Development of a Mixture of Lightweight Cell Crete for Green Roof Construction in Thailand

Hanny Chandra Pratama[1] Theerawat Sinsiri [1,2*] and Aphai Chapirom[2]

[1] *Civil Engineering Program, School of Engineering, Suranaree University of Technology, Nakhon Ratchasima, THAILAND*
[2] *Sustainable Innovative and Energy – Efficient Construction Materials (SIE-CON) School of Engineering, Suranaree University of Technology, Nakhon Ratchasima, THAILAND*
**Corresponding author; E-mail address: sinsiri@g.sut.ac.th*

Abstract

Green roofs are still not widely known in Thailand. It is caused by the complicated construction process, the need of imported materials, and the higher cost compared to conventional roofs. Green roofs are considered a new alternative due to their ability to reduce power usage, noise, air pollution. develop an urban ecosystem, and so on. Thus, the researcher is interested in using lightweight cell crete (LCC) as a load structural material to support the weight of the soil used to grow plants, since the lightweight cell crete has the following properties: strength, resistance to heat, waterproofness, soundproofness, and light weight. Moreover, the construction cost will be more affordable. The purpose of this study is to determine lightweight cell crete for applying on green roof. The density of lightweight cell crete is set range 600 – 1,800 kg/m^3. The result found that the properties of lightweight cell crete 1,200 and 1,400 kg/m^3 meets the standard to substitute the normal concrete. In addition, the researcher put the green roof with lightweight cell crete structure to the test in actual site and found that it can contribute to the increase of green space in urban life. The cost of construction was reduced, as was the temperature inside the building. It is advantageous for Thailand's green roof industry.

Keywords: green roof, energy-saving roof, lightweight cell crete, green roof lightweight cell crete

1. Introduction

Temperatures in cities continue to rise as a result of urban heat islands (UHI) and the consequences of climate change. As a result, energy consumption has increased over past four decades [1]. The Electricity Generating Authority of Thailand (EGAT) has collected electricity-related data and report in its Annual Report. In the past 13 years (2000 – 2012), Thailand's overall electricity usage has risen to 75.01 percent and is continuing to rise [2]. The air conditioning system consumes the majority of energy in order to cool the indoor air due to the high rate of thermal heat transfer into the room. Researchers are interested in resolving the UHI issue through the use of green roofs [3].

Reduction of surface temperature and thermal comfort are the two important functions of the green roof in urban areas. Green roofs offer a natural and sustainable way to cover building envelopes with vegetation to bring multiple benefit in urban life. Moreover, Green roofs limit heat transfer through building roofs by around 80% in the summer [4]. In tropical countries, green roof has an important performance of rainwater detention and retention. Because of the significant water content storage on humid-tropical green roofs, thermal performance is twice as effective as in temperate zones [5]. However, green roofs on buildings are not widely used in Thailand. Some of the reasons for not implementing green roofs are the high cost of heavy structure and layer installation, as well as the maintenance costs.

Lightweight Cell Crete (LCC) can be presented as a solution for load-supporting construction, taking into consideration building weight and cost. LCC is created by injecting air from a foam agent into a slurry concrete mixture. The essential benefit of LCC as a roof material is its low density and low thermal conductivity. LCC has a density range of 600 to 1800 kg/m3, which is significantly lower than normal concrete, and a thermal conductivity range of 0.1–0.7 W/m.K, which decreases with density [6].

This study is an experimental study of the properties of LCC to identify the feasibility standard for using LCC as load structural supports for green roofs. By analyzing the data on LCC properties and the green roof standard, it will be feasible to develop a potential guideline for integrating LCC in green roofs in order to enhance the efficiency of green roofs and minimize the cost problems.

2. Materials and Methods

2.1 Lightweight Cell Crete Materials

This study is a development mixture from the previous study, where the result obtains a recommended method to provide a proper LCC properties by horizontal mixer with 45 rpm [7]. The consistency of 45 rpm speed used to improve the quality of LCC properties better than those on general used in 60-70 rpm. Excessive rotation over 45 rpm can damage the mortar's foam bubbles. Fig 1 shows the horizontal mixer developed by Suranaree University of Technology.

Fig 1. Horizontal Concrete Machine

The LCC composition consists of Portland Cement Type-I, fine sand, foam agent, and water follows the requirements of ASTM C150 with the water to cement ratio (w/c = 0.5).

This current study, we used the SUT V2.1 foam agent (Suranaree University of Technology foam agent version 2.1) since it is made by natural protein to relate with green issues with a pH of 8.55, SG of 1-1.05, and foam density of 40-50 kg/m^3. Therefore, all of appliance material in LCC is found and made by local materials. Table 1 shows the composition of LCC mixed design.

Table 1 Composition of LCC density range 600 – 1800 kg/m^3

Density (kg/m^3)	Cement (kg)	Fine Sand (kg)	Water (kg)	Foam (kg)
600	460	0	205	30
800	429	160	184	27
900	417	280	177	25
1,000	408	395	172	24
1,200	396	617	165	20
1,400	388	834	160	17
1,600	382	1,047	157	14
1,800	377	1,258	154	10

The process of mix-design is described in Fig.2. Firstly, pour the cement, fine sand, and water into the horizontal mixer follows the composition of specified LCC density. After the mortar mixed well, in Fig. 3, the specified amount of foam agent is injected and mixed until the mortar has bubble textures following the guideline of ACI 523.3R-14. Last step before molding process, the mortar will be weighed to check the wet density according to the target density we want by a tolerance range ± 50 kg/m^3.

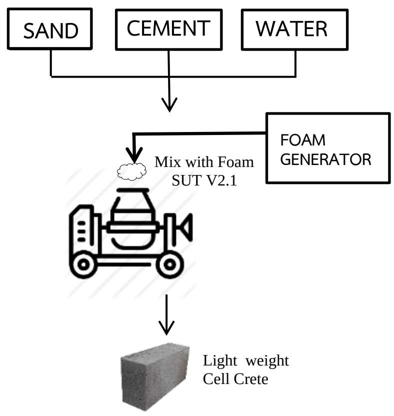

Fig 2. Method of LCC mix design

Fig 3. Adding foam agent into mortar

The following step is poured into the prepared molds. The mortar was poured into the mold immediately after preparation to get a target density range of 600 - 1,800 kg/m^3 of fresh concrete. The molds are the cubic shape at 150 x 150 x 150 mm and the rectangular shape at 300 x 300 x 75 mm., as shown in Fig. 4

Fig 4. LCC molding process

The curing treatment of the samples was by wet covering method (moist curing) for 28 days before the test.

2.2 Test Method

2.2.1 Thermal conductivity test

In determining the thermal conductivity of the LCC samples, the test was conducted accordance to ASTM C 177 – 97 [8]. The three samples of 300 x 300 x 75 mm. were examined using two isothermal cold surface assemblies and a guarded hot plate.

2.2.2. Compressive strength test

Compressive strength test for this study was conducted according to the BS EN 12390-3 [9]. For this test, three samples 150 x 150 x 150 mm. have been prepared for laboratories test. The testing machine will apply the selected load to the specimen and increase continuously until no greater load can be sustained. The maximum load will be recorded.

2.2.3. Water absorption test

Water absorption test was conducted in order to determine the percentage of the water absorption by the LCC. The test was accordance to the TIS 2601-2556 [10]. Initially, the LCC samples were dried in the oven at 100°C for 24 hours. The samples were then cooled down before immerse in the water tank for another 24 hours. In order to assess the percentage of water absorption, the weight of samples was measured before and after immersion in the tank

3. Results and Discussions

3.1. Thermal Conductivity

The thermal conductivity results of LCC range 600 – 1,800 kg/m^3 illustates in Fig. 5. The results shows that the number of thermal conductivity will increase follow the density.

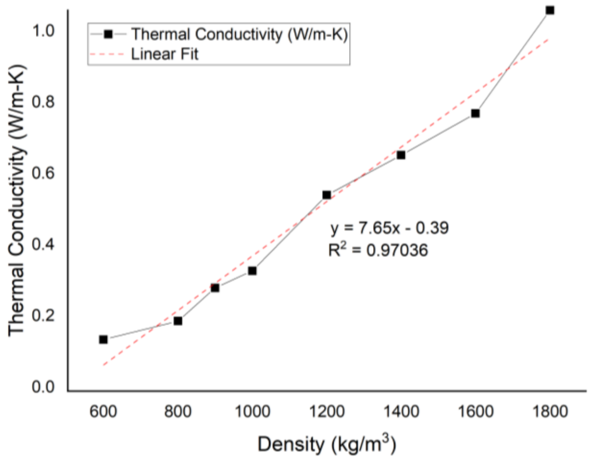

Fig 5. Thermal conductivity result

The LCC density (600, 800, 900, and 1,000 kg/m^3) reach the thermal conductivity at 0.134, 0.186, 0.276, and 0.327 W/m.K. The thermal conductivity is starting to significantly increase on LCC density 1,200, 1,400, and 1,600 kg/m^3 at 0.540, 0.652, and 0.769 W/m.K respectively. The highest density samples in this study, 1,800 kg/m^3 density reach at 1.059 W/m.K.

Based on general result in some previous studies, LCC has a lower thermal conductivity than conventional concrete [11-12]. It indicates that the prospective combination of a green roof and LCC as the roof deck will enhance the heat transfer resistance and result in a room with a cooler temperature than conventional concrete.

3.2. Compressive Strength

Compressive strength testing shows in Table 2. From the data, we can categorize the types of LCC based on the strength.

There are three different lightweight concrete type divisions in terms of strength range, which are low-density concretes (0.7-7.0 MPa), moderate-strength concretes (7-14 MPa) and structural concretes (17-63 MPa) [13]. The moderate-strength concretes are recommended to apply as a load bearing for supporting the roof deck of green roof.

Table 2 LCC categorizes based on the strength

Density (kg/m^3)	Compressive Strength (MPa)	Lightweight Concrete Category
600	1.2	low-density concretes
800	2.0	low-density concretes
900	2.8	low-density concretes
1,000	3.5	low-density concretes
1,200	4.8	low-density concretes
1,400	8.8	Moderate-strength concretes
1,600	16.4	Structural concretes
1,800	18.3	Structural concretes

3.3. Water Absorption

The percentage of water absorption for each density type illustrates in Fig 6. As can be seen, low-density concretes (600 and 800 kg/m^3) with high porosity exhibit substantial water absorption (42.94 and 28.54 percent, respectively). LCC with density 900 and 1,000 kg/m^3 decrease significantly to 16.92% and 12.42% respectively. The percentage of water absorption continuous to decrease where water absorption of LCC (1,200 and 1,400 kg/m^2) are 11.86% and 10.06%. The water absorption of LCC 1,600 and 1,800 kg/m^3 reach the slightly result at 7.30% and 7.19%. The result meets the recommendation since the percentage of water absorption of LCC 1,200 – 1,800 kg/m^3 less than 12% [14].

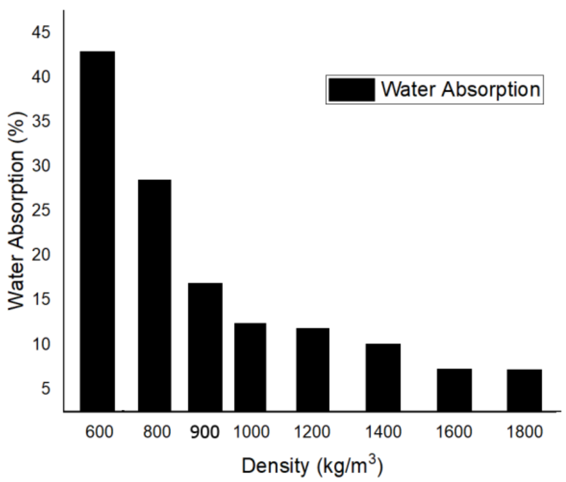

Fig 6. Water absorption result

4. Conclusions

1. LCC has a lower thermal conductivity more than normal concrete. Due to its low thermal conductivity, it indicates that green roof heat transmission will be enhanced when LCC is used as the roof deck material.
2. The outcome indicates that LCC with density 1,400 kg/m^3 has the potential to replace normal concrete as a roof deck since it categorized as moderate-strength concrete. Therefore, the roof deck will be more efficient in structure load, cost, and strength.
3. The aims of a green roof are to retain moisture content and nourish plant life. In other hand, the roof deck is also holding the important role to prevent the water leakage. Therefore, water absorption is an important factor to consider while utilizing a green roof's quality. The LCC range of 1,200 to 1,400 kg/m^3 is a suitable option for retaining water absorption since the value is less than 12%.

6. Recommendation and Future Works

Green roofs offer a natural and sustainable way to bring multiple environmental benefits, including improving building energy efficiency. Passive design with a green roof system offers a solution to reduce heat gain from solar radiation through the roof.

(a)

(b)

(c)

Fig 7. (a) Roof deck from LCC, (b) Planting the vegetation on green roof, and (c) Green roof integrated LCC

In addition, as shown in Fig. 7, the researcher put the green roof with LCC 1,200 kg/m^3 with extra adding structure support to test in actual site and found that it can contribute to the increase of green space in urban life.

This research studied the development of a mixture of lightweight cell crete for green roof construction in Thailand. According to the results, an LCC range of 1,200 to 1,400 kg/m^3 is recommended for use in green roof systems. By using LCC, the structure load and the cost of construction was reduced. It is advantageous for Thailand's green roof industry.

The application of LCC on green roof still requires additional research into the broader green roof system. The water leakage might be a main problem of the LCC green roof system in a long-term application. Therefore, the future research suggested the additional research concern on the drainage system model in LCC green roof system to prevent the water leakage and may reduce the installation cost and maintenance cost more than normal green roof.

Acknowledgement

This study is supported by research funds to extend knowledge from Thailand Science Research and Innovation (TSRI) on Precast Cellular Concrete. The authors are grateful to the Suranaree University of Technology, Sustainable Innovative and Energy Efficient Construction Material (SIE-CON), and Infinity Concrete Technology, Co. Ltd for providing support both financially and using its facilities.

References

[1] Santamouris, M. (2014). Cooling the cities - A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments, *Sol. Energy*, vol. 103, pp. 682–703..

[2] Suwapaet, N. (2016). Thailand electricity consumption during 2000 – 2012 ; facts and trends. no. September 2013.

[3] Munir, A. and Afifuddin, M. (2020). Thermal Performance of Precast Foam Concrete Integrated with Green Roofs System.

[4] Besir, A. B. and Cuce, e. (2018). Green roofs and facades: A comprehensive review, *Renew. Sustain. Energy Rev.*, vol. 82, no. July 2017, pp. 915–939.

[5] Hashemi, S. S. G., Bin Mahmud, H. and Ashraf, M. A. (2015). Performance of green roofs with respect to water quality and reduction of energy consumption in tropics: A review. *Renew. Sustain. Energy Rev.*, vol. 52, pp. 669–679.

[6] Chica, L. and Alzate, A. (2019). Cellular concrete review: New trends for application in construction. *Constr. Build. Mater.*, vol. 200, pp. 637–647.

[7] Chapirom, A., Sinsiri, T., Jaturapitakkul, C., and Chindaprasirt, P. (2019). Effect of speed rotation on the compressive strength of horizontal mixer for cellular lightweight concrete, *Suranaree J. Sci. Technol.*, vol. 26, no. 2, pp. 113–120.

[8] ASTM C177. (1997). Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate," p. 22.

[9] British Standard Institute. (2001). BS EN 12390-3:2001 Testing hardened concrete - Part 3: Compressive strength of test specimens," *BSI Standards Publication*. pp. 4–10.

[10] TIS 2601-2556. (2018). Lightweight Foamed Concrete, *Announc. Minist. Ind.*, vol. 1, no. 1, pp. 1–10.

[11] Ganesan, S., Othuman Mydin, M. A., Mohd Yunos, M. Y., and Mohd Nawi, M. N. (2015). Thermal Properties of Foamed Concrete with Various Densities and Additives at Ambient Temperature. *Appl. Mech. Mater.*, vol. 747, no. March, pp. 230–233.

[12] Tasdemir, C., Sengul, O., and Tasdemir, M. A. (2017). A comparative study on the thermal conductivities and mechanical properties of lightweight concretes. *Energy Build.*, vol. 151, pp. 469–475.

[13] Chaipanich, A. and Chindaprasirt, P. (2015). *The properties and durability of autoclaved aerated concrete masonry blocks*. Elsevier Ltd.

[14] Nurain Izzati, M. Y. *et al.*, (2019). Strength and water absorption properties of lightweight concrete brick. *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 513, no. 1.