A STUDY ON THE THERMAL AND ACOUSTIC INSULATIONS OF RUBBERIZED LIGHTWEIGHT FOAMED CONCRETE WITH A DENSITY OF 1400 – 1500 KG/M^3

CHEONG JIE KIN

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

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

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DECLARATION

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

Signature :

Name : Cheong Jie Kin

ID No. : 1603575

Date : 07/05/2021

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"A STUDY ON THE THERMAL AND ACOUSTIC INSULATIONS OF RUBBERIZED LIGHTWEIGHT FOAMED CONCRETE WITH A DENSITY OF 1400 – 1500 KG/M^3"** was prepared by **CHEONG JIE KIN** 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.

Approved by,

Signature : 

Supervisor : Dr. Lee Foo Wei

Date : 07/05/2021

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ABSTRACT

Nowadays, the amount of scrap tyres has been significantly increasing. As scrap tyres are non-biodegradable, it has caused severe impact on the environment such as landfill overcrowding, fire risk and pest threat. To overcome this problem, scrap tyres can be recycled and used as concrete aggregate in the construction industry. In this study, rubberized lightweight foamed concrete with a density range from 1400 kg/m^3 to 1500 kg/m^3 was produced using the mix proportion. Two different crumb rubber sizes, powdered and granular crumb rubber, were used to replace the fine aggregate in the replacement proportion from 0 % to 70 %. The effect of crumb rubber on the rubberized lightweight foamed concrete's thermal and acoustic insulation was investigated. For the thermal conductivity test, the thermal conductivity value, k of the concrete specimens, was determined using the guarded hot plate. As for the acoustic insulation test, the concrete specimens were tested in the frequency range from 100 Hz to 4000 Hz and the sound absorption coefficient was obtained by using an impedance tube. The results show that the inclusion of both crumb rubber improves the thermal conductivity whereby CR-G70 has the lowest thermal conductivity value of 0.5494 $W{\cdot}K^{-1}{\cdot}m^{-1}$. However, the control sample without the addition of crumb rubber achieved better acoustic performance than rubberized lightweight foamed concrete as it has the highest noise reduction coefficient of 19.75 %. This show that the addition of crumb rubber in the lightweight foamed concrete reduced the concrete's void content, thereby decreasing the sound absorption coefficient. Therefore, it is suggested to conduct further study on rubberized lightweight foamed concrete's acoustic insulation by reducing its density since the sound absorption coefficient increases with decreasing density of the concrete.

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LIST OF SYMBOLS / ABBREVIATIONS

α	sound absorption coefficient, %
k	thermal conductivity, $W \cdot K^{-1} \cdot m^{-1}$
ASTM	American Society for Testing and Materials
LWC	lightweight concrete
NWC	normal weight concrete
LWAC	lightweight aggregate concrete
NFC	no-fines concrete
RLWFC	rubberized lightweight foamed concrete
NRC	noise reduction coefficient
OPC	ordinary Portland Cement
W/C	water to cement ratio

CHAPTER 1

INTRODUCTION

1.1 General Introduction

In this present world, concrete is the main and most used construction material in the building industry, whereby it can use for the construction of columns, beams, slabs, foundation, and other load-bearing elements. It is a suitable material to be used in construction. It has remarkable compressive strength, durable, good fire resistance and has a variety of size and shape to be made. Concrete is the mixture of cement, aggregates, sand and water, which will eventually gain its strength and harden after mixing. A factor that plays an important role in concrete is the water to cement ratio, which will directly influence concrete properties such as strength, durability and workability. During the mixing of concrete, water will react with cement which causes the hydration process to begin. This process helps to bond the materials into durable and workable concrete if mixed with adequate water to cement ratio. Besides, the performance of the concrete can be further improved by adding concrete additives such as air-entraining admixtures, retarding admixtures, etc., during the mixing process.

Lightweight Concrete (LWC) is concrete that adds expanding agent, foam agent or uses lightweight coarse aggregates, sometimes fine aggregates in the mixing proportion, which results in lower density than the normal weight concrete (NWC). Normally, the density of NWC and LWC ranges from 2240 kg/m^3 to 2450 kg/m^3 and 300 kg/m^3 to 1850 kg/m^3, respectively (Hedjazi, 2019). The main difference between NWC and LWC is that conventional concrete use crushed natural stone as the coarse aggregates, whereas LWC uses manufacturing by-products by heating shale, clay or fly ash as the lightweight coarse aggregates. Basically, lightweight concrete can be divided into three categories, which are Lightweight Aggregate Concrete (LWAC), No-Fines Concrete (NFC) and Aerated or Foamed Concrete.

Among these three categories, lightweight foamed concrete under the type of aerated concrete has been widely used in the construction industry due to its advantages. Its lower density properties significantly reduce the overall dead load of a structure, which eventually reduces the cost of a project. Besides, it also has better fire resistance as well as suitable to use as an insulating material. To further study the lightweight foamed concrete’s properties such as thermal conductivity and acoustic insulation, a lot of research has been carried out using recycling waste materials such as fly ash, waste glass and waste tyres to replace a portion of the aggregates during the concrete mix. Therefore, in this research, crumb rubber is used as one of the concrete aggregates to study its effect on concrete’s thermal conductivity and acoustic insulation.

1.2 Problem Statement

In the past few decades, the number of scrap tyres in the world had increased dramatically. Non-biodegradable scrap tyres have caused a serious impact on the environment. According to Fadiel, et al. (2014), the amount of scrap tyres in the United Stated landfills has exceeded two billion, with 250 million abandoned tyres added each year, resulting in the disposal of waste tyres become a significant waste management issue. Besides, in Malaysia, the amount of waste tyres has reached a number of 8.2 million per year (Thiruvangodan, 2006).

In the way to reduce the number of scrap tyres, the most common method is by disposing of the scrap tyres in landfills. However, disposing of scrap tyres in landfills or illegal dumping areas can cause severe problems such as potential fire hazards and mosquitos habitation areas. Studies show that tyres fires can be continued for a few months and it will cause releasing of toxic chemicals which will eventually cause harm to our human health and environment. In 1983, a severe fire accident occurred near Winchester, where a tyre storage facility was on fire and burned continuously for almost nine months (Fadiel, et al, 2014). This fire has caused serious air pollution and environmental issue due to the emission of poisonous gas such as carbon monoxide, nitrogen dioxide, sulphur dioxide, etc. Therefore, an effective way is to recycle the scrap tyres and convert them into crumb rubber which can be used as a concrete aggregate in the construction industry.

1.3 Aim and Objectives

This study aims to investigate the thermal conductivity and acoustic insulation based on the proportion and type of crumb rubber added to the lightweight foamed concrete with a fresh concrete density ranging from 1400 kg/m^3 to 1500 kg/m^3.

The objectives are:

1. To study the effect of crumb rubber with a replacement proportion of 10 % interval from 0 to 70 % on the thermal conductivity of rubberized lightweight foamed concrete.
2. To study the effect of crumb rubber with a replacement proportion of 10 % interval from 0 to 70 % on the acoustic insulation of rubberized lightweight foamed concrete.
3. To determine the optimal mix proportion of granular and powdered crumb rubber that depict the most favourable thermal and sound insulation properties.

1.4 Scope of the Study

This study focuses on the thermal conductivity and acoustic insulation properties of rubberized lightweight foamed concrete. Two types of crumb rubber were used which are granular and powdered crumb rubber to replace the fine aggregate from 0% to 70% with an increment replacement proportion of 10%. The water to cement ratio was fixed at 0.5 throughout the study. To produce rubberized lightweight foamed concrete (RLWFC) within the density range of 1400 kg/m^3 to 1500 kg/m^3, the foaming agent is added into the concrete mix with the purpose to achieve the desired density.

Two laboratory tests were carried out to test the thermal conductivity and acoustic insulation properties of the RLWFC. For the thermal conductivity test, the size of the specimen was cast in 300 mm x 300 mm x 100mm, whereas for the acoustic insulation test, the size of the specimen was cast in 60 mm x 20 mm and 30 mm x 20mm. In both tests, the specimen without crumb rubber acting as the control sample for this study. All the specimens were incubated in the water tank for a curing process of 28 days before carrying out the test. The steady-state heat flux method was used to test for the concrete specimen's thermal conductivity and the impedance tube was used to determine the sound absorption coefficient of the concrete specimens.

1.5 Importance of the Study

Nowadays, the increasing amount of scrap tyres has become a challenging task in waste management. The major issue is that scrap tyres can cause several impacts on the environment such as landfill overcrowding, pest threat and fire risk. To overcome this problem, it is best to recycle scrap tyres in an environmentally friendly way. Specifically, the recycled scrap tyres can be used in a variety of applications such as asphalt pavement construction, vibration absorption systems in the railroad, improving concrete properties, etc.

In this study, crumb rubber, which is the product from recycling scrap tyres, will be utilized as the concrete aggregate to produce rubberized lightweight foamed concrete with two types of crumb rubber and mixing proportion. By taking advantage of crumb rubber as the concrete materials, it can enhance the concrete's thermal insulation, sound absorption, and electrical resistivity. Thus, throughout this study, thermal conductivity and acoustic insulation of rubberized lightweight foamed concrete (RLWFC) and its eligibility for various civil applications can be ascertained.

1.6 Contribution of the Study

In this study, the adoption of crumb rubber in lightweight foamed concrete benefits the construction industry. A built structure using lightweight foamed concrete is generally lighter than the conventional building due to its lower self-weight. Basically, it reduces the total loading impact on the foundation due to its lightweight properties. Hence, the size of the structural supports can be reduced, which eventually reduces the project's cost. Besides that, utilizing crumb rubber as concrete aggregate minimize the environmental impact. By recycling the scrap tyres into crumb rubber, the number of scrap tyres can be reduced. Thus, the problem of landfill overcrowding can be solved. Moreover, rubberized lightweight foamed concrete has better thermal and acoustic insulating properties compared to conventional concrete. Due to good thermal insulating properties, the RLWFC can be used to construct partition wall especially in tropical countries such as Malaysia to reduce the heat transfer into the building. The great acoustic performance of RLWFC also help to reduce the echoes and sound resonance, thus, a comfortable environment can be maintained.

1.7 Outline of the Report

This report consists of total five chapters.

Chapters 1 brief about the introduction, problem statement of this study, aim and objectives, scoping, importance, contribution of this study as well as the outline of the report.

Chapter 2 is the literature review, which discusses the use of crumb rubber in the construction industry. Besides, it also covers the properties of rubberized lightweight concrete in term of thermal and acoustic insulation and its application. All the information is based on previous research studies.

Chapter 3 is the methodology, where it includes the preparation of the raw material, mixing procedure, casting procedure, and curing process. The steps for testing the concrete specimens' thermal conductivity and the sound absorption coefficient are stated as well.

Chapter 4 includes the finalized mix proportion of the concrete specimens. The recorded data from the thermal conductivity test and acoustic insulation test for both types of rubberized lightweight foamed concrete is also explained.

Chapter 5 summarizes the results of this study according to the respective objectives. Recommendations for future study are also provided to improve the outcomes.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In today's era, concrete as the major building materials has been widely used to construct structural components such as the beam, column, slab, foundation, etc. However, the normal-weight concrete (NWC) has an impact that the total loading act on the structure is generally large. Therefore, the use of lightweight concrete (LWC) has gained popularity as it has the benefit to reduce the self-weight of a structure. Lightweight concrete has been known for the past 2000 years. Early notable structures such as the Pantheon Dome shown in Figure 2.1, Coliseum and the Port of Cosa are constructed by using lightweight concrete during the early Roman Empire (Akers., et al, 2003).

Lightweight concrete is a type of concrete, whereby an expanding agent is introduced into the concrete to increase the volume resulting in reducing the weight of the mixture while increasing its stability. It has a lower unit weight than the NWC with about 2/3 of the weight of NWC (Zareh, 1971). The density of lightweight concrete is generally lower than the conventional concrete's density, which range from 300 kg/m^3 to 1840 kg/m^3 (Gaur, 2017). Thus, the weight reduction has benefit in the construction industry, whereby the size of the structural members can be reduced, which provide more usable space. Therefore, the cost of the project can be minimized.

Figure 2.1: The Pantheon (Muench, 2015).

2.2 Types of Lightweight Concrete

There are several ways to prepare lightweight concrete. Firstly, lightweight concrete can be produced by using aggregates such as blast furnace slag, shale or slate to produce a porous structure. This type of concrete produced is classified as structural lightweight concrete. Besides, aggregates with lower density material can be used to produce non-structural lightweight concrete by creating air voids to increase the volume during the concrete mix. Basically, lightweight concrete can be divided into three categories:

i. Lightweight Aggregate Concrete (LWAC)
ii. No-Fines Concrete (NFC)
iii. Aerated/Foamed Concrete

2.2.1 Lightweight Aggregate Concrete

Lightweight aggregate concrete is produced by mixing the cement, water, and porous lightweight concrete aggregate, which has low specific gravity such as clay, volcanic pumice, perlite, clinkers, etc. Figure 2.2 shows an example of lightweight aggregate concrete.

Lightweight aggregate concrete can be further classified into two categories, which is structural lightweight aggregate concrete and partially compacted lightweight aggregate concrete. For partially compacted lightweight aggregate concrete, it is suitable for application such as cast-in-situ walls and precast concrete blocks. It has the benefit that it increases the thermal insulation if it is cast with adequate strength (Samidi, 1997). While for structural lightweight aggregate concrete, the steel reinforcement that bond with the concrete improves the strength of the concrete. Therefore, with a variety of lightweight aggregate, lightweight aggregate concrete with a strength ranges from 30 to 80 MPa can be produced easily (Haque., et al, 2004).

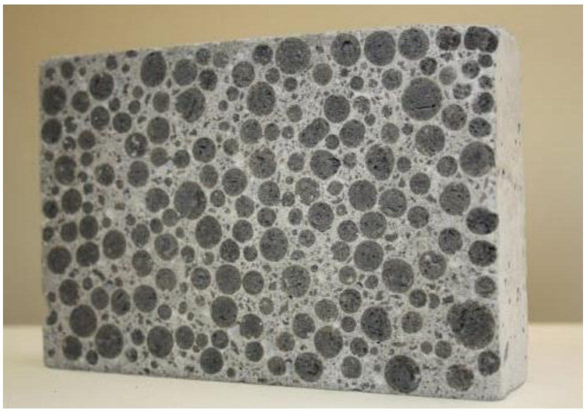

Figure 2.2: Lightweight Aggregate Concrete (Sharma, A, 2020).

2.2.2 No-Fines Concrete

No-fines concrete can be produced by mixing coarse aggregates, cement and water without the presence of fine aggregates. Generally, no-fines concrete has larger voids and low drying shrinkage compared to the normal weight concrete. It is suitable to be used for constructing both load-bearing and non-load-bearing walls. Besides, it can be used as a damp proof material. Figure 2.3 shows the no-fines concrete. Although no-fines aggregates can be used for both indoor and outdoor construction, it is important to use adequate water to cement ratio in producing the no-fines concrete, whereby different w/c ratio may result in different strength of the concrete. For example, insufficient water will reduce the cohesion between the aggregates and the cement, whereas excessive water can cause the formation of laitance layers due to cement running off from the aggregate, thereby loss in strength of the concrete.

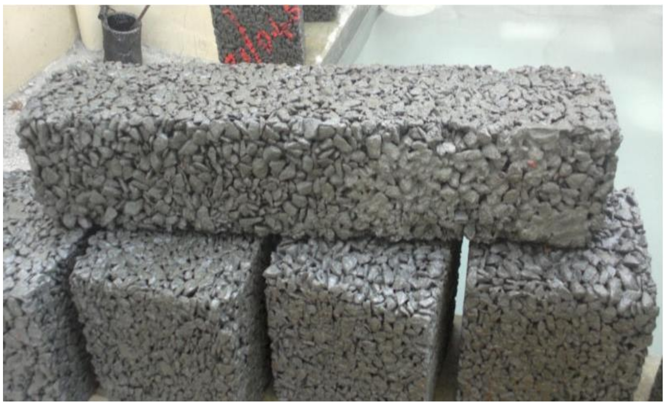

Figure 2.3: No-fines Concrete (Eathakoti, et al., 2015).

2.2.3 Aerated/Foamed Concrete

Aerated concrete is a type of lightweight concrete without the use of coarse aggregate in the concrete mix. Aerated concrete can be prepared by using two methods. The first method is by adding an expanding agent such as aluminium powder to react with the cement slurry to generate large voids in the concrete mix which will be known as autoclaved aerated concrete. For the second method, the foaming agent is introduced into the concrete mix, whereby the air will be entrapped into the concrete result in a lighter weight of the concrete, which is known as lightweight foamed concrete (LWFC) or lightweight cellular concrete. Autoclaved aerated concrete with high strength and low drying shrinkage is suitable to be used as precast concrete (Gaur, 2017). For lightweight foamed concrete, it is suitable to be used for in-situ concrete and non-structural concrete such as partition and roofing due to good thermal insulation properties. Figure 2.4 and Figure 2.5 show an example of AAC and LWFC.

Figure 2.4: Autoclaved Aerated Concrete (Krrish White Bricks, 2018).

Figure 2.5: Lightweight foamed Concrete (Sarmin, 2015).

2.3 Rubberized Lightweight Foamed Concrete

Rubberized lightweight foamed concrete (RLWFC) is the employment of crumb rubber in the concrete mix. In the past few decades, the amount of waste tyres has been increasing drastically and has become a serious environmental issue. To reduce the waste tyres problem, a lot of research has been done by recycling the waste tyres and use them as construction material. Therefore, it is expected that RLWFC will become more popular in the construction industry, whereby it achieved better thermal insulation and acoustic insulation than conventional concrete. Hence, according to Md Noor, et al, 2016, by using crumb rubber as an aggregate in the concrete, there is no doubt that RLWFC can help to stimulate one's country economy, especially from the construction industry.

2.4 Types of Rubber Aggregates

For the past few decades, a lot of investigation has been done on recycling the waste tyres as part of the aggregates in the concrete mix. These rubber aggregates are generally used to replace the coarse and fine aggregate in the concrete mix. Basically, these rubber aggregates can be classified into four categories depending on the rubber size and shape. Figure 2.6 shows the four types of rubber aggregates namely shredded, crumb, ground and fibre rubber aggregate.

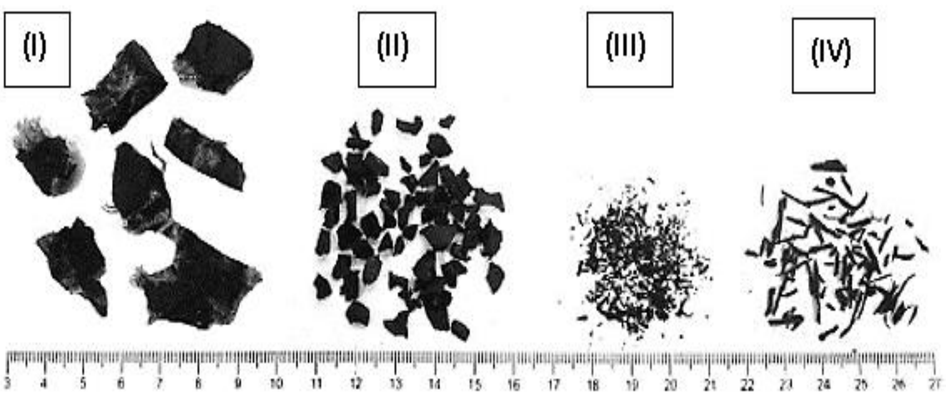

Figure 2.6: Rubber Aggregates: (I) Shredded, (II) Crumb, (III) Ground and (IV) Fibre (Busic, et al., 2018).

2.4.1 Shredded Rubber

Shredded rubber or also known as chipped rubber is produced by mechanical grinding with particles size ranging from 13 mm to 73 mm. It is usually used to replace the coarse aggregate or the natural gravel in the concrete. However, a study conducted by Panda, Parhi and Jena, 2012 on the shredded rubber aggregate as a replacement of coarse aggregate in concrete concluded that the compressive strength, split tensile strength and flexural strength has decreased when the replacement proportion of the shredded rubber aggregate increased. It is found that the reduction of the concrete strength is mainly due to the poor bonding between the rubber and the cement paste mix.

2.4.2 Crumb Rubber

Crumb rubber is a product of grinding waste tyres, which are free of fibre and steel. Crumb rubber can be produced through a few methods which include the cracker mill, micro mill and granulator method. The common size of crumb rubber particles produced ranges from 0.425 mm to 4.75 mm and it is suitable to be used to replace part of the proportion of the fine aggregates in the concrete mix. This type of rubber can be obtained easily in the market. Therefore, it is selected to be used in this study as the partial replacement of the fine aggregates in the concrete mix.

2.4.3 Ground Rubber

Ground rubber which also called granular rubber has a smaller size compared to shredded rubber. It is produced through two stages, which are magnetic separation and screening process. This type of rubber can be used as a partial replacement of the cement due to its size, which is smaller than 0.425 mm. However, the concrete’s workability is low due to the low friction between the rubber particles and the cementitious. Thus, it is recommended to add super-plasticized during the concrete mix to improve the workability of the concrete (Thomas and Gupta, 2016).

Comparing ground rubber and chipped rubber in term of their mechanical properties, it is found that the compressive strength and split tensile strength reduces when the percentage of rubber replacement increases. As shown in Figure 2.7, although the initial flexural strength of chipped rubber is higher, the reduction in the flexural strength for the ground rubber is lower than the chipped rubber (Ganjian, Khorami and Maghsudi, 2009). Therefore, with increasing rubber replacement, ground rubber possesses greater flexural strength compared to the chipped rubber.

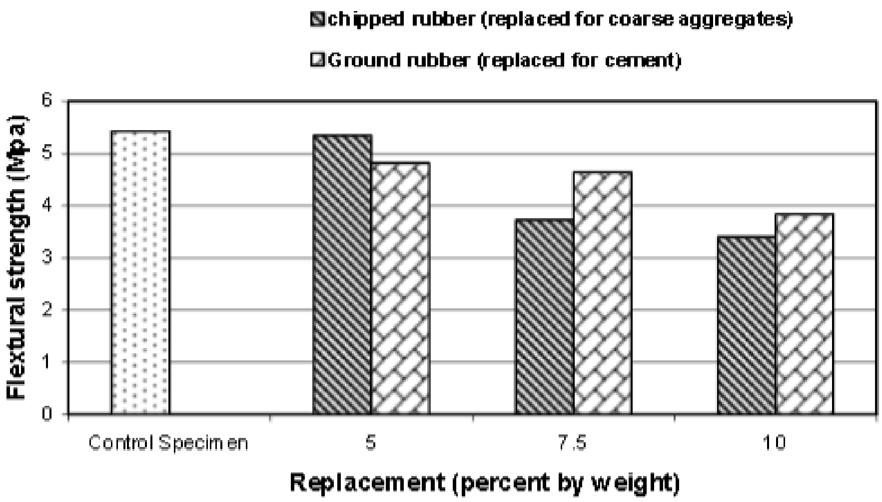

Figure 2.7: Flexural Strength Test for Shredded Rubber and Ground Rubber (Ganjian, Khorami and Maghsudi, 2009).

2.4.4 Fibre Rubber

Fibre rubber is another type of shredded rubber with a different shape. It is produced by using the tyre cutting machines which eventually will be cut in the form of strips. Normally, fibre rubber aggregate has a length between 8.5 mm to 21.5 mm with an average of 12.5 mm.

2.5 Application of Crumb Rubber

In the past 40 years, crumb rubber made from recycled tyres has been widely used in civil engineering applications, sports applications, and agricultural use. Besides, it also has been used as an additive in the asphalt mixture (Presti, 2013). The first country that implements crumb rubber in the asphalt application is in Phoenix, Arizona in 1960. By utilizing crumb rubber as an additive in the asphalt mixture, the performance of road pavement can be enhanced, whereby the crumb rubber has the benefit to increase the quality and the strength of the asphalt mixture (Wulandari and Tjandra, 2017). Figure 2.8 shows the production of rubberized asphalt through the wet process.

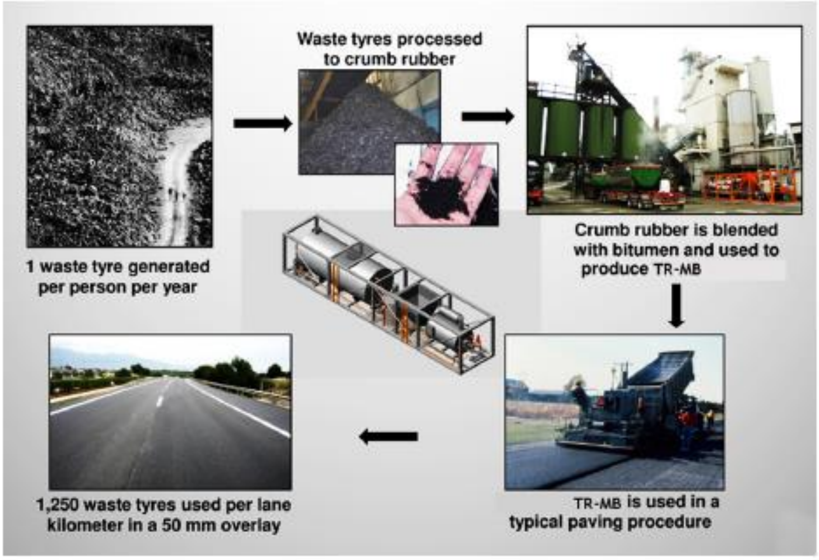

Figure 2.8: Production of Rubberized Asphalt Through Wet Process (Presti, 2013).

Other than that, according to Ganjian, et al, 2019, rubber has the capability to absorb the force of impact due to its great vibration resistance. With the inclusion of crumb rubber in the concrete mix, it is found that the seismic response acceleration can be reduced by about 27% which eventually reduce the seismic force that transfers to the foundation (Chiaro, et al., 2019). Therefore, it is suitable to be used to construct structures to reduce the seismic impact especially in those countries, which are in the seismic environment such as Japan.

2.6 Properties of Rubberized Lightweight Foamed Concrete

The percentage of crumb rubber replace the fine aggregate in the concrete mix will greatly affect the behaviour of the concrete. Studies have shown that mechanical properties such as compressive strength, flexural strength, splitting tensile strength will decrease with increasing crumb rubber particles content due to poor adhesion between the rubber particles and the cement paste. Although rubberized lightweight foamed concrete is not likely to be used for structural applications, however, it is found that the employment of crumb rubber in the concrete mix can increase the thermal and acoustic insulation of the concrete (Sukontasukkul, 2009).

2.6.1 Thermal Properties of Rubberized Lightweight Foamed Concrete

Thermal conductivity with the symbol k is defined as the amount of heat transferred through the cross-sectional area of an object differing to a unit of temperature. A high value of thermal conductivity indicates that the object is a great conductor, whereas a great insulator possesses a low value of thermal conductivity. From the previous studies, it is found that the thermal conductivity has an inverse relationship with the concrete's crumb rubber proportion. When the replacement proportion of crumb rubber increases, concrete's thermal conductivity decreases due to the crumb rubber's good insulating properties (Lim, et al., 2020). Besides, it is mainly due to air is entrapped on the surface of crumb rubber result in higher porosity of the concrete, which limit the quantity of heat to be transmitted (Kashani, et al., 2016). Figure 2.9 shows that the thermal conductivity decreases with increasing crumb rubber proportions. Therefore, rubberized lightweight foamed concrete which possesses low thermal conductivity is suitable to be used in tropical countries such as Malaysia.

Table 2.1: Thermal Conductivity of The Concrete Specimen with Increasing Crumb Rubber Proportions (Lim, et al., 2020).

Designation	**Thermal Conductivity ($W{\cdot}k^{-1}{\cdot}m^{-1}$)**	**Reduction percentage as opposed to the control sample (%)**
CR 0	1.1863	0
CR15	1.0737	9.49
CR30	0.9969	15.97
CR45	0.9733	17.95

2.6.2 Acoustic Properties of Rubberized Lightweight Foamed Concrete

Sound absorption coefficient (α) is defined as the ability of an object to absorb sound. However, it is difficult to determine which concrete specimen possesses greater acoustic performance with just the sound absorption coefficient. Therefore, the noise reduction coefficient (NRC) is introduced. According to Mohammed, 2012, rubberized lightweight concrete had better sound insulation properties as compared to conventional concrete where it is found that the NRC increases with an increasing percentage of the crumb rubber replacement. It is because the transmittance of sound is slower in the rubberized lightweight concrete due to the low velocity of sound in the crumb rubber. Figure 2.10 shows that PC without the inclusion of crumb rubber has the lowest NRC.

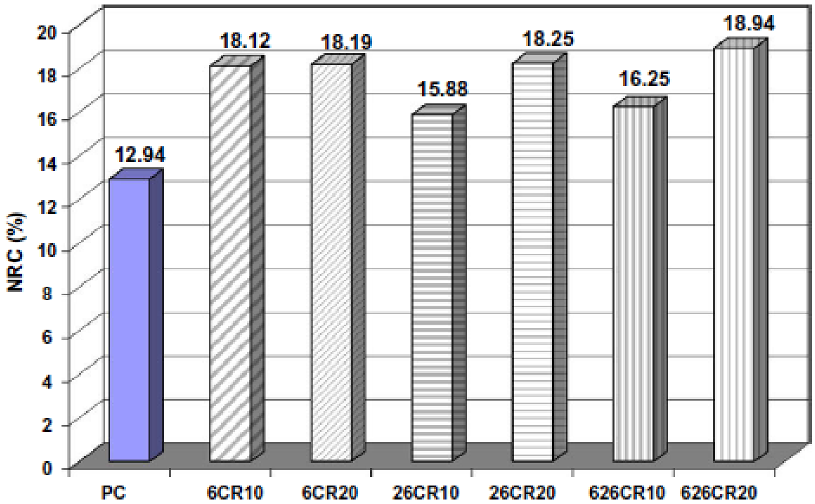

Figure 2.9: Noise Reduction Coefficient (Sukontasukkul, 2009).

2.7 Ordinary Portland Cement

Ordinary Portland Cement (OPC) is the most common cement used in the construction industry. According to ASTM C150, it is categorized as Type I cement. Table 2.2 shows the chemical composition of OPC, whereas Table 2.3 shows the compound composition of OPC.

Table 2.2: Chemical Composition of OPC (Neville, 2010).

Oxide	**Content %**
Al_2O_3	3 – 8
CaO	60 – 70
MgO	0.5 – 4.0
SO_3	2 – 3.5
Na_2O	0.3 – 1.2
Fe_2O_3	0.5 – 6.0
SiO_2	17 – 25

Table 2.3: Compound Composition of OPC (Neville, 2010).

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

2.8 Fine Aggregate

Aggregate plays an important role in the formation of concrete. The proportion and type of aggregate added into the concrete mix has a significant effect on the strength, workability and mechanical properties of the concrete. Generally, there are two types of aggregate which are fine and coarse aggregate. The coarse aggregate has a size which is above 4.75 mm, whereas the size of fine aggregate is smaller than 4.75mm and usually used in producing lightweight concrete. Lightweight concrete possesses higher compressive strength as compared to the conventional concrete produced by coarse aggregate. It is mainly due to its higher surface area which improves the force transfer between the fine aggregate particles (Lee, et al., 2018).

2.9 Foam

The foaming agent is usually added to produce concrete with lower density. There are two methods to produce foamed concrete which are the pre-foaming method and the mixed-foaming method. The pre-foaming method is by producing stable preformed aqueous foam and base separately, which will then be added into the base mix for blending. For the mixed-foaming method, the surfactant is added into the base mix and then thoroughly blend.

Preformed foam is produced by using a foam generator machine. It can be either wet foam or dry foam. Dry foam is produced by adding the foaming agent while compressed air is introduced into the mixing chamber simultaneously, whereas sprinkling the foaming agent over a fine mesh will produced wet foam. Generally, the size of dry foam is smaller than 1 mm whereas wet foam is larger than dry foam with a bubble size of 2 mm to 5 mm. Therefore, dry foam is considered more stable than wet foam due to its smaller size. Hence, according to Aldridge, 2005, dry foam is easier to be used for blending with the raw material in producing a foamed concrete.

2.10 Summary

Lightweight concrete has a lower unit weight than conventional concrete. Basically, there are three types of lightweight concrete, which consists of Lightweight Aggregate Concrete (LWAC), No-fines Concrete, and Aerated Concrete. Aerated Concrete can be further divided into autoclaved aerated concrete and lightweight foamed concrete. The difference between them is autoclaved aerated concrete is produced by adding an expanding agent while lightweight foamed concrete is produced by adding a foaming agent.

Over the past few decades, waste tyres have become a major environmental issue. Therefore, a lot of research has been done on recycling the waste tyres and used them in recreational and sport application, civil engineering application and products, asphalt road pavement, etc., to reduce the problem of waste tyres. Crumb rubber which is recycled waste tyres can be used as an additive in the asphalt mixture to improve the performance of the road pavement. Besides, it can also be used as an aggregate in the concrete mix to enhance the thermal insulation and acoustic insulation of the concrete. The concrete with the employment of crumb rubber is known as rubberized lightweight foamed concrete (RLWFC), whereby it possesses better thermal insulation and acoustic insulation than conventional concrete. Hence, it is suitable to be used to build the partition wall and roofing.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the raw materials used, mixing procedure, casting, and concrete to produce the rubberized lightweight foamed concrete (RLWFC) with fresh density ranging from 1400kg/m^3 to 1500kg/m^3 were discussed. Two types of crumb rubber were used which are granular and powdered and were replaced at an increment of 10% replacement proportion from 0% to 70%. Laboratory tests will be further conducted to study the thermal conductivity and acoustic insulation of RLWFC.

3.2 Raw Materials

The mixing compound used in producing RLWFC mainly consists of 5 types of raw materials: ordinary Portland cement, fine aggregate, crumb rubber, water, and foaming agent.

3.2.1 Ordinary Portland Cement

In this study, the cement used was Ordinary Portland Cement (OPC) named as “ORANG KUAT” branded from YTL Cement Sdn. Bhd which is certified to MS EN 197-1, CEM 1 42.5N. Portland cement has high strength and suitable to use for structural applications such as concreting, brickmaking, and screeding. The chemical composition and physical properties of the OPC were shown in Figure 3.2. Before mixing the concrete, the OPC was sieved through a 600 μm sieve and was put into the airtight container to prevent the entering of humid air that cause a premature hydration process.

Figure 3.1: "ORANG KUAT" Branded Ordinary Portland Cement (OPC).

Table 3.1: Chemical Composition and Physical Properties of OPC (YTL, 2017).

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

3.2.2 Fine Aggregate

In this study, sieve analysis was used to prepare for the fine aggregate. Before the sieving test, the sand was oven-dried at a temperature between 100 $°C$ to 110 $°C$ to remove the excess of water in the concrete. According to the standard specification of ASTM C778, sand that passes through 600 μm sieve size is categorized as fine aggregate. Thus, sand that sieved through 600 μm sieve size was used as the fine aggregate for concrete mixing.

3.2.3 Crumb Rubber

Two types of crumb rubber were used to mix the concrete, which is granular and powdered crumb rubber. The granular crumb rubber size is between 4.76 mm (No.4 Mesh) to 0.420 mm (No.40 Mesh) whereas powdered crumb rubber is below No.40 Mesh. Both types of crumb rubber were used to replace the fine aggregate from 0 % to 70 % with a 10 % replacement proportion.

3.2.4 Water

According to ASTM C1602, potable and non-potable water can be used as the mixing water. In this study, tap water was used in the concrete mix. The water-cement ratio was fixed as a constant variable with a ratio of 0.50 as this study mainly focuses on the crumb rubber's effect on the thermal conductivity and acoustic performance of RLWFC.

3.2.5 Foaming Agent

In this study, the rubberized lightweight foamed concrete (RLWFC) that produced was controlled at a density of 1450 kg/m^3 with a tolerance of ± 50 kg/m^3. A Foaming agent was introduced to control the density of RLWFC. The pre-form foaming method was performed to produce foam by using a foam generator and operate at a pressure of 0.5 MPa. Figure 3.3 shows the foam generator used to produce the foam with a density of 45 ± 5 kg/m^3. It was then mixed with the fresh rubberized lightweight concrete evenly until the desired density was achieved.

Figure 3.2: Foam Generator.

3.3 Mixing Procedure

In this study, all the materials were weighed based on the design mix proportion. The amount of crumb rubber to replace the fine aggregate was calculated according to the requirement of the specimens. Firstly, OPC, fine aggregate and crumb rubber were weighed and mixed uniformly in the concrete mixer. Next, the w/c ratio was set at a level of 0.5 and was mixed uniformly with the dry mix until the mortar was formed. The fresh density of the mortar was measured with the purpose to calculate the amount of foam to be added to reach the desired density. Foam is produced by using a foam generator which the volume of foam agent to water ratio is set at 1:20. Lastly, the foam is added to the mortar to achieve the desired density which is 1450 kg/m^3 with a tolerance of ± 50 kg/m^3.

3.4 Casting

The casting of the concrete specimen was cast in two types of moulds. Different types and sizes of mould were used to carry out the subsequent laboratory test. Before putting the fresh mixed concrete into the mould, a layer of oil was applied on the surface of the mould to ease the de-moulding work. The tampering and tapping process was conducted to remove trapped air in the fresh concrete. Table 3.1 shows the type and the dimension of mould prepared and the subsequent laboratory test to be conducted.

Table 3.2: Mould Dimension.

Laboratory Test	Type of Mould	Dimension of Mould (mm)
Thermal Conductivity Test	Rectangular	300 x 300 x 100 (length x width x height)
Acoustic Insulation Test	Cylindrical	60 x 20 and 30 x 20 (diameter x height)

3.5 Specimen Designation

In this study, thermal conductivity test and acoustic insulation test were conducted. The concrete specimens were classified into different type of crumb rubber used and different replacement proportion of the crumb rubber (from 0 % to 70 % with an increment replacement proportion of 10 %), shown in Table 3.2 and Table 3.3. CR–P0 act as the control sample in this study which it is without the replacement of crumb rubber.

Table 3.3: Thermal Conductivity Test Specimens.

Designation	W/C Ratio	Size of Specimen (mm)	Quantity
CR–P0	0.5	300 x 300 x 100	1
CR–P10	0.5	300 x 300 x 100	1
CR–P20	0.5	300 x 300 x 100	1
CR–P30	0.5	300 x 300 x 100	1
CR–P40	0.5	300 x 300 x 100	1
CR–P50	0.5	300 x 300 x 100	1
CR–P60	0.5	300 x 300 x 100	1
CR–P70	0.5	300 x 300 x 100	1
CR–G10	0.5	300 x 300 x 100	1
CR–G20	0.5	300 x 300 x 100	1
CR–G30	0.5	300 x 300 x 100	1
CR–G40	0.5	300 x 300 x 100	1
CR–G50	0.5	300 x 300 x 100	1
CR–G60	0.5	300 x 300 x 100	1
CR–G70	0.5	300 x 300 x 100	1

Note:

CR–P10 = 10% replacement proportion of Powdered Crumb Rubber.

CR–G10 = 10% replacement proportion of Granular Crumb Rubber.

Table 3.4: Acoustic Insulation Test Specimens.

Designation	W/C Ratio	Quantity	
		Diameter 60mm	Diameter 30mm
CR–P0	0.5	1	1
CR–P10	0.5	1	1
CR–P20	0.5	1	1
CR–P30	0.5	1	1
CR–P40	0.5	1	1
CR–P50	0.5	1	1
CR–P60	0.5	1	1
CR–P70	0.5	1	1
CR–G10	0.5	1	1
CR–G20	0.5	1	1
CR–G30	0.5	1	1
CR–G40	0.5	1	1
CR–G50	0.5	1	1
CR–G60	0.5	1	1
CR–G70	0.5	1	1

Note:

CR–P10 = 10% replacement proportion of Powdered Crumb Rubber.

CR–G10 = 10% replacement proportion of Granular Crumb Rubber.

3.6 Curing

After casting, the concrete specimens were let dry for 24 hours. The concrete specimens were then de-moulded and water curing process was conducted. The main purpose of conducting water curing is to let the concrete specimens gain strength. Then, the concrete specimens were incubated in the water tank for a water curing process of 28 days after de-moulded. The curing water temperature was controlled in a range of 24°C to 28°C.

3.7 Laboratory Tests

In this study, two laboratory tests were conducted to analyse crumb rubber's effect on the thermal conductivity and acoustic insulation of the concrete. For the thermal conductivity test, the concrete specimens' thermal properties were tested by using a thermal insulation measurement machine. Whereas for the acoustic insulation test, the sound absorption coefficient was obtained which tested by using an impedance tube.

3.7.1 Thermal Conductivity Test

To test for the concrete specimens' thermal conductivity, steady-state heat flux measurements and thermal transmission properties were conducted as complied with ASTM C177. Initially, the concrete specimen with a 300 mm x 300 mm x 100 mm dimension was placed in between two plates. One plate was heated to a temperature of 40 °C while another plate was maintained at room temperature at around 22 °C ± 2 °C. Simultaneously, the temperature changes between the cold plate, hot plate and concrete specimen were recorded every hour until the steady-state condition was achieved. The time to achieve the steady-state condition was recorded and the thermal conductivity value, k was determined for each concrete specimen.

3.7.2 Acoustic Insulation Test

According to ISO 10534-1, 1996, an impedance tube was used to determine the coefficient of sound absorption and impedance of the concrete specimens. Initially, the concrete specimen is placed into the sample holder. The sample holder was then set firmly into the impedance tube. The concrete specimens were tested at a variety range of frequency from 100 Hz to 4000 Hz. The concrete specimens with 60 mm diameter were tested at a low-mid frequency range from 100 Hz to 800 Hz whereas 30 mm diameter of concrete specimens were tested at a high-frequency range from 1000 Hz to 4000 Hz. When the experiment starts, the standing wave was produced in the tube and the ratio between minimum and maximum sound pressure was recorded. The concrete specimens' sound absorption coefficient was then tabulated from the recorded data.

3.8 Summary

To produce rubberized lightweight foamed concrete (RLWFC) with a density ranging from 1400 kg/m^3 to 1500 kg/m^3, five raw materials were prepared consist of ordinary Portland cement, fine aggregate, water, crumb rubber and foam. Firstly, the dry mix was carried out by mixing the cement, fine aggregate and crumb rubber according to the design mix proportion. Water was added last with a water to cement ratio of 0.5 to produce the mortar. The pre-forming method was used to produce foam to be added to the mortar to produce RLWFC with a density of 1450 kg/m^3 with a tolerance of ± 50 kg/m^3. The cement mortar was then cast in different size of mould for different test purpose.

After casting, all the specimens were oven-dried for 24 hours and incubated in the water tank to undergo the water curing process of 28 days. In this study, the concrete specimens with 300 mm x 300 mm x 100 mm dimension were used for the thermal conductivity test while 60 mm x 20 mm and 30 mm x 20 mm dimension were used for the acoustic insulation test. The size of the specimens was cast based on the standard size of the testing apparatus. A total of 30 concrete specimens was prepared for thermal conductivity test and acoustic insulation test. These specimens were cast by adding powdered crumb rubber and granular crumb rubber with an increment of 10% replacement proportion from 0 % to 70 %. The concrete specimen without the replacement of crumb rubber act as the control sample in this study.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter shows the mix proportion to prepare the rubberized lightweight foamed concrete with a density range from 1400 kg/m^3 to 1500 kg/m^3 with water to cement ratio maintained at a constant value of 0.5. Besides, two main tests were carried out, namely in thermal conductivity test and acoustic insulation test. For the thermal conductivity test, a guarded hot plate apparatus was used to determine the thermal conductivity, k, while an impedance tube was used to determine the sound absorption coefficient of the concrete specimens. The powdered and granular crumb rubber results that replace the fine aggregates from 0 % to 70 % were recorded and tabulated throughout the test. The lightweight foamed concrete without the addition of crumb rubber will act as the control sample in this study.

4.2 Mixed Proportion

In this study, rubberized lightweight foamed concrete with a density range from 1400 kg/m^3 to 1500 kg/m^3 was achieved by using the mixed proportion as shown in Table 4.1. The fine aggregate was replaced by powdered and granular crumb rubber in an increasing proportion from 0% to 70% and the proportion of each raw materials is shown in term of density in Table 4.1.

Table 4.1: Mix Proportion of each Concrete Specimens.

Concrete Specimen	**Cement (kg/m^3)**	**Sand (kg/m^3)**	**Water (kg/m^3)**	**Crumb Rubber (kg/m^3)**		**Foam (kg/m^3)**
				Powdered	**Granular**	
CR–P0	574.35	574.35	287.18	0.00	0	14.12
CR–P10	587.77	528.99	293.89	25.95	0	13.40
CR–P20	601.83	481.47	300.92	53.14	0	12.64
CR–P30	616.58	431.61	308.29	81.67	0	11.85
CR–P40	632.08	379.25	316.04	111.63	0	11.02
CR–P50	648.37	324.18	324.18	143.13	0	10.14
CR–P60	665.52	266.21	332.76	176.30	0	9.22
CR–P70	683.60	205.08	341.80	211.27	0	8.24
CR–G10	587.77	528.99	293.89	0	25.95	13.40
CR–G20	601.83	481.47	300.92	0	53.14	12.64
CR–G30	616.58	431.61	308.29	0	81.67	11.85
CR–G40	632.08	379.25	316.04	0	111.63	11.02
CR–G50	648.37	324.18	324.18	0	143.13	10.14
CR–G60	665.52	266.21	332.76	0	176.30	9.22
CR–G70	683.60	205.08	341.80	0	211.27	8.24

Note:

CR–P10 = 10% replacement proportion of Powdered Crumb Rubber.

CR–G10 = 10% replacement proportion of Granular Crumb Rubber.

4.3 Thermal Conductivity Test

In this study, the thermal conductivity value, k was determined by using the guarded hot-plate apparatus. A total of 23 hours were used in this test. The thermal conductivity value, k, for both powdered rubberized lightweight foamed concrete and granular rubberized lightweight foamed concrete was recorded.

4.3.1 Thermal Conductivity of Powdered Rubberized Lightweight Foamed Concrete

The thermal conductivity of the powdered rubberized lightweight foamed concrete was recorded and tabulated in Table 4.2. The achieved density and the foam volume percentage used was also shown in Table 4.2 for further discussion.

Table 4.2: Thermal Conductivity of Powdered Rubberized Lightweight Foamed Concrete.

Concrete Specimens	Density (kg/m^3)	Foam Volume Percentage (%)	Thermal Conductivity, k ($W·K^{-1}·m^{-1}$)
CS	1448	31	0.7634
CR–P10	1436	30	0.7224
CR–P20	1455	28	0.6642
CR–P30	1488	24	0.7223
CR–P40	1453	24	0.6751
CR–P50	1464	22	0.6502
CR–P60	1437	21	0.5837
CR–P70	1472	17	0.5783

Note:
CS = Control Sample.
CR–P10 = 10% replacement proportion of Powdered Crumb Rubber.

Throughout the thermal conductivity test, it is found that the control sample which is without the replacement of crumb rubber has the highest thermal conductivity, k value which is 0.7634 $W·K^{-1}·m^{-1}$. In contrast, the lightweight foamed concrete with 70 % replacement of powdered crumb rubber shows the lowest k value of 0.5783 $W·K^{-1}·m^{-1}$. Therefore, based on figure 4.1, the graph has shown that thermal conductivity has an inverse relationship to the crumb rubber replacement proportion.

When the powdered crumb rubber replacement proportion increases, the thermal conductivity decreases. However, at the replacement percentage of 30 %, there is a sudden increment of the thermal conductivity which opposes the relationship. According to Mydin, 2011, lightweight foamed concrete density has a linear relationship to thermal conductivity. The higher the density, the higher the thermal conductivity. Due to the higher density of CR-P30, it will cause a decrease in the porosity value, which means that the amount of air entrapped inside the concrete specimen will be lesser. Since air is a poor conductor, less air content inside CR–P30 will increase the thermal conductivity (Mydin, 2011). Besides that, it is found that CR–P40 has a slightly higher thermal conductivity compared to CR–P20 which is about 1.64 % of increment of k value. Due to its lower foam volume percentage, as shown in Table 4.2, the decrease of foam content will cause a decrease in the concrete's air content result in an increase in the thermal conductivity (Habsya, et al., 2018).

Overall, the thermal conductivity of RLWFC decreases as the replacement of powdered crumb rubber proportion increases. This is mainly due to powdered crumb rubber possessing a lower thermal conductivity value than the fine aggregate, which means when more and more of the fine aggregates are replaced by powdered crumb rubber, the thermal conductivity will eventually decrease. Furthermore, the higher the crumb rubber content, the higher the air will be entrapped inside the concrete, resulting in a lower thermal conductivity value (Medina, et al., 2017). Thus, the inverse relationship of crumb rubber to the thermal conductivity is satisfied.

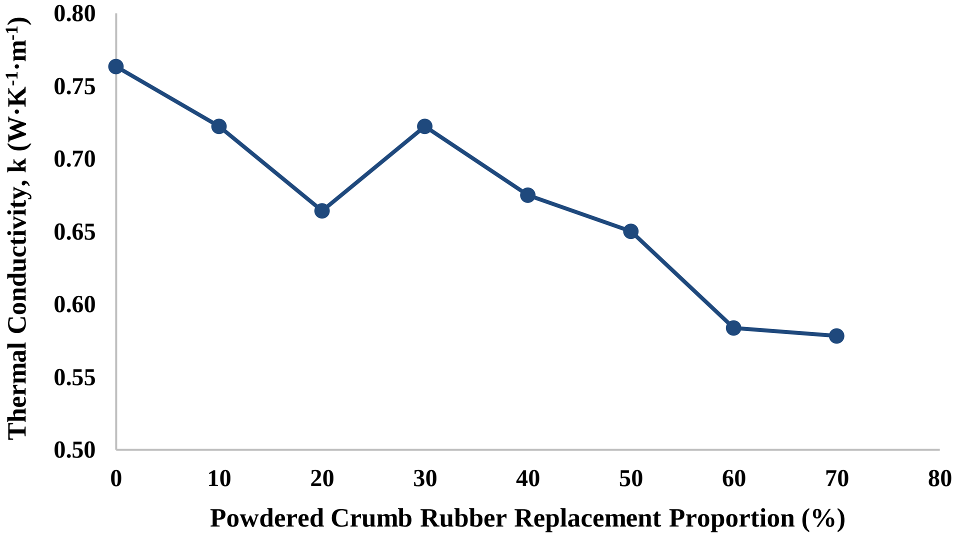

Figure 4.1: Graph of Thermal Conductivity versus Powdered Crumb Rubber Replacement Proportion.

4.3.2 Thermal Conductivity of Granular Rubberized Lightweight Foamed Concrete

The Thermal conductivity of the granular rubberized lightweight foamed concrete was recorded and tabulated in Table 4.3. The achieved density and the foam volume percentage used was also shown in Table 4.3 for further discussion.

Table 4.3: Thermal Conductivity of Granular Rubberized Lightweight Foamed Concrete.

Concrete Specimens	Density (kg/m^3)	Foam Volume Percentage (%)	Thermal Conductivity, k ($W \cdot K^{-1} \cdot m^{-1}$)
CS	1448	31	0.7634
CR–G10	1442	30	0.7196
CR–G20	1467	27	0.6492
CR–G30	1451	26	0.6204
CR–G40	1475	23	0.6274
CR–G50	1447	23	0.6117
CR–G60	1461	20	0.5643
CR–G70	1424	20	0.5494

Note:
CS = Control Sample.
CR–G10 = 10% replacement proportion of Granular Crumb Rubber.

Based on Figure 4.2, the thermal conductivity decreases when the percentage of granular crumb rubber replacement proportion become higher. Basically, the control sample still shows the highest thermal conductivity, whereas the RLFWC at 70 % replacement proportion of the crumb rubber shows the least thermal conductivity value. As shown in the graph in Figure 4.2, the thermal conductivity, k decreases from 0.7634 $W \cdot K^{-1} \cdot m^{-1}$ to 0.6204 $W \cdot K^{-1} \cdot m^{-1}$ at the replacement proportion from 0 % to 30 %.

However, when the fine aggregate is replaced by granular crumb rubber with 40 % replacement proportion, there is a slight increase of the thermal conductivity which is from 0.6204 $W \cdot K^{-1} \cdot m^{-1}$ to 0.6274 $W \cdot K^{-1} \cdot m^{-1}$. The increase of 1.1% of the thermal conductivity is mainly due to two factors. Firstly, the density of CR–G40 is slightly higher than CR–G30. Due to the difference in density, RLWFC with a higher density will have a lower porosity value, which means the air content inside the concrete is lesser, thus, increase the thermal conductivity. Another factor is because the foam content decrease as the granular crumb rubber replacement proportion increases. As stated in Table 4.3, the lower foam volume percentage of CR–G40 will cause a decrease in the air cavities of the concrete specimen. Since air possesses poor conductivity properties, lesser air content in the CR–G40 will cause a little increase in the thermal conductivity when compared to CR–G30.

As from 40 % to 70 % of the granular crumb rubber replacement proportion, the thermal conductivity decreases regardless of the percentage of foam volume in the RLWFC. It is because the decreases in the thermal conductivity are mostly contributed by the addition of granular crumb rubber. As the granular crumb rubber proportion increases, the proportion of sand in the concrete mix also decrease subsequently. Furthermore, since crumb rubber possesses great insulating properties than sand, the amount of air entrapped onto the crumb rubber surface is larger. Therefore, the thermal conductivity dropped with the increased proportion of crumb rubber (Benazzouk, et al., 2008). Hence, CR–G70 with the highest replacement proportion of granular crumb rubber will result in the lowest thermal conductivity value due to higher air content inside the concrete specimen.

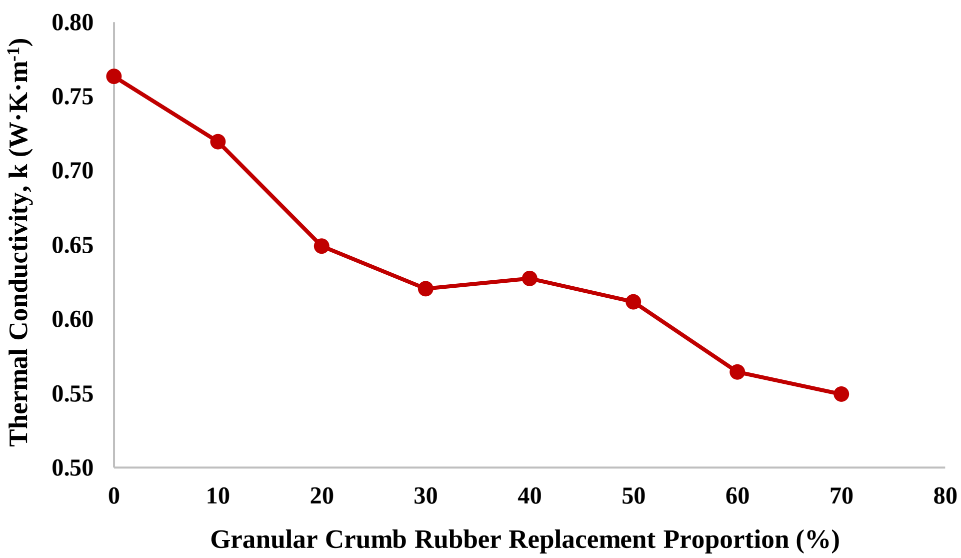

Figure 4.2: Graph of Thermal Conductivity versus Granular Crumb Rubber Replacement Proportion.

4.3.3 Comparison of Thermal Conductivity between Powdered Crumb Rubber and Granular Crumb Rubber

According to Figure 4.3, the graph shows that the inclusion of both powdered and granular crumb rubber into lightweight foamed concrete has reduced the thermal conductivity. When compared powdered and granular crumb rubber, it is found that the concrete specimen's thermal conductivity with the replacement of granular crumb rubber is generally lower than powdered crumb rubber. The results have shown that the thermal conductivity of CR-G70 with the k value of 0.5494 $W \cdot K^{-1} \cdot m^{-1}$ is the lowest among all the concrete specimens.

The main factor is due to the difference in the size of the crumb rubber. Since granular crumb rubber has a larger surface than powdered crumb rubber, the chance to contact the air will increase. As crumb rubber are non-polar and due to the higher area of contact of granular crumb rubber, more air particles will be entrapped on their surface. As a result, with the highest crumb rubber content of CR–G70, it will significantly increase the air content in the concrete specimen, which eventually decreases the thermal conductivity.

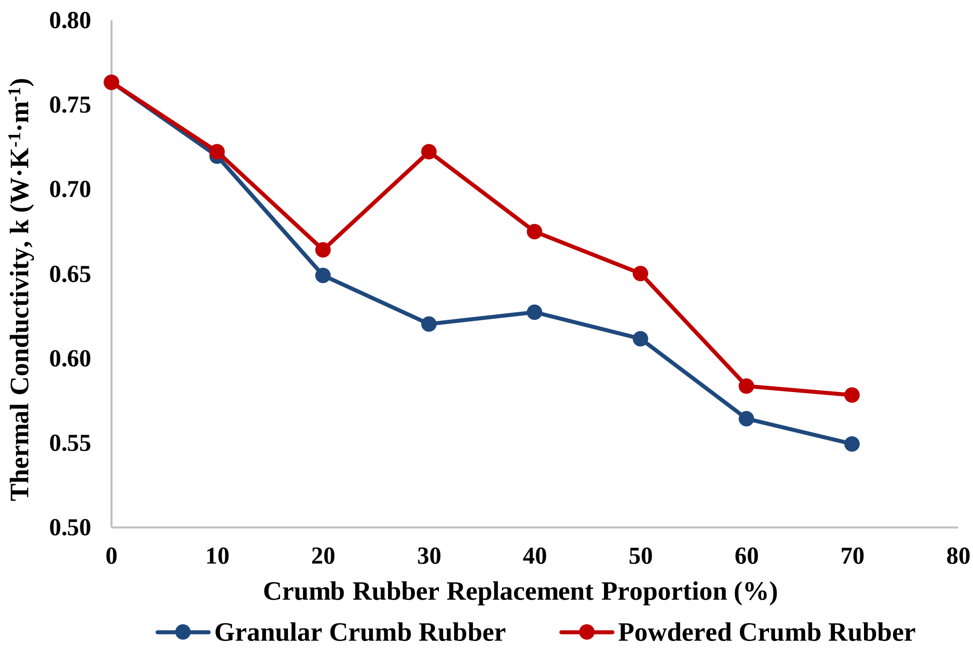

Figure 4.3: Graph of Thermal Conductivity versus Powdered and Granular Crumb Rubber Replacement Proportion.

4.3.4 Thermal Conductivity Reduction Efficiency

Table 4.4 shows the reduction efficiency of concrete specimens, which is calculated with respect to the control sample.

Table 4.4: Thermal Conductivity Reduction Efficiency of Concrete Specimens

Concrete Specimens	Thermal Conductivity, k ($W \cdot K^{-1} \cdot m^{-1}$)	Reduction Efficiency (%)
CS	0.7634	–
CR–P10	0.7224	5.37
CR–P20	0.6642	13.00
CR–P30	0.7223	5.38
CR–P40	0.6751	11.57
CR–P50	0.6502	14.83
CR–P60	0.5837	23.54
CR–P70	0.5783	24.25
CR–G10	0.7196	5.74
CR–G20	0.6492	14.96
CR–G30	0.6204	18.73
CR–G40	0.6274	17.82
CR–G50	0.6117	19.87
CR–G60	0.5643	26.20
CR–G70	0.5494	28.03

Note:

CS = Control Sample.

CR–P10 = 10% replacement proportion of Powdered Crumb Rubber.

CR–G10 = 10% replacement proportion of Granular Crumb Rubber.

Based on Figure 4.4, the thermal conductivity reduction efficiency increases with increasing replacement proportion of crumb rubber. Among the lightweight foamed concrete with powdered crumb rubber, CR–P70 shows the greatest thermal conductivity reduction efficiency with a value of 24.25 %. This concludes that the higher the replacement proportion of crumb rubber, the higher the thermal conductivity reduction efficiency due to higher air content in the concrete specimens. Comparing thermal conductivity reduction efficiency between powdered and granular crumb rubber, CR–G70 has a reduction efficiency value of 28.03 % which is more effective than CR–P70 due to its larger surface of crumb rubber. A larger surface of crumb rubber tends to entrap more air onto it resulting in a lower thermal conductivity value.

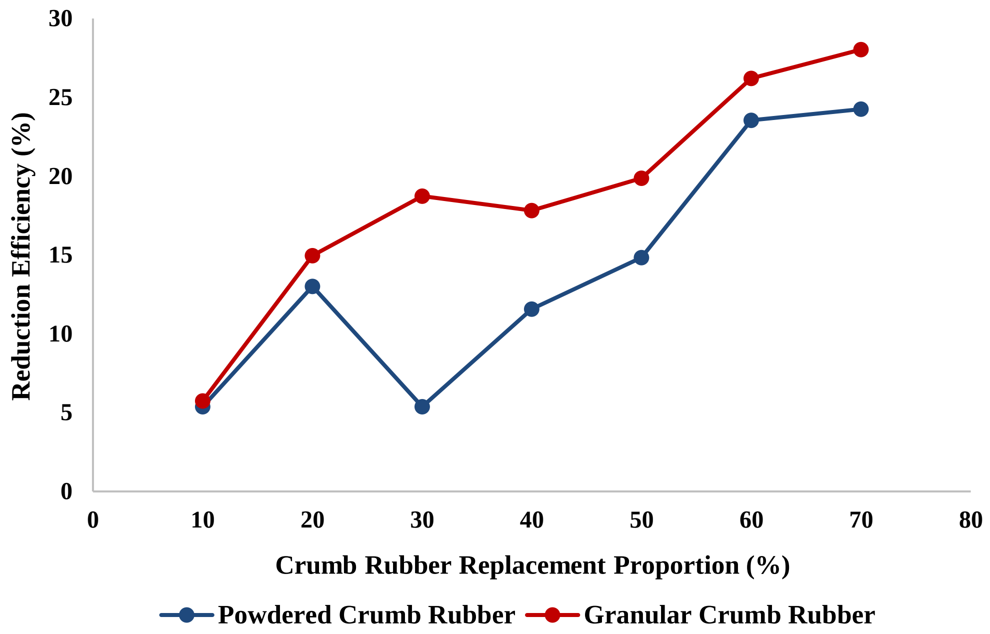

Figure 4.4: Graph of Thermal Conductivity Reduction Efficiency versus Powdered and Granular Crumb Rubber Replacement Proportion.

4.4 Acoustic Insulation Test

In this study, the impedance tube was used to test for concrete specimens' sound absorption coefficient. Two different sizes were prepared for each concrete specimen. Concrete specimens with 60 mm diameter were tested at a low-mid frequency range from 100 Hz to 800 Hz, whereas 30 mm diameter were tested at a high-frequency range from 1000 Hz to 4000 Hz. The sound absorption coefficient of each concrete specimen tested in the frequency range from 100 Hz to 4000 Hz was recorded and combined.

4.4.1 Acoustic Performance of Powdered Rubberized Lightweight Foamed Concrete

Table 4.5 illustrate the sound absorption coefficient of powdered rubberized lightweight foamed concrete at the frequency range from 100 Hz to 4000 Hz.

Table 4.5: Sound Absorption Coefficient of Powdered Rubberized Lightweight Foamed Concrete.

Frequency (Hz)	**Sound Absorption Coefficient, α (%)**							
	CS	**P10**	**P20**	**P30**	**P40**	**P50**	**P60**	**P70**
100	68	24	10	46	39	51	10	16
125	36	18	2	20	6	26	11	4
160	40	36	13	8	2	3	27	30
200	57	2	3	8	4	2	21	12
250	51	2	2	7	9	9	10	14
315	23	9	7	7	10	11	14	9
400	13	8	8	8	7	7	8	7
500	9	4	4	7	4	4	5	6
630	7	2	1	1	2	2	2	1
800	4	3	3	3	3	3	2	3
1000	10	8	9	10	9	9	10	8
1250	7	5	3	6	6	6	6	4
1600	9	10	6	7	5	6	7	4
2000	9	11	8	7	7	10	7	10
2500	16	19	10	10	10	12	11	7
3150	17	16	10	6	8	6	11	5
4000	29	11	11	5	10	9	13	7

Note:

CS = Control Sample.

P10 = 10% replacement proportion of Powdered Crumb Rubber.

Based on Figure 4.5, it is found that most of the powdered rubberized lightweight foamed concrete including the control sample are having a great sound absorption coefficient at the low frequency range from 100 Hz to 400 Hz. As the frequency increase to the middle frequency range of 500 Hz to 800 Hz, the sound absorption coefficient decreases to an average value of 3 %, which shows the poor ability of powdered rubberized lightweight foamed concrete to absorb the sound at the middle frequency range. At a higher frequency range of 1000 Hz to 4000 Hz, it is found that there is an improvement of the sound absorption coefficient of the concrete specimens which indicate that the concrete specimens are capable to absorb sound where the control sample showed the highest value of sound absorption coefficient of 29 %.

Therefore, when comparing the sound absorption coefficient, the control sample exhibit the best acoustic performance compared to the lightweight foamed concrete with the inclusion of powdered crumb rubber. Basically, the sound absorption coefficient is affected by the density of concrete, void content, and the concrete's crumb rubber replacement proportion. In this study, since density is maintained in the range of 1400 kg/m^3 to 1500 kg/m^3, density does not contribute much to the sound absorption coefficient. Since the control sample, which is the lightweight foamed concrete without the inclusion of powdered crumb rubber, the concrete's void content is said to be the highest. The higher the void content, the easier the sound to be absorbed into the concrete. Hence, powdered crumb rubber's addition into the lightweight foamed concrete reduces the void content due to its impervious nature properties resulting in a lower sound absorption coefficient than the control sample (Holmes, 2014).

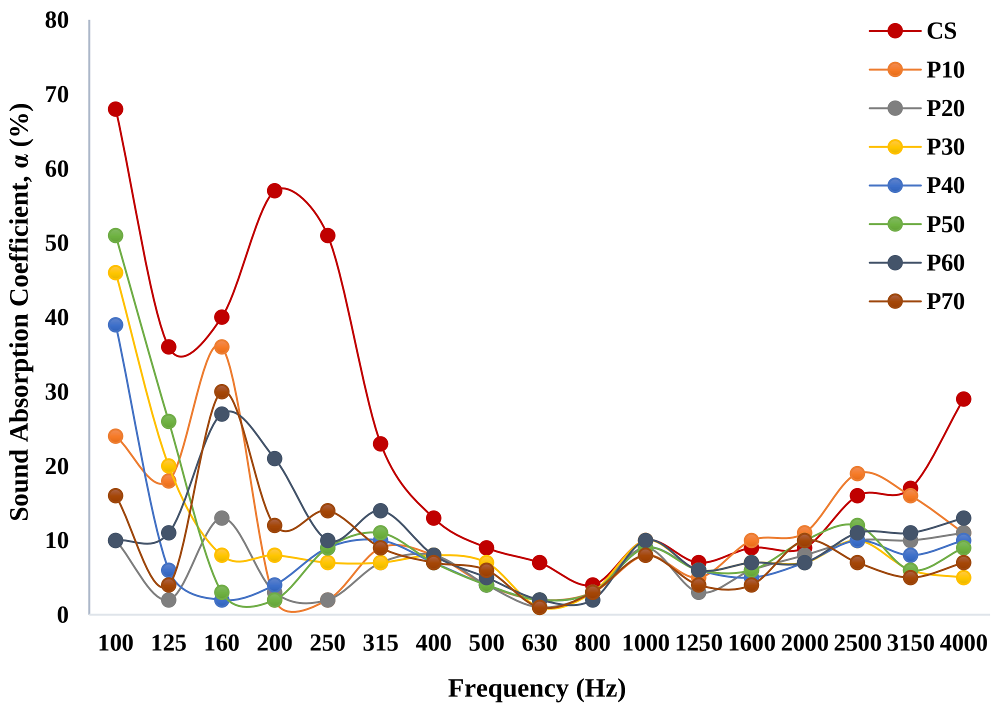

Figure 4.5: Graph of Sound Absorption Coefficient of Powdered Rubberized Lightweight Foamed Concrete versus Frequency.

4.4.2 Acoustic Performance of Granular Rubberized Lightweight Foamed Concrete

Table 4.6 illustrate the sound absorption coefficient of powdered rubberized lightweight foamed concrete at the frequency range from 100 Hz to 4000 Hz.

Table 4.6: Sound Absorption Coefficient of Granular Rubberized Lightweight Foamed Concrete.

Frequency (Hz)	**Sound Absorption Coefficient, α (%)**							
	CS	**G10**	**G20**	**G30**	**G40**	**G50**	**G60**	**G70**
100	68	56	54	56	57	56	57	54
125	36	11	28	22	22	26	42	33
160	40	39	54	22	53	30	38	16
200	57	43	41	54	47	39	39	51
250	51	39	40	39	41	40	40	41
315	23	9	9	7	11	11	14	13
400	13	1	2	3	3	2	1	2
500	9	5	4	5	5	4	6	4
630	7	1	1	2	2	2	1	2
800	4	4	4	4	3	4	4	4
1000	10	10	9	10	10	9	9	10
1250	7	7	6	8	8	6	8	6
1600	9	8	8	11	11	6	10	8
2000	9	11	6	10	9	8	9	12
2500	16	17	9	12	14	4	14	18
3150	17	16	5	10	7	5	4	17
4000	29	20	17	13	5	6	14	16

Note:

CS = Control Sample.

G10 = 10% replacement proportion of Granular Crumb Rubber.

Based on Figure 4.6, it is found that the concrete specimens exhibit similar sound absorption coefficient value at the low-mid frequency range of 100 Hz to 800 Hz. This concluded that the concrete specimens are effective in absorbing sound at low-mid frequency. As the frequency raise from 1000 Hz to 4000 Hz, the control sample still leading in the sound absorption coefficient with a value of 29% whereas the lightweight foamed concrete with a 40 % replacement proportion of granular crumb rubber shows the least sound absorption coefficient of only 5%.

When comparing granular crumb rubber with powdered crumb rubber, granular rubberized lightweight foamed concrete seems to have a better sound absorption coefficient. The main reason is mainly due to the difference in the size of the crumb rubber. According to Holmes, 2014, a larger size crumb rubber is more effective in absorbing sound due to its large surface area. Since granular crumb rubber is larger, the surface area exposed in the concrete is generally bigger than powdered crumb rubber result in a higher sound absorption coefficient. Moreover, powdered crumb rubber is easier than granular crumb rubber to enter into concrete's void. Hence, the porosity of the concrete reduces result in a lower sound absorption coefficient (Sukontasukkul, 2009).

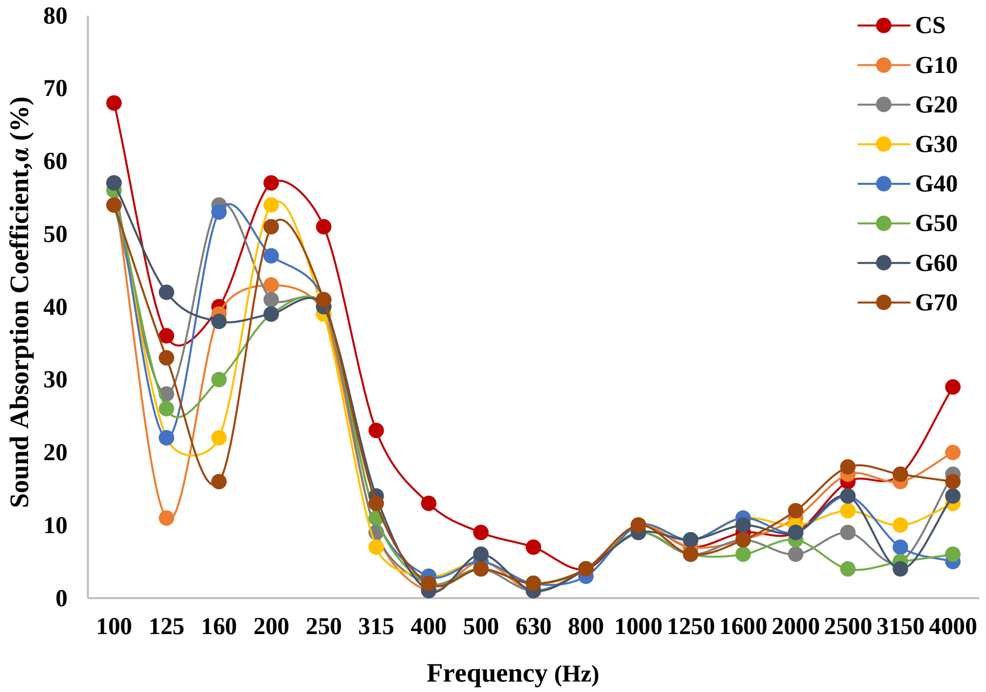

Figure 4.6: Graph of Sound Absorption Coefficient of Granular Rubberized Lightweight Foamed Concrete versus Frequency.

4.4.3 Overall Acoustic Performance of Concrete Specimens

Since the sound absorption coefficient are tested in a wide range of frequency, it is difficult to determine which specimens show better acoustic performance. Therefore, the noise reduction coefficient is introduced, which can be calculated by using Equation 1 as shown below. Table 4.7 show the noise reduction coefficient of the concrete specimens.

$$NRC = (\boldsymbol{\alpha}_{250} + \boldsymbol{\alpha}_{500} + \boldsymbol{\alpha}_{1000} + \boldsymbol{\alpha}_{2000})/4 \quad (1)$$

Table 4.7: Noise Reduction Coefficient of Concrete Specimens.

Concrete Specimens	Frequency (Hz)				Noise Reduction Coefficient (%)
	250	500	1000	2000	
	Sound Absorption Coefficient, α (%)				
CS	51	9	10	9	19.75
P10	2	4	8	11	6.25
P20	2	4	9	8	5.75
P30	7	7	10	7	7.75
P40	9	4	9	7	8.00
P50	9	4	9	10	8.00
P60	10	5	10	7	8.00
P70	14	6	8	10	9.50
G10	39	5	10	11	16.25
G20	40	4	9	6	14.75
G30	39	5	10	10	16.00
G40	41	5	10	9	16.25
G50	40	4	9	8	15.25
G60	40	6	9	9	16.00
G70	41	4	10	12	16.75

Note:

CS = Control Sample.

P10 = 10% replacement proportion of Powdered Crumb Rubber.

G10 = 10% replacement proportion of Granular Crumb Rubber.

Based on Figure 4.7, the control sample which is the lightweight foamed concrete without the inclusion of crumb rubber show the highest noise reduction coefficient of 19.75 %. Among the powdered rubberized lightweight foamed concrete, P70 has the greatest noise reduction coefficient of 9.50 %. Meanwhile, G70 has the highest noise reduction coefficient of 16.75% among the granular rubberized lightweight foamed concrete. Therefore, the control sample is said to have the best acoustic performance among all the concrete specimens. The reason is that the control sample possesses the greatest amount of void content in which it tends to absorb more sound than the rubberized lightweight foamed concrete. The addition of crumb rubber will reduce the void content in the concrete causes a decrease in the sound absorption coefficient.

Besides, for concrete specimens with the inclusion of crumb rubber, the noise reduction coefficient increases with the increasing replacement proportion of crumb rubber. According to Mohammed, 2012, when the replacement proportion of crumb rubber increases, the amount of air entrapped on the crumb rubber surface also increase. As a result, sound can be easily absorbed into the concrete and less sound will be reflected, thereby increasing the noise reduction coefficient. Moreover, since granular crumb rubber has a larger surface area than powdered crumb rubber, more sound can be absorbed, which is proved by the results in this study that G70 has a higher noise reduction coefficient than P70.

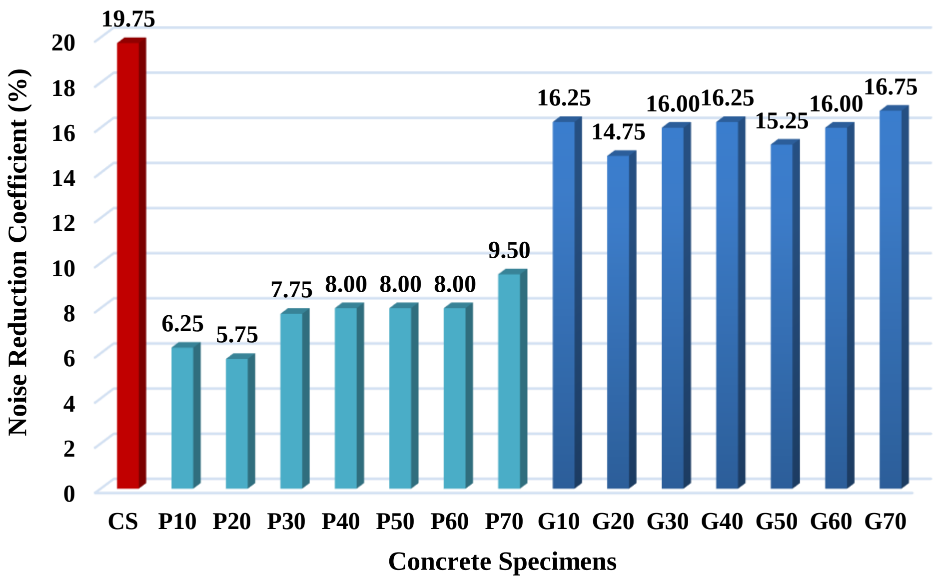

Figure 4.7: Noise Reduction Coefficient of Concrete Specimens.

4.5 Summary

With the mix proportion, the produced rubberized lightweight foamed concrete was within the desire density range of 1400 kg/m^3 to 1500 kg/m^3. For the thermal conductivity test, it was found that the addition of crumb rubbers is capable in reducing the concrete specimens' thermal conductivity. Basically, crumb rubber replacement proportion has shown an inverse relationship with thermal conductivity. With a larger size and higher proportion of the crumb rubber, the air content in the concrete increase significantly which lead to the lowest thermal conductivity value as proven by CR-G70. Besides, the thermal conductivity reduction was also due to the great insulation properties possessed by crumb rubber.

As for the acoustic insulation test, the inclusion of crumb rubber in the lightweight foamed concrete reduced the acoustic performance. It was found that the addition of crumb rubber reduces the void content in the concrete. As the void space is occupied, the sound is hardly to be absorbed by the concrete result in a low sound absorption coefficient. Since the control sample which is the lightweight foamed concrete without the inclusion of crumb rubber has the highest void content, it is more effective in absorbing the sound result in the best acoustic performance among the concrete specimens. Comparing powdered crumb rubber and granular crumb rubber, granular rubberized lightweight foamed concrete shows better results of the sound absorption coefficient due to its larger surface. Larger surfaces entrap more air, which helps to absorb more sound, therefore increase the sound absorption coefficient.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

With the mix proportion stated in the discussion and w/c ratio of 0.5, rubberized lightweight foamed concrete with a density range from 1400 kg/m^3 to 1500 kg/m^3 was produced, which satisfy this study's aim. The density of the concrete specimens is found to be fall within the range of the desired density.

The first objective in this study is to investigate the effect of crumb rubber with a replacement proportion of 10 % interval from 0 to 70 % on the thermal conductivity of rubberized lightweight foamed concrete. The results show that the lightweight foamed concrete, which is the control sample, has the highest thermal conductivity value of 0.7634 W·K^{-1}·m^{-1}. As for rubberized lightweight foamed concrete with increasing replacement proportion of crumb rubber, the thermal conductivity shows a decreasing trend due to crumb rubber's great insulation properties. The granular rubberized lightweight foamed concrete achieved the highest thermal conductivity reduction efficiency of 28.03 % with respect to the control sample.

For the second objective, the effect of crumb rubber with a replacement proportion of 10 % interval from 0 to 70 % on the acoustic insulation of rubberized lightweight foamed concrete is determined. From the results, by calculating the noise reduction coefficient of the concrete specimens, it is found that the lightweight foamed concrete which is the control sample shows the best acoustic performance with the NRC value of 19.75 % followed by granular rubberized lightweight foamed concrete and powdered rubberized lightweight foamed concrete. The inclusion of crumb rubber tends to reduce the void content which generally lowers the sound absorption coefficient. However, with increasing crumb rubber replacement proportion, more air will be entrapped on the surface of crumb rubber resulting increase in the sound absorption coefficient.

The optimal mix proportion of granular and powdered crumb rubber that depict the most favourable thermal and sound insulation properties is determined for the last objectives. In term of thermal conductivity, with the increasing crumb rubber proportion, CR-G70 show the lowest thermal conductivity value of 0.5494 $W \cdot K^{-1} \cdot m^{-1}$. As for powdered rubberized lightweight foamed concrete, CR-P70 has the lowest thermal conductivity value of 0.5783 $W \cdot K^{-1} \cdot m^{-1}$ but still slightly higher than CR-G70 which show that granular crumb rubber possesses better thermal insulation properties than powdered crumb rubber. In term of acoustic performance, with increasing replacement proportion of crumb rubber, there is no improvement of the sound absorption coefficient. The noise reduction coefficient of the rubberized lightweight foamed concrete decreases as compared to the control sample. As compare between granular crumb rubber and powdered crumb rubber, the lightweight foamed concrete with a 70 % replacement proportion of granular crumb rubber shows a better noise reduction coefficient than powdered crumb rubber due to its larger surface area.

5.2 Recommendations

Throughout the study, the thermal conductivity was improved by the addition of crumb rubber in the lightweight foamed concrete. However, there is still not much of research on lightweight foamed concrete's acoustic performance in the construction field. Therefore, some recommendations can be taken into consideration for future research.

i. Decrease the density of the concrete specimens since the sound absorption coefficient has an inverse relationship with density.
ii. Adopt a longer curing period to study the long-term effects of crumb rubber on the thermal conductivity and acoustic insulation properties of lightweight foamed concrete.
iii. Adopt the different way of curing processes such as steam curing or air curing to reduce the formation of crack that will affect the results.

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