient was reduced by 20 % to 60 %. With increasing the crumb rubber proportion in LWC is unable to reduce the sound absorption of the LWC. This is due to the replacement of crumb rubber was causing the void content in LWC to be reduced. As the void content in LWC reduced, the sound absorption coefficient is acting directly proportionally.

The last objective is to determine the optimal mix proportion of both granular and powdered crumb rubber lightweights foamed concretes that depict the most favourable thermal and sound insulating properties. The objective was achieved as two different types of crumb rubber with a total of seventeen sets specimen were conducted in the tests. By increasing the powdered crumb rubber content in LWC, the thermal conductivity has been reduced more than as compared to granular crumb rubber content in LWC. Powdered CRLWC has better thermal conductivity as the crumb rubber proportion increase whereas granular CRLWC remains at thermal conductivity value from 0.2400 $W{\cdot}K^{-1}{\cdot}m^{-1}$ to 0.2600 $W{\cdot}K^{-1}{\cdot}m^{-1}$ after 30 % of granular crumb rubber proportion. For acoustic performance, with an increment of both type crumb rubber proportion in LWC is fail to improve the sound absorption coefficient of LWC in the early frequency from 100 Hz to 630 Hz. As comparing with powdered and granular crumb rubber in LWC, powdered CR has better sound absorption coefficient. This is due to the powdered crumb rubber particle size is smaller than granular crumb rubber. With smaller particle size, the less void in concrete to be occupied by the crumb rubber particle.

5.2 Recommendations

The study of the thermal and acoustic performances of crumb rubber lightweight foamed concrete with a density of 1050 kg/m^3 to 1150 kg/m^3 is still limited in this field. In order to improve the specifications of the study in the future, there are some recommendations and suggestions to be taken into consideration:

1. Use more water to cement ratio with a smaller interval in trial mix casting in order to find out the optimal water to cement ratio for crumb rubber lightweight foamed concrete mix.

2. Attempt different ways of drying crumb rubber concrete specimens such as air drying, instead of oven drying. This might be able to mitigate the crack of the concrete during oven drying.
3. Increase the cement and foam contents in the mix proportion in order to reduce the concrete density so that the resultant crumb rubber lightweight foamed concrete possesses better thermal and sound insulating properties.

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