A STUDY OF LIGHTWEIGHT CONCRETE ADMIXED WITH PERLITE

Methawee Sriwattanapong[1], Theerawat Sinsiri[1*], Saksith Pantawee[2], and Prinya Chindaprasirt[3]

Received: June 11, 2012; Revised: February 06, 2013; Accepted: February 07, 2013

Abstract

The purpose of this study is to develop a lightweight concrete by admixing with perlite. The concrete is targeted to have a density of less than 2000 kg/m^3 and a 28-day compressive strength of not less than 30 MPa. The control group concrete was designed to have a compressive strength at 44 MPa. Perlite was then used to replace sand at 30, 40, and 50% by mass (resulting in concrete of a strength less than the targeted 30 MPa). The compressive strength of the control group concrete was increased by 25 and 50% (by increasing the cement content) for the next trial mixes. The workability of the fresh concrete was controlled to have a slump at 80-100 mm. It was found that the 125% compressive strength control group with 30 to 50% of the sand replaced with perlite reduced the density from 2479 kg/m^3 to 2086-1917 kg/m^3 and reduced the compressive strength from 84.1 MPa to 53.9-40.3 MPa. For the 150% compressive strength control group with 30 to 50% of the sand replaced with perlite the density was reduced from 2458 kg/m^3 to 2121-1783 kg/m^3 and the compressive strength was reduced from 84.5 MPa to 54.2-31.8 MPa.

Keywords: Perlite, natural pozzolan, lightweight concrete

Introduction

Generally concrete building components such as columns, beams and footings need to be large and bulky, especially for high-rise buildings, to carry the high density of concrete at about 2400 kg/m^3 (SCG Cement, 2008). One way to reduce the size of the components is to develop a concrete of a lower density while keeping the compressive strength at a reasonable value.

There are a number of methods to produce lightweight concrete. In one method, the fine portion of the total concrete aggregate is omitted, which is called no-fines. Another way of producing lightweight concrete is to introduce stable air bubbles inside the concrete by using chemical admixtures and

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

[2] *Department of Civil Engineering, Rajamangala University of Technology Isan, Muang, Nakhon Ratchasima, 30000 Thailand.*

[3] *Department of Civil Engineering, Faculty of Engineering Khon Kaen University, Muang, Khon Kaen, 40000 Thailand.*

* *Corresponding author*

mechanical foaming. This type of concrete is known as aerated, cellular, or gas concrete. The most popular way of lightweight concrete production is by using lightweight aggregate. Such aggregates, natural or artificial, are available in many parts of the world and can be used for producing concrete in a wide range of densities and suitable strength values for different fields of applications (Neville, 1998).

Perlite is obtained from pumice, which is a glassy form of dacitic magma. It contains 2-5% water (Mladenovic *et al.*, 2004). Upon rapid heating, perlite transforms into a cellular material of low bulk-density. As the chemical water held within the perlite boils (at temperatures of 900-1100°C), the resultant steam forms bubbles within the softened rock into a frothy-like structure. The formation of these bubbles allows perlite to expand up to 15-20 times of its original volume (Gunning, 1994). Expanded perlite aggregate (EPA) has been used in constructional elements such as brick, plaster, pipe, and wall and floor blocks (Cobanli, 1993).

The area with perlite in Thailand covers n Kanchanaburi and Lopburi provinces, with the capability of perlite production of over 10000 tons annually (Department of Primary Industries and Mines, 2010).

The economical benefits of lightweight concrete are its low-heat conductivity and density (Topcu, 1999). For over 30 years, the lightweight property of concrete has been desirable in constructional elements (Yalgin, 1983). In most studies, EPA has been used as an admixture in cement or directly in concrete as an aggregate. In concrete, EPA is used instead of fine aggregate with various replacement ratios depending on the required strength. For cement, perlite is easier to be ground than the Portland cement clinkers; therefore, this results in less of an energy requirement to produce blended cement by grinding clinker and perlite together. However, blended cement with perlite may cause strength losses at an early age compared with Portland cement, and the strength has been improved by pozzolanic reactions lately (Erdem *et al.*, 2007). The strength of EPA-based concrete is explained with the bonds between cement and perlite aggregate (Glenn *et al.*, 1999).

Generally, mineral admixtures such as silica fume and fly ash have been used in concrete to improve mechanical properties (hydration, alkali silica reaction, and permeability) (Demirboga *et al.*, 2001). Nonetheless, EPA is an alternative material to these admixtures; density and compressive strength are decreased with the replacement of EPA in concrete mixtures. As is known, the effect of EPA on concrete is increased with increasing the cure periods (Demirboga and Gul, 2003). Furthermore, the natural perlite powder has a significant pozzolanic effect and is a good active mineral admixture for concrete; it also has high freeze-thaw resistance and fire protection capability (Mo and Fournier, 2007). Hence, there has been an increasing interest in EPA-based concrete.

The objective of this study is to investigate the use of perlite in making lightweight concrete of reasonable compressive strength. The concrete is to have a target density of less than 2000 kg/m^3 and a target 28-day compressive strength of not less than 30 MPa.

Experimental Design

Materials

Materials used in this study consisted of Portland cement type I, fine and coarse aggregates, perlite, silica fume, superplasticizer, and water.

The coarse aggregate used was crushed limestone with 20 mm maximum size. The fine aggregate was river sand, having a fineness modulus of 2.40. The coarse and fine aggregates had a specific gravity of 2.70 and 2.63, respectively.

The perlite, which was obtained from a perlite plant in Thailand, was heated between 900-1100°C. Figures 1 and 2 show Portland cement type I and perlite, respectively.

Experimental Design

The control group concrete was designed to have a compressive strength of 44 MPa (w/c = 0.38). To vary the compressive strength, 2 more strength levels were used: 125 and 150% of the control. To vary the density, sand was replaced by perlite at 30, 40, and 50% by mass, designated as P30, P40, and P50, respectively. Table 1 shows the mix proportions in each group of concrete. A sufficient amount of concrete of each group was mixed using a concrete mixer. The workability of the fresh concrete was controlled by keeping the slump at 80-100 mm. For each group 15 cylindrical samples of size 150 mm in diameter and 300 mm in height were cast. After casting for

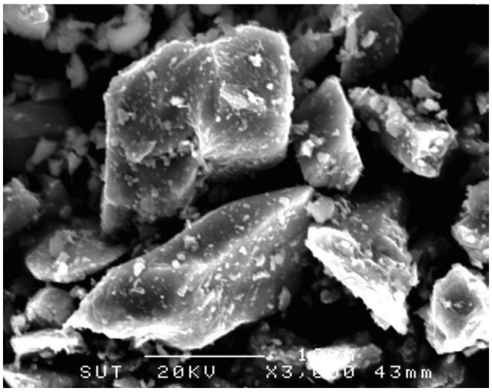


Figure 1. Scanning electron microscopy of Portland cement type I

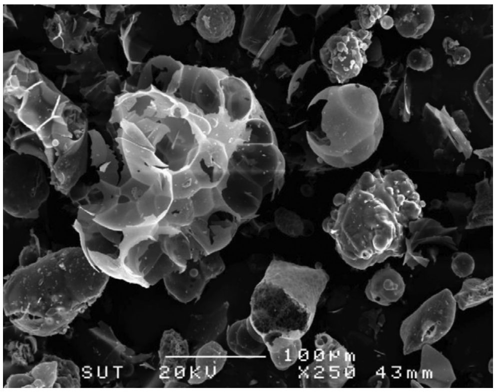


Figure 2. Scanning electron microscopy of perlite

Table 1. Mixture proportion of concrete

Mix No.	Symbol	Mix proportion (kg/m^3)							
		Cement	Perlite	Fine aggregate	Coarse aggregate	Water	Super plasticizer	Silica fume	Slump (mm)
1	CT	526	0	643	997	200	5.3	79	85
2	P30	526	193	450	997	400	5.3	79	93
3	P40	526	257	386	997	490	5.3	79	90
4	P50	526	322	322	997	625	5.3	79	93
5	1.25CT	658	0	643	997	156	5.3	-	90
6	1.25P30	658	193	450	997	322	5.3	-	94
7	1.25P40	658	257	386	997	350	5.3	-	96
8	1.25P50	658	322	322	997	473	5.3	-	100
9	1.50CT	789	0	643	997	195	5.3	-	90
10	1.50P30	789	193	450	997	348	5.3	-	94
11	1.50P40	789	257	386	997	380	5.3	-	98
12	1.50P50	789	322	322	997	512	5.3	-	100

24 h, the concrete samples were removed from the molds and cured in water at room temperature for 1, 7, 14, 28, and 60 days. The compressive strength, density, and modulus of elasticity of the concretes at each age were the average value of 3 samples.

Results and Discussion

Particle Size and Shape of Materials

Table 2 shows the physical properties of the Portland cement type I and perlite. It was found that the specific gravity and the density of the cement and perlite were 3.15 and 0.560, and 1450 and 205 kg/m^3, respectively. The median particle size (d_{50}) of the cement and perlite were 16.2 and 77.8 µm, respectively. The results suggested that perlite particles be hollow or porous. The particle size distribution curves of the materials are shown in Figure 3. The particles of the cement were smaller than those of the perlite. Figures 1 and 2 show the scanning electron microscopy of the cement and perlite, respectively. The shape of the cement particles was irregular, whereas that of the perlite was hollow and porous with many shapes.

Chemical Compositions of Materials

The chemical compositions of the Portland cement type I and perlite are analyzed by using X-ray fluorescence analysis and are presented in Table 3. The main chemical component of the perlite was silicon dioxide (SiO_2) which accounted for 73.7%. The loss on ignition (LOI) and the sum of SiO_2, Al_2O_3, and Fe_2O_3 were 1.02% and 85.6%, respectively. Due to its amorphous structure and high SiO_2 and Al_2O_3 contents, perlite is a pozzolan as specified by ASTM C 618 (ASTM, 2001;

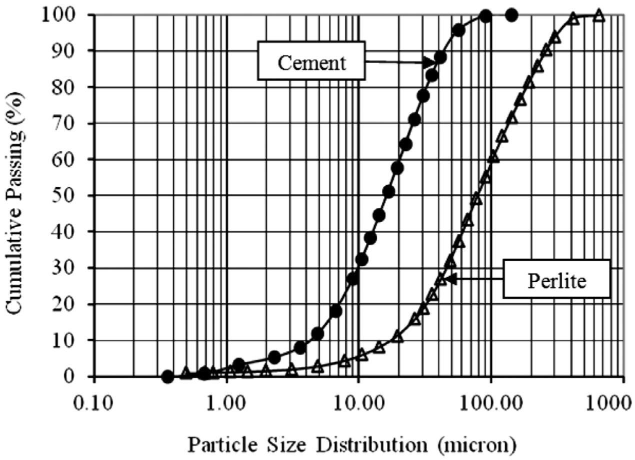


Figure 3. Particle size distributions of Portland cement type I and perlite

Table 2. Physical properties of Portland cement type I and perlite

Properties	Portland cement	Perlite
Specific gravity	3.15	0.560
Density (compacted[1]) (kg/m^3)	1450	205
Median particle size, d_{50} (µm)	16.2	77.8

compacted[1] = Fill the measure with fresh concrete consolidated in 3 layers. After each layer, rod the layer with 25 strokes of the tamping rod evenly distributed over the surface.

Erdem *et al*., 2007).

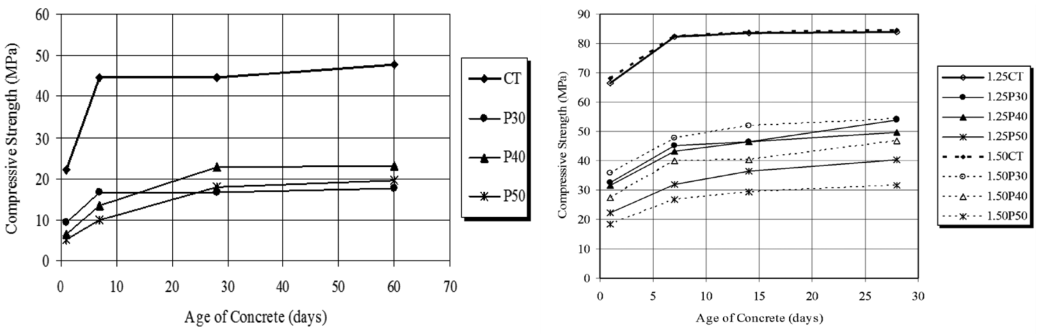
Compressive Strength

The compressive strength and normalized compressive strength of concretes containing perlite compared with the control concrete (CT) are shown in Figures 4 and 5. Each data point was the average strength of 3 samples.

In the first mix, the compressive strengths of sample P40 varied from 13.4 MPa at 7 days to 23.0 MPa at 28 days or increased from 7 days by about 71.6%. However, the compressive strengths of sample P40 increased slightly from 23.0 MPa at 28 days to 23.1 MPa at 60 days or increased from 28 days by only 0.44%. This means that the effect of the perlite on the improvement of the compressive strength is not significant after 28 days. As shown in Figure 4(a), using 40% of perlite in concrete can cause a larger improvement in the compressive strength than that caused by using 30 and 50% of perlite at 7, 28, and 60 days. At 28 days, the normalized compressive strengths of the perlite concrete varied between 37 and 51% of the control as shown in Figure 5(a).

In the second mix, the compressive strengths of sample 1.25P30 varied from 45.3 MPa at 7 days to 53.9 MPa at 28 days or increased from 7 days by about 19.0%.

In the third mix, the compressive strengths of sample 1.50 P30 varied from 47.8



(a) (b)

Figure 4. Relationship between compressive strength of concrete and age

Table 3. Chemical compositions of Portland cement type I and perlite

Chemical compositions (%)	Portland cement	Perlite
SiO_2	18.1	73.7
Al_2O_3	3.51	9.18
Fe_2O_3	3.05	2.75
CaO	67.5	1.72
K_2O	0.630	10.0
TiO_2	0.232	0.501
SO_3	3.30	0.0158
MgO	1.81	1.09
Na_2O	0.05	-
LOI	1.53	1.02

MPa at 7 days to 54.2 MPa at 28 days or increased from 7 days by about 13.4%. As shown in Figure 4(b), using 30% of perlite in the concrete can cause a larger improvement in the compressive strength than that caused by using 40 and 50% of perlite at all ages. At 28 days, the normalized compressive strengths of perlite concrete varied between 38 and 64% of the control as shown in Figure 5(b).

Density

Table 4 presents the 28-day air dry density of the concretes mixed with perlite. Each result was the average of 3 samples.

An air dry density is relevant for the weight of concrete in a structure. The density of structural lightweight concrete should be 1200-2000 kg/m^3 (Mannan and Ganapathy, 2004). In this study, the 28-day air dry densities of P30, P40, P50, 1.25P50, and 1.50 P50 were in the range of structural lightweight concrete or about 27.5% lower than the normal weight concrete because of a lower density of perlite. The low air dry densities in this study were due to the low density of the perlite.

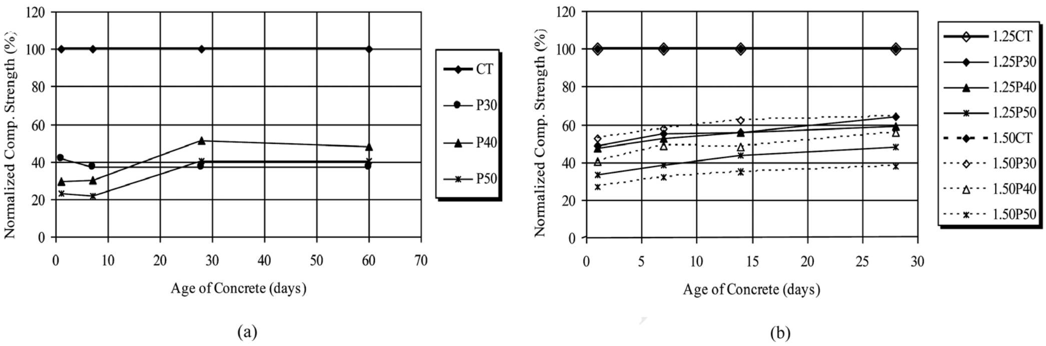


Figure 5. Relationship between normalized compressive strength concrete and age

Table 4. The 28-day of air dry density and compressive strength of concretes

Mix No.	Symbol	Air dry density (kg/m^3)	Compressive strength (MPa)
1	CT	2267	44.6
2	P30	1980	16. 7
3	P40	1832	23.0
4	P50	1741	18.1
5	1.25CT	2479	84.1
6	1.25P30	2089	53.9
7	1.25P40	2051	49.8
8	1.25P50	1917	40.3
9	1.50CT	2458	84.5
10	1.50P30	2121	54.2
11	1.50P40	2015	46.9
12	1.50P50	1783	31.8

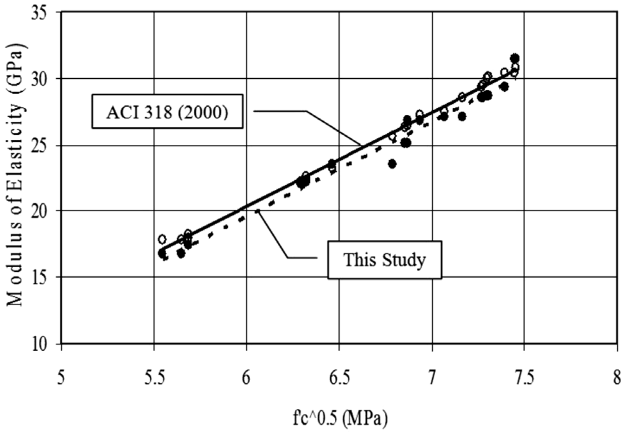


Figure 6. Modulus of elasticity of perlite concrete

Modulus of Elasticity

The modulus of elasticity is defined as the slope of the stress-strain curve of concrete which is obtained at 40% of the ultimate compressive strength since, at that point, the slope of stress-strain is almost a straight line (ASTM C 469, ASTM, 2001). The 28-day modulus of elasticity of concrete was tested according to ASTM C 469. The test results were averaged from 3 concrete specimens and varied between 16.9 and 31.5 GPa in 1.50 P50 and 1.25 P30, respectively. Figure 6 shows comparisons of the predicted values of the modulus of elasticity using ACI 318 (American Concrete Institute, 2000) and the results were obtained from this study. The ACI 318 equation was obtained from the data on light and normal weight concretes with compressive strengths between 31.8 and 54.2 MPa. Furthermore, the ACI 318 was slightly higher than the values of the modulus of elasticity from this study. It can be concluded that the ACI 318 equation fairly well predicts the modulus of elasticity of concrete when perlite is used.

Conclusions

According to the experimental results, conclusions can be draw as follows:

1. The replacement of sand with 30, 40, and 50% of perlite produces lightweight concrete and 50% sand replacement with perlite gives the lowest density.

2. Concretes 1.25 P50 and 1.50 P50 are the mixes of lightweight concrete admixed with perlite that have a density of less than 2000 kg/m^3 and a 28-day compressive strength of more than 30MPa.

3. The density of concrete can be reduced significantly by replacing perlite. In this study, the air dry density of the concrete was reduced to a minimum of 1783 kg/m^3

4. The compressive strength and modulus of elasticity of concretes are reduced as the content of the perlite increases. Loss of modulus of elasticity is more substantial compared to the loss in strength.

Acknowledgements

The authors gratefully acknowledge the financial support of the Thailand Research Fund (TRF) under grant No. RDG525008 and the Siam City Cement Public Company Limited and express sincere thanks to the authorities of Suranaree University of Science and Technology for their encouragement.

References

American Concrete Institute. (2000). 318: Building Code Requirements for Structural Concrete. American Concrete Institute, Farmington Hills, MI, USA, 443p.

ASTM C469. (2001). Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. Annual Book of ASTM Standards, Vol. 04.02. ASTM International, West Conshohocken, PA, USA, p. 248-251.

ASTM C618. (2001). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete. Annual Book of ASTM Standards, Vol. 04.02. ASTM International, West Conshohocken, PA, USA, p. 310-313.

Cobanli, M. (1993). Producing high-heat transfer coefficient light construction materials, [M.Sc. thesis]. Osmangazi University, Eskisehir, Turkey, 64p.

Demirboga, R. and Gul, R. (2003). The effects of expanded perlite aggregate, silica fume and fly ash on the thermal conductivity of lightweight concrete. Cement Concrete Res., 33(5):723-727.

Demirboga, R., Orung, I., and Gul, R. (2001). Effects of expanded perlite aggregate and mineral admixtures on the compressive strength of low-density concretes. Cement Concrete Res., 31(11):1627-1632.

Erdem, T.K., Meral, C., Tokyay, M., and Erdogan, T.Y. (2007). Use of perlite as a pozzolanic addition in producing blended cements. Cement Concrete Comp., 29(1):13-21.

Glenn, G.M., Gray, G.M., Orts, W.J., and Wood, D.W. (1999). Starch-based lightweight concrete: effect of starch source, processing method, and aggregate geometry. Ind. Crop. Prod., 9(2):133-144.

Gunning, D.F. (1994). Perlite Market Study Report. Gunning and McNeal Associates Ltd., Crown Publications Inc., Victoria, BC, Canada, p. 2-8.

Department of Primary Industries and Mines. (2010). Bangkok, Thailand. Available from: www.dpim.go.th. Accessed date: Feb 10, 2010.

Mannan, MA. and Ganapathy, C. (2004). Concrete from an agricultural waste-oil palm shell (OPS). Build. Environ., 39:441-448.

Mladenovic, A., Suput, J.S., Ducman, V., and Skapin, A.S. (2004). Alkali-silica reactivity of some frequently used lightweight aggregate. Cement Concrete Res., 34(10):1809-1816.

Mo, X. and Fournier, B. (2007). Investigation of structural properties associated with alkali-silica reaction by means of macro-and micro-structural analysis. Mater. Charact., 58 (2):179-189.

Neville, A.M. (1998). Properties of Concrete. 3rd ed. ELBS edition of Longman Ltd., Singapore, 711p.

SCG Cement. (2008). Cement and Applications. 4th ed. Siam Cement Public Company Limited, Bangkok, Thailand, 293p.

Topcu, I.B. (1999). High heat transfer coefficient brick produce with perlite. Journal of the Faculty of Engineering and Architecture of Osmangazi University. 5 (12):71-82.

Yalgin, S. (1983). Using Expanded Perlite in Construction Sector. 1st ed. Etibank, Ankara, Turkey, 138p.