EFFECT OF SPEED ROTATION ON THE COMPRESSIVE STRENGTH OF HORIZONTAL MIXER FOR CELLULAR LIGHTWEIGHT CONCRETE

Aphai Chapirom[1], Teerawat Sinsiri[1*], Chai Jaturapitakkul[2], and Prinya Chindaprasirt[3]

Received: February 15, 2019; Revised: March 28, 2019; Accepted: March 28, 2019

Abstract

This research study is on the rotation speed of a cellular concrete mixer. The study looks at how the mixer affects the properties - the compressive strength, water absorption, and drying density - of cellular concrete. A cellular concrete wet density of 1,000 kg/m^3 then foam agent density of 49 kg/m^3 and water to cement ratio is 0.5 and sand to cement ratio is 0.95 of cellular concrete will test age 28 days to dry with foaming agent (SUT V2.1) in the mixer. The impeller has 5 rotation speeds, which are 15, 30, 45, 60, and 75 rpm. The study compares the properties of the cellular concrete produced at each speed. The test found that the rate of rotation affects the properties of the cellular concrete. Setting the rotation speed of the concrete mixer at 45 rpm provides a higher compressive strength and water absorption in which the foam size and spread is more even in the concrete than at all the other speeds.

Keywords: **Effect of speed cellular concrete , cellular lightweight concrete, speed mixer of cellular concrete**

---

[1] *School of Civil Engineering, Faculty of Engineering, Suranaree University of Technology, Nakhon Ratchasima, 30000, Thailand. E-mail: sinsiri@sut.ac.th*

[2] *Department of Civil Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi, Bangkok, 10140, Thailand.*

[3] *Sustainable Infrastructure Research and Development Center, Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40000, Thailand.*

[*] *Corresponding author*

Introduction

Statement of Problems

Nowadays, cellular lightweight concrete or cellular concrete (CLC) bricks are widely used in construction works. This is because CLC bricks have a light unit weight which is approximately 800-1,760 kg/m^3 (American Concrete Institute, 2014). They also have the advantages of a lower water absorption rate and a higher fire resistance than concrete blocks. The manufacturing process of the CLC bricks adds air into the cement mortar. During the mixing process, the air will scatter and produce the lightweight concrete. The mixture of the cellular concrete consists of ordinary Portland cement, fine aggregate, water, and a foaming agent. The chemical compositions of the foaming agent are a hydrolyzed and synthetic detergent. The air bubbles obtained from this chemical composition are more stable and are able to be retained for a longer period. A longer time is required for the injection into the prepared mixture of Portland cement, fine aggregate, and water. Five to 10 minutes are normally required in the slow movement drum mixture in order to let the air bubbles spread throughout during the mixing process. The optimum rotation of the mixing drum should be considered carefully, to let the air bubbles spread through the mixture consistently.

A horizontal agitator blade is used in the mixing machine, and the rate of rotation will directly affect the mix of air bubbles. This research studies the rate of rotation of the horizontal agitator blade in order to determine the effect on the properties of the CLC bricks.

Objectives of the Study

The objectives of the study were to investigate the engineering properties of the cellular concrete caused by rotating the mixing agitator at various speeds and to determine the optimum speed of rotation of the mixing agitator in the mixing process. The engineering properties are the compressive strength, water absorption, and dry density. In the determination, the dry density of the cellular concrete is 1,000 kg/m^3, the aerated foam agent density is 49 kg/m^3, the water to cement ratio (w/c) is 0.5, and the sand to cement ratio (s/c) is 0.95. The cellular concrete consists of cement, sand, water, and foam. The study focussed on the mixing rotation speeds at 15, 30, 45, 60, and 75 rpm.

Research Review

Type of Lightweight Concrete

Currently, there are 2 types of lightweight concrete in the construction field. The 2 types are categorized by the manufacturing process. The first type of lightweight concrete has no steam pressure applied in the process. It consists of other lightweight materials added into the mixture, such as sawdust, ashes, and waste from sugar cane or foam seed. These lightweight materials are directly mixed into concrete, sometimes with the addition of a CLC agent to swell up and become porous after hardening. The process is completed without steam and will make the color of the product similar to normal concrete. In the second type of lightweight concrete, steam pressure is applied in the process with the addition of lime. The applied steam pressure provides more quality control of the product. The unstable lime will be crystalized and became calcium silicate (Ferraris, 2001). This process leads to better properties, such as higher strength and more durability. The observed color of the finished product will be white.

Types of Cellular Lightweight Concrete

Cellular concrete can be divided into 2 categories by the method of the air bubbles' reformation. The first is the generation of hydrogen bubbles by chemical reaction. The chemical reaction is generated from the reaction of aluminum powder with the cement. The reaction of aluminum and calcium in the cement will generate tiny hydrogen bubbles in the concrete and cause expansion with the increasing of the volume. The porous air will be spread around after the hardening period and form the lightweight concrete with the volume as shown in Equation (1):

$$2Al+3Ca(OH)_2+6H_2O \rightarrow CaO.Al_2O_3.6H_2O+3H_2 \quad (1)$$

The second method of the air bubbles' reformation is from the addition of the agent trapped into the cement. The additional agent is the detergent which will create a high volume of air bubbles. However, when using detergent the bubbles are not stable and break out easily. The addition of hydrolized protein into the detergent will make the air bubbles more stable (Nambiar and Ramamurthy, 2007).

Related Research

In the study, better concrete should have more prosperous microstructures (Ferraris, 2001). Moreover, the major factors that have an effect will be the method of curing, the mixing procedure, and the composition of the mixture itself. Meanwhile, there are 2 methods of commercial mixing, which are batch mixing and continuous mixing. The later method is further categorized into drum mixing and pan mixing.

As stated, the study found that the mixing procedure has a direct effect on the microstructure of the concrete, and it affects the flow ability (Han and Ferron, 2015). The comparison of the 2 methods is between ASTM Standards C305 and C1738.

Materials and Methods

In its basic form, cellular concrete is made by blending preformed foam into a cement slurry, and it may not contain aggregate materials. A brief description of the basic ingredients, as well as the other materials that may be used in cellular concrete, follows.

Portland Cement

There are many types of Portland cement conforming to the requirements of ASTM C150-07, the standard specification for Portland cement (ASTM, 2007), that are used in cellular concrete. Blended cements may result in slower rates of strength development during the first 3 to 5 days. Higher rates of early strength development may be achieved by using high early strength Portland cement type III (Fouard, 2006) and the recommended value specific gravity (SG) is 3.15.

Fine Aggregate

Generally the fine aggregate consists of natural river sand meeting the requirements of ASTM C33-03, the standard specification for concrete aggregates (ASTM, 2003) to be used in cellular concrete. Sand of other gradations not conforming to this standard have also been used in some cases, and tests or service records have shown that they produced cellular concrete of the desired quality and the recommended SG of 2.65

Water

The water used for foamed concrete is crucial when using a protein-based foaming agent because organic contamination can have an adverse effect on the quality of the foam and subsequently on the concrete produced. The w/c ratio of the base mix required to achieve adequate workability is dependent upon the type of binder, the required strength of the concrete, and whether or not a water-reducing or a plasticizing admixture has been used. In most cases the w/c ratio will be between 0.4-0.8 (Nandi *et al.*, 2016).

Foam Agent

A very high stability foam is produced by the SUT V2.1 (Suranaree University of Technology form foam agent cellular concrete version 2.1). The foaming agent is mainly used to produce the foam and is then added to make the cellular concrete. To use the agent, it has to be diluted by adding water at the ratio of 1:40 (foam agent:water). The SUT V2.1 is made from natural protein, and is a brown liquid with a pH of 8.55, SG of 1-1.05, and foam density of 49 kg/m^3. The foam will be generated by pumping this diluted agent using a foam generator machine, and at the same time mixing the air with an air compressor. The SUT V2.1 foaming agent can produce foam with a very high foam stability and high standing condition during the processes of making cellular concrete, such as the mixing, pouring, and casting processes. During the processes of setting and hydration, the chemical reaction caused by the foam will act as a binding for air entrapment in order to obtain the perfect cellular concrete.

Preformed foam is produced by blending a foam concentrate, water, and compressed air in predetermined proportions in a foam generator. The liquid expands in volume up to about 30 times, resulting in preformed foam with a density approximately in the range of 32-56 kg/m^3. Foam concentrates are typically based on hydrolyzed protein or synthetic detergents and the standard method for testing foaming agents for use in producing cellular concrete using preformed foam is ASTM C796-97 (ASTM, 1993).

Concrete Mixing Machine

The mixer is important for foam that is characterized by low durability. A machine of the horizontal mixing type is the most appropriate for cellular concrete. Research has shown that it has more advantages when compared with the conventional vertical stirring type. A vertical stirring type needs higher power, more maintenance, a longer mixing time, and provides less volume output. A higher output of cellular concrete can be obtained more easily using the horizontal mixing type which makes it the most appropriate type. The different horizontal rotation speeds can be adjusted directly by the motor's gear to match different cellular concrete formulas in order to obtain a better homogeneous mixture for each mixing formula. The stirring mixer can be adjusted to be able to rotate in either a counterclockwise or clockwise direction. A friendly-user control panel is also provided which enables the operator to set the electrical frequency to control the machine. The machine has a small 5 hp motor, a guard rail and strong staircase, an electrical control panel, and a mixing tank with a capacity of 0.8 cubic meters.

The horizontal mixing machine (Thai patent no. 1603001086 (Sinsiri and Chapirom, 2016)) is shown in Figure 1. The features of the machine are the mixing tank capacity of 0.8 cubic meters, the steel structure, the ribbon type horizontal mixer, the 5 hp power motor gear box, the motor speed of 1,440 rpm, the variable speed drive, and the electronic equipment. In our study, the mixing machine's cellular concrete rotation speeds can be set at 15, 30, 45, 60, and 75 rpm.

Composition of Mix Proportion

The mixing proportions begin with the unit weight of the wet density, the cement content, and the w/c ratio. Then the proportions of the mixture can be calculated by the method of absolute volumes. The sum of the absolute volumes of cement, water, and sand for 0.76 m^3 gives the volume of air required per cubic meter of concrete. The mass ratio of the w/c of 0.4-0.6 was used for the mixture.

(a) **(b)**

Figure 1. Horizontal mixing machine: (a) punch mixer, (b) machine body

Cellular concrete should be mixed mechanically to produce a uniform distribution of materials at the specified as-cast density. Excessive mixing should be avoided, as it can cause changes in the density and consistency. Specific batching and mixing sequences should be followed. Water and water-soluble admixtures are added to the mixer first, followed by the cement, aggregate, and other admixtures. All ingredients except the preformed foam, which is added last of all, should then be mixed to a uniform consistency. This sequence minimizes the destruction of gas cells. Varying the recommended sequence is permissible if it proves advantageous. The proportions of the materials are calculated to obtain the design cast density at the point of placement. Allowances should be made for any changes in the cast density caused by the method of placement, such as pumping (American Concrete Institute, 2014).

Normally mixing the cellular concrete must depend on the formula under the American Concrete Institute Guide 523.3R-14 and ASTM C796 to adjust for the various materials in an appropriate ratio. The mix can be designed for the density of the cellular concrete and the weight of the cellular concrete for the machine with each type of requirement. If there is no need for high density, it can be set in the mix design method. The mix design for cellular concrete with a wet density 1,000 kg/m^3 is shown in Table 1.

Results and Discussion

The basic properties of cellular concrete have been tested in order to obtain the compressive strength, dry density, and rate of water absorption using TIS 2601-2556, the test standard (Thai Industrial Standards Institute, 2013). The wet density at 1,000 kg/m^3 has been specified and then tested according to the variation of the agitator speed at 15, 30, 45, 60, and 75 rpm.

Testing for Compressive Strength

The test results have been demonstrated, as in Table 2, for cured concrete samples. It was found that the maximum compressive strength occurred at 2.5 MPa from a mixing speed of 45 rpm and the minimum compressive strength result occurred at the

Table 1. Composition and properties of cellular concrete (mix design cellular concrete)

As-wet density (kg/m^3)	Cement (kg)	Sand (kg)	Water (kg)	Foam Agent (kg)	Estimated Compressive strength (MPa.)
800	428	161	177	30.45	1.9
900	417	280	171	28.65	2.4
1000	409	395	166	26.82	3.0
1200	396	618	160	23.08	4.7
1400	388	834	156	19.30	7.3
1600	382	1047	153	15.48	11.3

Table 2. Compressive strength, water absorption, and drying density of cellular lightweight concrete with mixer speeds at rounds per minute at 28 days

No	Testing	Mixer speed rounds per minute				
		15	30	45	60	75
1	Compressive Strength (MPa)	1.20	1.50	2.51	1.90	1.00
2	Water Absorption (%)	22.30	19.50	15.89	18.20	24.40
3	Drying Density (kg/m^3)	916	923	941	930	914

higher speed of 75 rpm at 1 MPa. It can be seen that the rotation cycle is very fast, causing the compressive strength to decrease because the bubbles are larger. It was found that if the bubbles are large, they have a low compressive strength (Yu and Luo, 2010). The TIS 2601-2556 standard requires a compressive strength of not less than 2.0 MPa. Test results for a mixing speed of 45 rpm are higher than the specified values.

Testing for Water Absorption

As shown in Table 2, testing for the water absorption rate resulted in a maximum of 24.40% which was found at 75 rpm. Conversely, at 45 rpm the result revealed the minimum absorption at 15.89%. At the higher speed of 75 rpm there will be large bubbles causing less compressive power, resulting in greater water absorption. The TIS 2601-2556 standard requires no more water absorption than 20%. Test results at a mixing speed of 45 rpm are less than the specified values.

Testing for Drying Density

The test results of volumetric density, at a dry age of 28 days, are as shown in Table 2. The maximum density at 941 kg/m^3 was found at the rotation of 45 rpm. The TIS 2601-2556

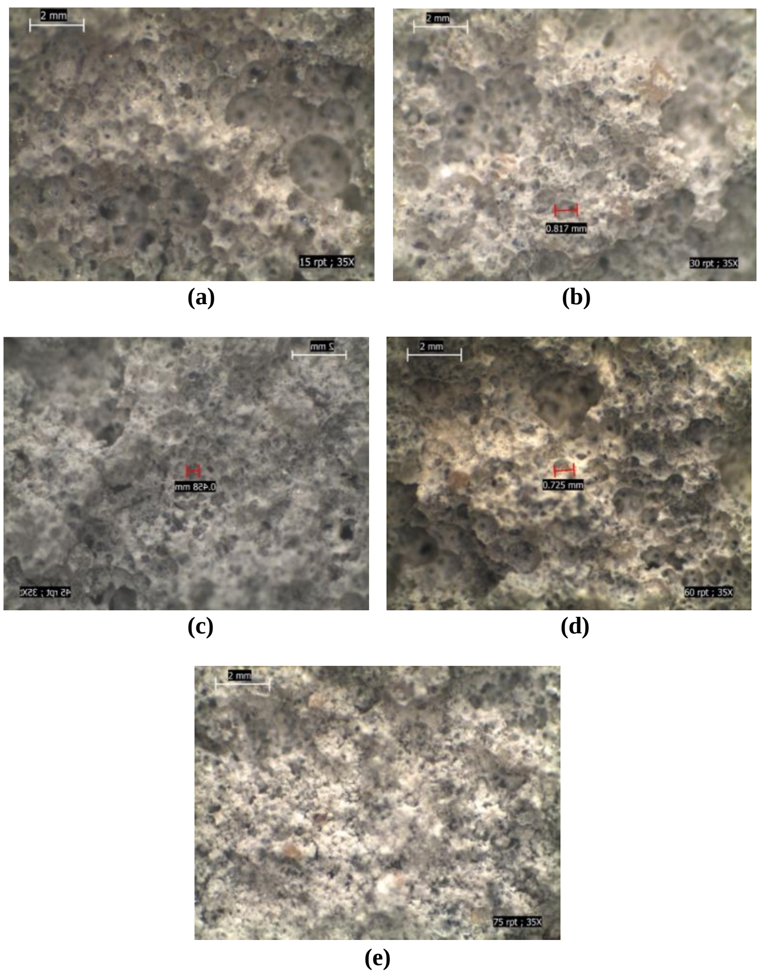

Figure 2. Cellular concrete surface imaged by light microscopy combined with digital image analysis (mixer speed rounds per minute: (a) 15, (b) 30, (c) 45, (d) 60, and (e) 75 rpm)

standard requires a dry density of 900-1,000 kg/m^3. The test results at the mixing speed of 45 rpm are between the specified values.

Testing for Light Microscopy Combined with Digital Image Analysis

The pore structure of the cellular concrete has been tested by light microscopy combined with digital image analysis. The influence of the method used to prepare the test samples is clearly shown in Figure 2. The pore structure of the cut sample in (a) shows that the foam size is scattered and is both small and large, in (b) the foam size is small around the size of 0.7-3 micron, in (c) the foam size is around the size of 0.4-1.0 micron, in (d) the foam size is around the size of 0.7-3.0 micron, and in (e) the foam is blurred and unclear.

Conclusions

The results have been presented and show that the best results were at a 45 rpm agitation speed. At this rate, it provided the maximum compressive strength, maximum dry density, and the lowest rate of water absorption. As a result, the foam size will be identical and it spreads evenly around the cellular concrete. This result is significant when compared with setting the concrete mixer at other speeds and complies with the standards set by ASTM C796.

For the 45 rpm rotation rate, the results have been compared to the standard specifications as set out in the TIS 2601-2556 standard. The dry density at 28 days of curing had a variation less than ±50 kg/m^3 which can be classified into group C9 of the standard. The significant points that have been confirmed are that the rate of water absorption is lower, with a higher compressive strength when compared with the TIS 2601-2556 standard.

Acknowledgment

The authors would like to express gratitude to Suranaree University of Technology and Infinity House Co., Ltd. for providing the funds for this research. The research, as agreement number PhD 5910064, was delegated for the PhD. program in accordance with the support by the Development of Researchers and Research for Industry, Office of Research Fund (TRF).

References

American Concrete Institute. (2014). 523.3R-14. Guide for Cellular Concretes above 50 lb/ft^3. American Concrete Institute, Farmington Hills, MI, USA.

ASTM. (2003). C33-03. Standard Specification for Concrete Aggregates. ASTM International, West Conshohocken, PA, USA.

ASTM. (2007). C150-07. Standard Specification for Portland Cement. ASTM International, West Conshohocken, PA, USA.

ASTM. (1993). C796-97. Standard Test Method for Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam. ASTM International, West Conshohocken, PA, USA.

ASTM. (1999). C869-91. Standard Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete. ASTM International, West Conshohocken, PA, USA.

Chindaprasirt, P., Jaturapitakkul, C., and Sinsiri, T. (2005). Effect of fly ash fineness on compressive strength and pore size of blended cement paste. Cement Concrete Comp., 27(4):425-428.

Ferraris, C.F. (2001). Concrete mixing methods and concrete mixers: state of the art. J. Res. Natl. Inst. Stan., 106:391-399.

Fouad, H.F. (2006). Cellular concrete. In: Significance of Tests and Properties of Concrete and Concrete-Making Materials STP 169D. Lamond, J.F. and Pielert, J.H., (eds). ASTM International, West Conshohocken, PA, USA, p. 561-599.

Han, D. and Ferron, R.D. (2015). Effect of mixing method on microstructure and rheology of cement paste. Constr. Build. Mater., 93:278-288.

Kearsley, E.P. and Wainwright, P.J. (2002). The effect of porosity on the strength of foamed concrete. Cement Concrete Res., 32(2):233-239.

Nambiar, E.K.K. and Ramamurthy, K. (2007). Air-void characterisation of foam concrete. Cement Concrete Res., 37(2):221-230.

Nandi, S., Chatterjee, A., Samanta, P., and Hansda, T. (2016). Cellular concrete & its facets of application in civil engineering. Int. J. Civ. Eng., 5(Special 1):37-43

Sinsiri, T. and Chapirom. A., inventors; Suranaree University of Technology, assignee. June 29, 2016. Horizontal Concrete Mixer. Thailand patent no. 1603001086.

Thai Industrial Standards Institute. (2013). Thai Industrial Standard, 2601-2556. Cellular Lightweight Concrete of Bricks. Ministry of Industry, Bangkok, Thailand.

Yu, X. and Luo, S. (2010). Pore structure and microstructure of foam concrete. Adv. Mat. Res., 177:530-532.