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Published by the Faculty of Engineering, Khon Kaen University, Thailand

Effect of size and amount of lightweight expanded clay aggregate on normal incidence sound absorption coefficient of concrete

Siwat Lawanwadeekul*, Pincha Torkittikul, Soravich Mulinta, Thitima Khunyotying, Winai Tasang and Mattika Bunma

Faculty of Industrial Technology, Lampang Rajabhat University, Lampang 52100, Thailand

Received 17 November 2022
Revised 19 March 2023
Accepted 21 March 2023

Abstract

This study focused on lightweight expanded clay aggregate (LECA) sizes and quantitatively on concrete's average incidence sound absorption coefficient. LECA samples were produced in three different sizes, namely, large (20 mm), medium (10 mm), and small (5 mm), and were used as the coarse aggregate replacement for cement in various ratios. All the samples were analyzed for physical properties, mechanical properties, and normal-incidence sound absorption coefficients. The results revealed that samples containing less than 50% LECA replacement passed the standard requirement. Nevertheless, a small LECA with a 100% sample is also intriguing. The normal-incidence sound absorption coefficient was more than ten times higher than that of normal concrete.

Keywords: Lightweight expanded clay aggregate, Sound absorption coefficient, Concrete, Compressive strength

1. Introduction

The focus on noise problems in building materials was not prevalent 15 years ago. Nevertheless, noise pollution in highly populated countries is expected to increase dramatically [1]. Thus, noise pollution causes people to be more sensitive to it. Despite their harmful effects on human health, these building materials continue to be developed.

Concrete is one of the most common construction materials used globally. It comprises four essential ingredients: cement, gravel as a coarse aggregate, sand as a fine aggregate, and water. The authors recently proposed the thermal-acoustic clay brick to solve heat and noise pollution [2]. The normal-incidence sound absorption coefficient of clay bricks increases because they are rich in porosity, but these pores cause the compressive strength to drop rapidly. However, the authors asserted that these porous bricks could be converted into aggregates for use as concrete by transforming porous granulates.

A lightweight expanded clay aggregate (LECA) is a porous ceramic product with a uniform porous structure fired between 1100 and 1300℃ [3-4]. In addition, LECA consists of abundant small air-filled cavities, resulting in lightweight, thermal, and sound isolation characteristics [5, 6]. LECA is a multipurpose material used in various applications and is widely used to produce lightweight concrete or precast in the construction field [7]. However, the standard incidence sound absorption coefficient of LECA is a minor focus in this research field [8-10].

All materials can absorb sound to some extent, but it is necessary to resort to sound wave motion and acoustic impedance. The acoustic impedance was defined at the surface of the material. It should be noted that acoustic impedances vary according to the thickness of the material and backing condition. Concrete using LECA is a porous absorber. When sound waves crash on a porous material containing an air pipe, they propagate into crevices. The sound energy is slightly decreased by friction and viscosity within the pores and by the vibration of the material [11].

H.K. Kim and H.K. Lee studied the influence of various aggregates added to concrete on mechanical and acoustic characteristics [12]. Their results demonstrated that the total porous ratios of samples were higher when used with small aggregates and higher percentages because they are related to the surface area of the aggregates. In addition, G. Lannace used the shredding of worn tires and various green materials with different particle sizes and thicknesses to fabricate sound-absorbing materials [13, 14]. The absorption coefficient was then measured using the impedance tube method. The results showed that the materials with different particle sizes and thicknesses differed because of their density and flow resistivity.

Some studies have shown that the particle sizes of porous media affect acoustic properties, but this is a minor focus. The authors explained that the normal incidence sound absorption coefficient of clay bricks is increased because they are rich in porosity, but these pores cause the compressive strength to drop rapidly. Thus, the authors focused not only on the effect of LECA sizes and quantities on the normal incidence sound absorption coefficient but also on the compressive strength that can pass the standard. In addition, the acoustic impedance is described in this study.

*Corresponding author.
Email address: b_siwat@g.lpru.ac.th
doi: 10.14456/easr.2023.21

2. Materials and methods

2.1 Raw materials and preparation of concrete samples

The Ordinary Portland Cement type1 was used in this study. It is a general-purpose cement suitable for all applications. The good-grade sand and gravel were dried in an oven at 110 °C for 48 h to ensure the aggregates would not wet before mixing. At the same time, LECA was produced from 2-mm sized charcoal mixed with clay at a ratio of 30 wt%. The components were blended by hand until they became homogeneous and fired at 1100°C for 6 h. The firing LECA was sieved in three different sizes: large (L:20 mm), medium (M:10 mm), and small (S:5 mm), as shown in Figure 1. The physical properties of sand, gravel, and LECA are presented in Table 1.

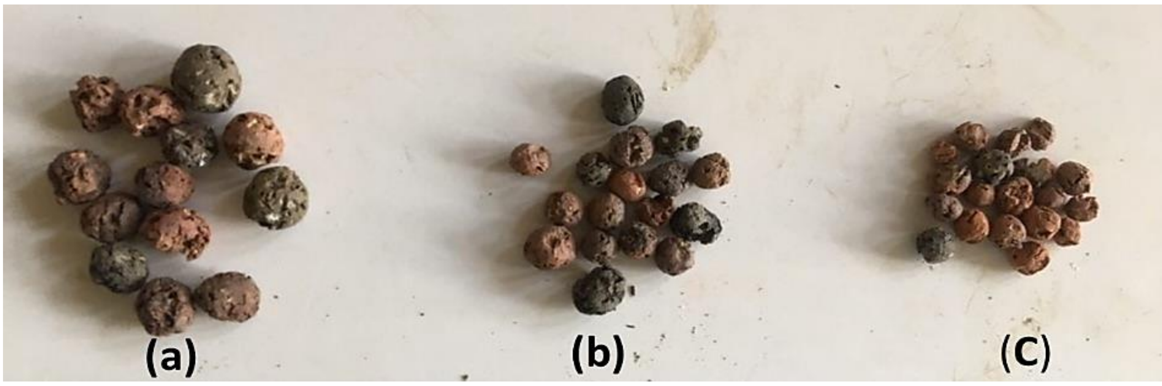

Figure 1 Three different sizes of the LECA: (a) large, (b) medium, and (c) small.

Table 1 Physical properties of aggregates.

Aggregates	Maximum size	Specific gravity	Water absorption
	(mm)	-	(%)
Sand	4	2.60	1.12
Gravel	20	2.61	1.03
LECA	20	0.90	40.12

Concrete samples were prepared using four different formulas. Because the LECA was highly porous (40 %, as shown previously), thus the LECA was pre-immersed in tap water for 24 h before being added to the concrete mixtures. Wet LECA was used as a coarse aggregate replacement at 25, 50, 75, and 100% by volume. The mix had a 1:2:4 ratio of cement, sand, and gravel. A water-to-cement ratio of 0.5 was used throughout the investigation. The mixed proportions of concrete are listed in Table 2. The Ordinary Portland Cement's first step was dry-blended with sand. Water was then added, and all components were mixed correctly. Coarse aggregates with various amounts of wet LECA were then added to the mixture and continuously blended until they became homogenous. All the concrete mixes were cast in a cube mold (150 mm ×150×150 mm3). After 24 h, the samples were removed from the mold and cured in water at room temperature. All the samples were tested for compressive strength at 28 days.

Table 2 Mixed proportion of concretes containing various amounts of LECA.

Part	Mix designation	Cement	Sand	LECA	Gravel	Water
		(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)
Concrete	0% LECA	395	639	0	1136	198
	25% LECA	395	639	98	852	198
	50% LECA	395	639	196	568	198
	75% LECA	395	639	294	284	198
	100% LECA	395	639	392	0	198

2.2 The physical, mechanical, and acoustic properties of sample determination

Water absorption and bunk density tests were used to test the physical properties of the concrete. In this study, the water absorption procedure was performed by BS 1881-122:2011 [15], and the bulk density was determined following BS EN 12390-7:2019 [16]. Compressive strength tests were taken according to BS EN 12390-3 and BS 8110-1:1997 using the compression machine (ADR-1500, ELE International) [17, 18].

The normal-incidence sound absorption coefficients of the concrete were measured using an impedance tube (Nihon Onkyo Eng.) following BS EN ISO 10534-2:2001 [19, 20]. The samples measured ø 99 × 50 mm3 ± 1 mm. The measurable frequency range is 100-1600 Hz. The concrete diameter was smaller than the tube diameter; therefore, vibrations were likely to occur at specific resonance frequencies. The authors used two-face tape to prevent the sample from moving and reduce the vibration effect [21]. An illustration of the measurement setup is shown in Figure 2.

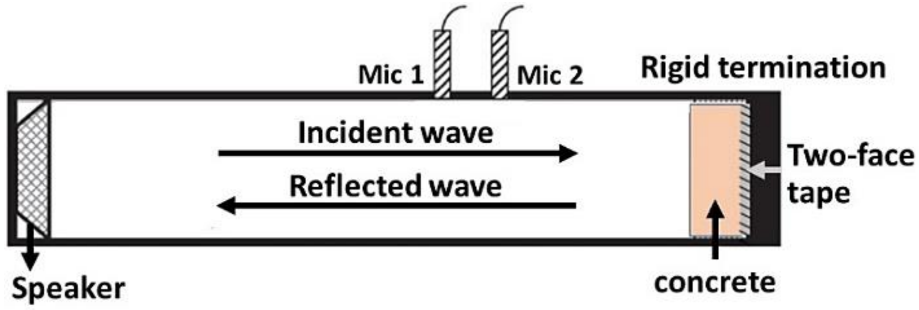

Figure 2 Sample setup and receiving points of measurements.

3. Results and discussions

This section discusses the physical, mechanical, and acoustic properties of these samples. The influence of the size and amount of LECA on the physical properties of concrete is discussed.

3.1 Physical properties of concrete

The property of LECA is water absorption, which plays a vital role in proportioning concrete mixtures. The porous nature of the aggregate is responsible for its high absorption [7, 22, 23]. This high absorption only encourages good concrete development if proper countermeasures are available because it directly affects the durability of concrete. As shown in Figure 3(a), the water absorption values exhibited an upward trend. The increasing percentage of LECA led to higher values ranging from 4.33% to 27.11%; the standard deviation is displayed in the error bar. A range of 0.09 to 0.14 was observed. The highest water absorption value was observed for concrete containing 100% small LECA additions. The results were consistent with those reported by Muñoz-Ruiperez et al., who replaced sand with LECA sizes of 2-8 mm and found that water absorption increased after replacing sand with LECA [24] because LECA is a highly porous material compared to the traditional aggregate.

The bulk density of the concrete is the mass of freshly mixed concrete required to fill the container in a unit volume. The bulk density depends on the relative density of the material used, such as cement and aggregate, and its inverse relationship with porosity. The density decreased as the amount of LECA increased and the quantity of entrained air increased. Thus, it reflects the ability of concrete to function as a structural support, water and solute movement, and durability. This method helps to calculate the yield of concrete per cubic meter. Figure 3(b) shows that the bulk density exhibited a downward tendency when the quantity of LECA was increased. The bulk density of concrete ranged from 1600 to 2250 kg/m^3. The standard deviations ranged from 0.04 0.09. The experimental results were consistent with those of Madadi et al., who found a decline in density when the amount of LECA was increased [25].

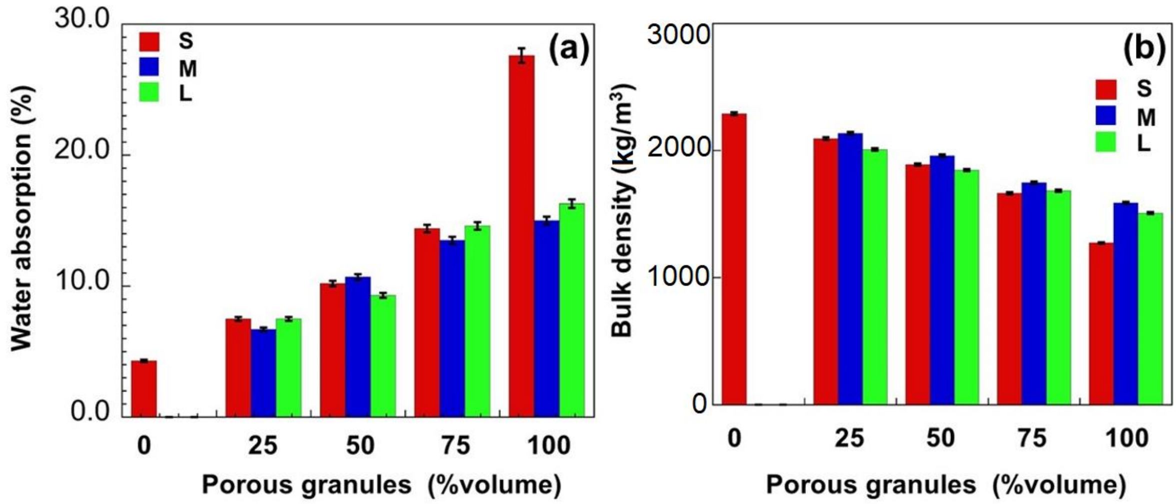

Figure 3 Physical properties of concrete added LECA in different sizes and quantities (a) water absorption and (b) bulk density.

3.2 Mechanical properties of concrete

An important property of building materials is their compressive strength. This ensured the engineering quality of these materials. The number of LECA was highly influenced by the compressive strength of the concrete, as shown in Figure 4. The compressive strength ranged from 12.05-23.22 MPa, and the standard deviation increased at higher values. Standard deviation of 0.42-0.63 was observed. Generally, in structural applications, the strength of the concrete must be greater than 20 MPa [17]. Some samples met the criteria specified for compressive strength of not less than 20 MPa. The samples that passed the BS standard requirements were all LECA added at 25% and 50% with small sizes.

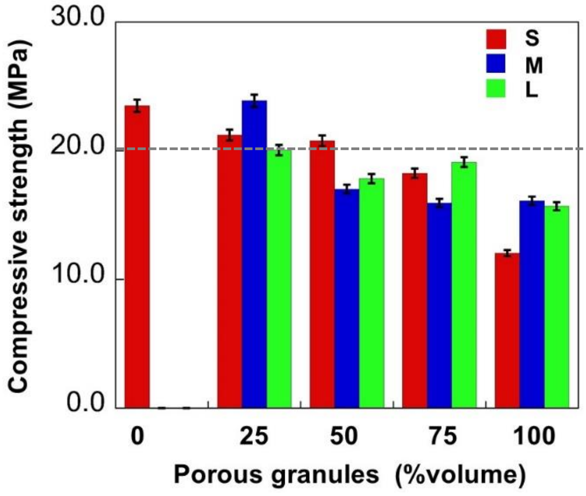

Figure 4 Compressive strength of concrete added LECA in different sizes and quantities. The dashed gray line indicates the minimum compressive strength of the British Standards Institution (BS EN 12390-3 and BS 8110-1:1997).

3.3 Acoustic properties of concrete

The tube method investigated the normal-incidence sound absorption coefficient (α) of concrete with variations in the size and ratio of the LECA at frequencies between 100 and 1600 Hz [25, 26]. Figure 5 shows a more significant normal-incidence sound absorption coefficient at a medium frequency of approximately 800 Hz. Sound absorption improved with an increased amount of LECA. The sample that contained 100% small LECA demonstrated the highest normal-incidence sound absorption coefficient value of approximately 0.50. The second highest normal-incidence sound absorption coefficient value was 100% LECA, 0.21. All samples had a normal-incidence sound absorption coefficient higher than that of normal concrete. The available normal-incidence sound absorption coefficient can characterize the sound absorbability. Various physical properties (porosity and density) are the main factors that play a major role in determining the outcome [20, 27, 28]. When sound waves hit a porous material, they spread into the crevices; frictional and viscous losses within the porous material dissipated a part of the sound energy.

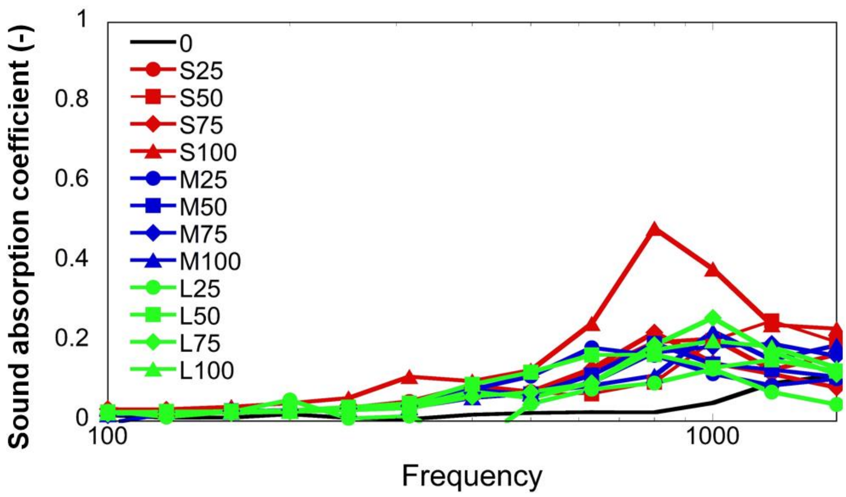

Figure 5 The normal-incidence sound absorption coefficient of concrete added LECA in different sizes and quantities.

Acoustic impedance is an essential parameter involving acoustic energy transfer [29]. The mean values of the normal surface impedance (z/ρc) are shown in Figure 6. Sound waves propagate in free space through a medium without loss. Part of the acoustic energy is redirected and transmits the remaining energy to another medium. The quantity of redirected or transmitted energy can be expressed as the acoustic impedance. Most acoustic impedance values from to 100-800 Hz showed stable behavior in the real and imaginary parts. However, at 1000 Hz, some samples in the imaginary parts crossed the zero line because they had a slight resonance [30].

3.4 Image analysis

The concrete sample images were analyzed with an open-source software called "ImageJ" to examine the fundamental reason for the enhancements in normal-incidence sound absorption coefficients obtained when a high amount of LECA was used. As shown in Figure 7 (a)–(c), the images were presented at the same magnification, lightness, and contrast as the images in (d)–(f) after analysis. The black color in Figure 7 (d)–(f) refers to the number of areas of LECA on the concrete surface. In addition, the percentage of LECA analyzed from the black areas is shown in gray: L100, 17.39%, M100 20.39%; and S100, 33.20%. In LECA's small size, the black area accounted for the greatest percentage. This is consistent with the porosity and density in Figure 3, indicating that the normal incidence sound absorption coefficient of 100 the small size is higher than that of the others.

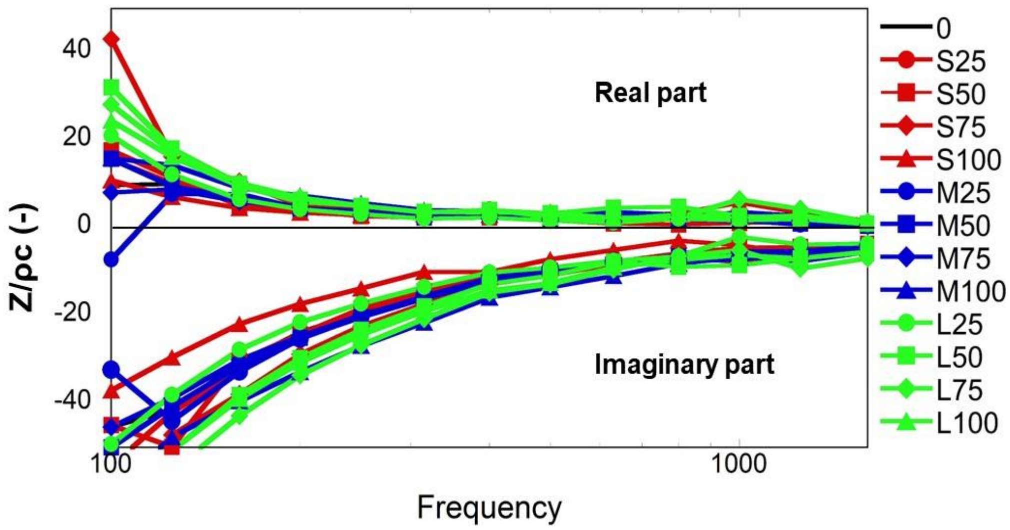

Figure 6 The acoustic impedance of concrete added LECA in different sizes and quantities.

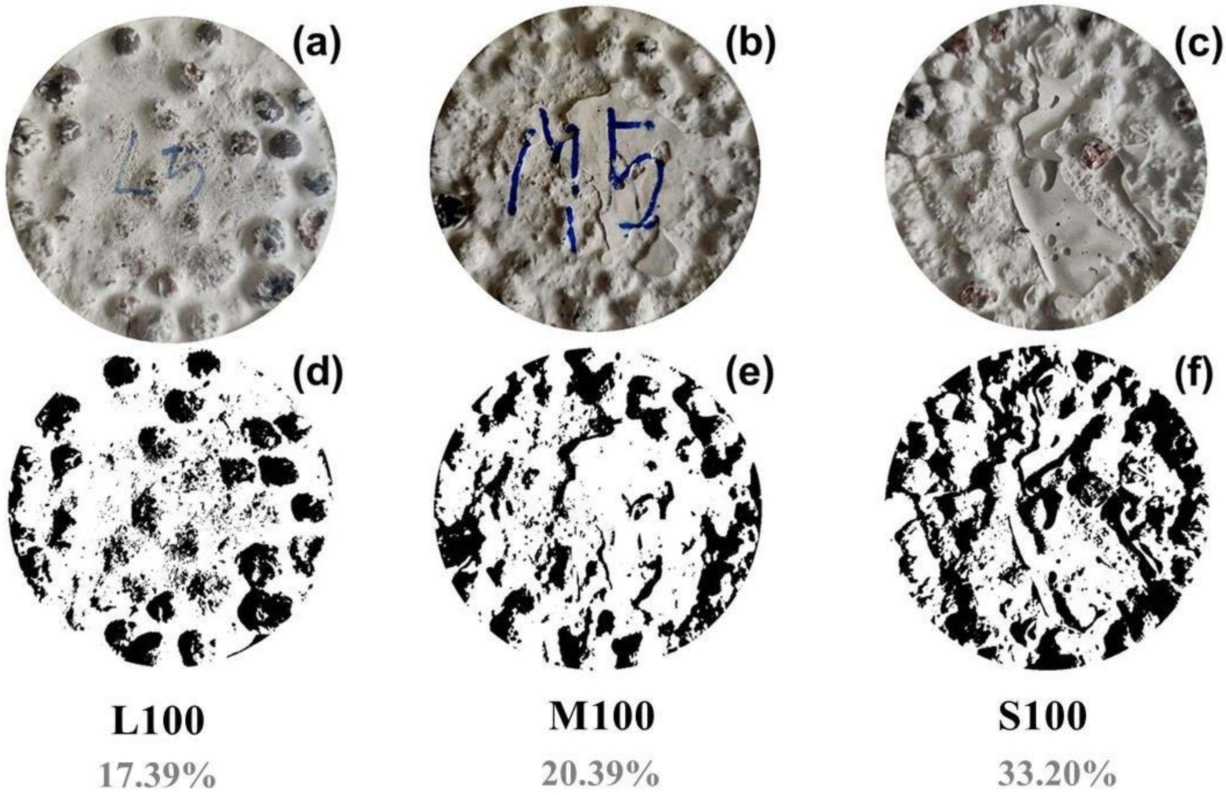

Figure 7 Image analysis of concrete: (a)–(c) are real images of concrete that contain LECA for 100%, from large, medium, and small, respectively, and (d) – (f) is the black and white image after analysis by ImageJ. The gray color values are a percentage of the black area in (d)–(f).

3.5 Regression analysis

The linear regression determining the relationship between the physical properties affected the compressive strength and the sound absorption coefficient. In this analysis, the sound absorption coefficient was represented by the arithmetic average of all octave band center frequencies from 100-1600 Hz.

The water absorption and compressive strength showed an excellent correlation above 0.88 but were slightly lower than the bulk density, as shown in Figures 8(a) and (c). This result was expected because water absorption should increase with decreasing bulk density. These porosities lead to a reduction in compressive strength [31]. At the same time, the correlations between water absorption and the average absorption coefficients were stronger than those between the bulk density and the average absorption coefficients, as shown in Figures 8(b) and (d). Besides, this result still agrees with the area of LECA on the concrete surface.

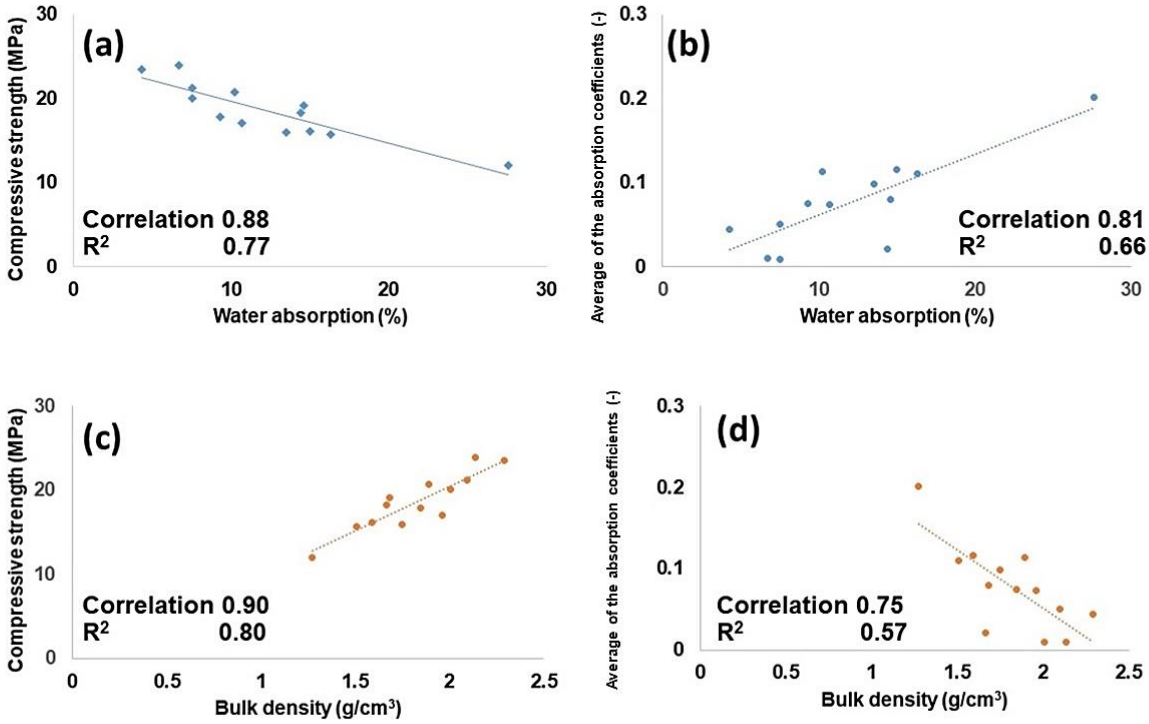

Figure 8 Regression analysis: (a) compressive strength and water absorption, (b) an average of the absorption coefficient and water absorption, (c) compressive strength and bulk density, and (d) an average of the absorption coefficient and bulk density.

4. Conclusion

A preliminary study demonstrated that using LECA as a substitute for coarse aggregates in concrete can significantly improve lightweight concrete's normal incidence sound absorption coefficient. The samples with less than 50% LECA passed the standard requirement because of the decreased density caused by the increased porosity, as specified in the relevant BS standard for lightweight concrete. However, using a small LECA with 100% replacement is also attractive, as it increases the sound absorption coefficient tenfold compared with normal concrete.

Our findings also show a strong correlation between increased porosity, decreased density, and compressive strength (correlations of ±0.88 and ±0.90, respectively). Based on this correlation, we concluded that the porosity of concrete must be carefully evaluated and compared with its density and compressive strength to ensure that the desired performance characteristics are achieved.

Furthermore, porosity was found to be more critical than bulk density in the sound absorption coefficient. Therefore, future studies on the sound absorption properties of concrete should focus on evaluating and comparing the porosities of concrete samples.

5. Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. The author would like to thank the faculty of Industrial Technology, Lampang Rajabhat University, and the Graduate School of Engineering at Oita University members who helped conduct this research.

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