

PERFORMANCE AND APPLICATIONS OF LIGHTWEIGHT FOAMED
CONCRETE WITH VARIOUS DENSITY

LAW CHIN YONG

A project report submitted in partial fulfilment of
the requirements for the award of the degree of
Master of Engineering (Structure)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JANUARY 2017

ACKNOWLEDGEMENTS

It is a great pleasure to address those people who helped me throughout this project to enhance my knowledge and practical skills. Firstly, I would like to extend my deepest and most heartfelt gratitude to my supervisor, Dr. Shek Poi Ngian. The continuous guidance and support from him have enabled me to approach work positively, and make even the impossible seem possible.

Apart from that, I wish to express my sincere appreciation to my lecturers, Dr. Lee Yeong Huei, Dr. Ma Chau Khun and Assoc. Prof. Dr. Tan Cher Siang who has provided assistance at various occasions. Never forget too, I would like to give my heartily and thousand thankful to all the technicians who helped me a lot in this study.

I wish to express my special thanks to my friend, Miss Siti Nurul Nureda binti Mohamad Zukri, who always encourages and gave me advices when I faced problem in my study. Besides that, she also willing to share her knowledge about concrete properties with me which is very helpful in my study. And, she is an unselfish, generous and broad person as she willing to share her experimental workplace with me even though the place is not enough for her.

Last but not least, I would like to thanks my beloved family and friends who gives me spirit, support and encouragement to me in completion this project.

ABSTRACT

Lightweight foamed concrete (LFC) has become an innovative product for the construction field. It is made by mixing the mortar with stable foam. Studies showed that lightweight foamed concrete using fine sand gains higher strength compared to coarse sand. Thus, an experimental work is conducted to produce lightweight foamed concrete incorporated sieved sand (100% passing 0.6mm sieve opening) as filler with target density of 800kg/m^3 , 1000kg/m^3 , 1300kg/m^3 , 1500kg/m^3 and 1700kg/m^3 . This study aims to determine the compressive strength-density ratio (performance index) of lightweight foamed concrete. Besides, a guideline about the lightweight foamed concrete's preparation and casting as well as application of lightweight foamed concrete also delivered in this paper. Total nine cubes have been casted for various densities of lightweight foamed concrete and all specimens were cured under water until testing ages (7, 14 and 28 days). The results revealed that high density foamed concrete gained higher compressive strength and performance index compared to low density foamed concrete. Besides, the compressive strength of foamed concrete displayed a continuous increase with concrete age. The lightweight foamed concrete's preparation and casting had been developed as a guideline and discussed step by step. For the application, only LFC-1700 specimen can be proposing for structural purpose as its compressive strength is more than 17MPa while other specimens are proposing for non-structural purpose except LFC-800 specimen.

ABSTRAK

Konkrit ringan berbuih (LFC) telah menjadi salah satu inovatif produk untuk bidang pembinaan. Perbuatan LFC ialah mencampurkan mortar dengan buih yang stabil. Kajian menunjukkan bahawa penggunaan pasir halus dalam konkrit ringan berbuih menghasilkan kekuatan yang lebih tinggi berbanding dengan pasir kasar. Oleh itu, kerja-kerja eksperimen dijalankan untuk menghasilkan konkrit ringan berbuih diperbadankan pasir disaring (100% melepaskan 0.6 mm ayak pembukaan) sebagai pengisi dengan kepadatan sasaran 800kg/m^3 , 1000kg/m^3 , 1300kg/m^3 , 1500kg/m^3 dan 1700kg/m^3 . Kajian ini bertujuan untuk menentukan *compressive strength-density ratio* (*performance index*). Selain itu, garis panduan mengenai penyediaan and pemutus konkrit ringan berbuih serta aplikasi konkrit ringan berbuih juga disampaikan dalam kajian ini. Jumlah sembilan kiub telah dibuatkan untuk pelbagai ketumpatan konkrit ringan berbuih dan semua spesimen telah disembuhkan dalam air sehingga umur ujian (7, 14 dan 28 hari). Hasil kajian menunjukkan bahawa ketumpatan konkrit ringan berbuih yang tinggi mendapat kekuatan mampatan dan *performance index* yang lebih tinggi berbanding dengan ketumpatan konkrit ringan berbuih yang rendah. Selain itu, kekuatan mampatan konkrit berbuih memaparkan peningkatan yang berterusan dengan umur konkrit. Dalam kajian ini, penyediaan dan pemutus konkrit ringan berbuih telah dihasilkan sebagai panduan dan dibincangkan langkah demi langkah. Bagi aplikasi LFC dalam kajian ini, hanya spesimen LFC-1700 boleh dicadangkan untuk tujuan struktur kerana kekuatan mampatan adalah lebih daripada 17MPa manakala spesimen lain kecuali spesimen LFC-800 dicadangkan untuk tujuan bukan struktur.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xiii
	LIST OF ABBREVIATIONS	xv
	LIST OF SYMBOLS	xvi
	LIST OF APPENDICES	xvii
1	INTRODUCTION	1
	1.1 Background of Study	1
	1.2 Problem Statement	3
	1.3 Objectives	3
	1.4 Scope of Study	3
	1.5 Significance of Study	4
	1.6 Outline of Thesis	5
2	LITERATURE REVIEW	6
	2.1 Introduction	6
	2.2 Application of Foamed Concrete	9
	2.3 Constituent Material of Foamed Concrete	12
	2.3.1 Binder	12

2.3.2	Foam	14
2.3.2.1	Foaming Agents	15
2.3.3	Water	15
2.3.4	Fillers	16
2.3.4.1	Fine Aggregate	16
2.3.4.2	Coarse Fly Ash	16
2.3.4.3	Clay	17
2.3.4.4	Lime	18
2.4	Mechanical Properties of Foamed Concrete	19
2.4.1	Compressive Strength	19
2.4.1.1	Effect of Concrete Density and Foamed Volume	19
2.4.1.2	Effect of Water-Cement Ratio	20
2.4.1.3	Effect of Sand-Cement Ratio	21
2.4.1.4	Effect of Gradation of Sand	22
2.4.1.5	Effect of Binder or Filler Replacement	24
2.4.1.6	Effect of Curing Method	26
2.4.1.7	Summary on Mechanical Properties	27
2.5	Summary	30
3	PERFORMANCE OF LIGHTWEIGHT FOAMED CONCRETE	31
3.1	General	31
3.2	Pilot Study on Filler in Lightweight Foamed Concrete	33
3.3	Experimental Program	34
3.3.1	Material Preparation	34
3.3.2	Mix Details and Specimens Preparation	35
3.3.3	Mixing Procedures	36
3.4	Curing Method	37
3.5	Fresh Properties Test	37
3.5.1	Flow Table Test	38
3.5.2	Inverted Slump Test	38
3.6	Mechanical Properties Test	40

3.6.1	Compressive Strength Test	40
3.7	Consistency and Stability	42
3.8	Results and Discussion	42
3.8.1	Fresh Properties of Lightweight Foamed Concrete	43
3.8.2	Results of Consistency and Stability	43
3.8.3	Compressive Strength and Performance Index of LFC	47
3.9	Summary	51
4	GUIDELINE ON LIGHTWEIGHT FOAMED CONCRETE'S PREPARATION AND CASTING	52
4.1	Introduction	52
4.2	Pre-calculation of Mix Proportions	52
4.3	Mortar Mixture	54
4.4	Foam Formation	56
4.5	Mixture of Foamed Concrete	57
4.6	Summary	59
5	APPLICATIONS OF LIGHTWEIGHT FOAMED CONCRETE	61
5.1	Introduction	61
5.2	Application on Structure	62
5.3	Application on Non-Structure	63
5.3.1	Lightweight Aggregate for Concrete Masonry Units	63
5.3.1.1	Loadbearing Concrete Masonry Units	63
5.3.1.2	Nonloadbearing Concrete Masonry Units	64
5.3.2	Insulating Concrete	65
5.3.3	Trench Reinstatement	65
5.3.4	Bridge Abutment	66
5.3.5	Void Filling	66
5.4	Summary	67

6	CONCLUSION AND RECOMMENDATION	70
6.1	Summary of Research Works	70
6.2	Conclusion	71
6.3	Recommendation	71
	REFERENCES	73
	Appendices A-E	78-82

LIST OF TABLES

TABLE NO.	TITLE	PAGE
1.1	Definitions of concrete	1
2.1	Different types of concrete containing air	8
2.2	Applications of foamed concrete	12
2.3	Main compounds in Portland cement	13
2.4	General of clay characteristics	18
2.5	Compressive strength of LFC with different densities and additives	20
2.6	Summary on factors affect compressive strength of foamed concrete	28
3.1	Typical chemical composition of the OPC based on the manufacture's specification	34
3.2	The mix proportions of the specimens	36
3.3	Laboratory testing with the parameter obtained from the test	40
3.4	Fresh properties test	43
3.5	Consistency and stability of lightweight foamed concrete	44
3.6	Compressive strength and performance index	48
3.7	The effect of void percentage on performance index of lightweight foamed concrete	49
5.1	Compressive strength of lightweight foamed concrete at 28 days	61
5.2	Compressive strength and splitting tensile strength requirements	62

5.3	Strength and density classification requirements for loadbearing concrete masonry units	64
5.4	Strength and density classification requirements for nonloadbearing concrete masonry units	65
5.5	Summary on the application of lightweight foamed concrete	69

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Basic form lightweight concrete	6
2.2	Diagrammatic representation of the mines	9
2.3	Placement of foamed concrete in trial trench fill foundations and ground slab	10
2.4	Road making construction in Canary Wharf London	10
2.5	Foamed concrete application at the SMART tunnel in Kuala Lumpur	11
2.6	Stable dry type foam	14
2.7	Schematic diagram of the production of foam for foamed concrete	15
2.8	Effect of FA_{coarse} fine aggregate on 100mm cube sealed-cured compressive strength development	17
2.9	The compressive strength and thermal conductivity of soil-based concrete for different dry densities	18
2.10	Different formations of voids	19
2.11	Effect of water-to-cement (w/c) ratios on spread and invert slump values, and seven-day compressive strength of foamed mortar	21
2.12	Compressive strength versus density of foamed concrete cured in water and air with respect to S/C ratios	22
2.13	Effect of different sand gradations on 28 and 56 days compressive strength of CLFC cube specimens under two different curing condition	23
2.14	The strength density variation for mixes with sand of different fineness	23
2.15	Compressive strength development for LCF-CM, LFC-PF10 and LFC-PF20 up to 90 days of age	24

2.16	28-day compressive strength versus wet density	25
2.17	Effect of polypropylene fiber on the compressive strength of foamed concrete	26
3.1	Flow chart of methodology	32
3.2	The mixture of mortar incorporated with red clay soil	33
3.3	Water curing	37
3.4	Flow table test for mortar	38
3.5	Process of inverted slump test for lightweight foamed concrete	39
3.6	Compression test machine	41
3.7	The surface condition of LFC-800 specimen	45
3.8	The surface condition of LFC-1000 specimen	46
3.9	The surface condition of LFC-1300 specimen	46
3.10	The surface condition of LFC-1500 specimen	46
3.11	The surface condition of LFC-1700 specimen	47
3.12	28-days compressive strength versus density	49
3.13	Compressive strength development of specimens	50
4.1	The condition of cement (a) fresh cement (b) hydrated cement paste	54
4.2	The condition of tap water (a) clean (b) colourise	55
4.3	Procedures of mortar mixture	55
4.4	Foam formation	57
4.5	The condition of foam after 15 minutes	58
4.6	Casting of lightweight foamed concrete	58
4.7	Manufacturing process of lightweight foamed concrete	60

LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
BSI	-	British Standard Institution
CLFC	-	Cement based lightweight foamed concrete
FA _{coarse}	-	Coarse fly ash
GGBFS	-	Ground granulated burst furnace slag
HAUC	-	Highway Authorities & Utilities Committee
ISF	-	Incinerated sugarcane filter cake
LFC	-	Lightweight foamed concrete
LFC-CM	-	LFC with 100% sand filler as control mix
LFC-PF10	-	LFC with 10% POFA replacement as a part of filler
LFC-PF20	-	LFC with 20% POFA replacement as a part of filler
MC	-	Mortar
OPC	-	Ordinary Portland cement
PI	-	Performance Index
POFA	-	Palm oil fuel ash
S.G	-	Specific gravity
s/c ratio	-	Sand-to-cement ratio
SEM	-	Scanning Electron Microscopy
TRL	-	Transport Research Laboratory
w/c ratio	-	Water-to-cement ratio

LIST OF SYMBOLS

A_c	-	Cross-section area of the specimen
Al_2O_3	-	Aluminium oxide
$Ca(OH)_2$	-	Calcium hydroxide
CaO	-	Calcium oxide
f_c	-	Compressive strength
Fe_2O_3	-	Iron oxide
K_2O	-	Potassium oxide
MgO	-	Magnesium oxide
Na_2O	-	Sodium oxide
P	-	Maximum load carried by the specimen
SiO_2	-	Silicon dioxide
SO_3	-	Sulfur trioxide

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Mix Proportion Calculation of LFC-800 Specimen	78
B	Mix Proportion Calculation of LFC-1000 Specimen	79
C	Mix Proportion Calculation of LFC-1300 Specimen	80
D	Mix Proportion Calculation of LFC-1500 Specimen	81
E	Mix Proportion Calculation of LFC-1700 Specimen	82

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Concrete is a material that used widely in the construction field, from basic work to multi-storey building. The basic materials that used to manufacture concrete are cement, water and aggregate (coarse and fine). The cement known as the binder reacts with water to form cementitious paste and fill the void between the aggregate particles and glue them together to produce concrete or mortar (Mindess *et al.*, 2003). Besides, admixture sometimes added/replaced during the mixing to modify the concrete properties such as strength, durability and workability. Table 1.1 had showed the definitions of concrete.

Table 1.1: Definitions of concrete (Mindess *et al.*, 2003)

Concrete	=	Filler	+	Binder
Portland cement concrete	=	Aggregate (fine and coarse)	+	Portland cement paste
Mortar	=	Fine aggregate	+	Paste
Paste	=	Cement	+	Water

With the advancement of technology, the development of concrete has attracted great interest and focused by the researchers or contractors. One of the innovative concrete product that is popular nowadays is foamed concrete which had been used in both structural and non-structural purpose. Foamed concrete is classified as lightweight concrete, where stabilized bubble foam created by foaming agent is added into the mortar with appropriate proportions to produce low density concrete (400 to 1800kg/m³) (Amran *et al.*, 2015). The differences between foamed concrete and conventional concrete are the elimination of coarse aggregate and existence of artificial air bubbles trapped in mortar. Besides that, no compaction is needed as foamed concrete does not settle easily and it is free flowing, self-leveling, thus, spreads to fill all voids and reduce the strain on manpower as well as faster construction work. Aldridge (2005) had reported that the characteristic of foamed concrete is normally depending on its mix design but there are several properties which are general across a range of mix designs such as:

- High strength-to-weight ratio
- Low coefficient of permeability
- Low water absorption
- Good freeze/thaw resistance
- High modulus of elasticity
- Low shrinkage
- Thermal insulating properties
- Shock absorbing qualities
- Not susceptible to breakdown due to hydrocarbons, bacteria or fungi

In this study, an experimental work on lightweight foamed concrete incorporated with sieved sand as filler is conducted to determine the engineering properties in term of compressive strength. Besides, a guideline on foamed concrete's preparation and casting is also developed. The application of lightweight foamed concrete based on the compressive strength is proposed and discussed in this study.

1.2 Problem Statement

Sand (fine aggregate) is one of the filler materials contribute to the strength of lightweight foamed concrete. The sand used in the mix can reduce the material cost and produce cheaper mix of foamed concrete compare to that fully cement paste is used (Hamidah *et al.*, 2005). The study on different gradations of sand had reported that the lightweight foamed concrete using fine sand gains higher strength compare to coarse sand (Lim *et al.*, 2015). This is owing to more hydrated cement paste are required to bond the larger total surface area of the finer sand particles together and made the microstructure more solid. Therefore, an experimental work is conducted to investigate the performance of lightweight foamed concrete incorporated with sieved sand at various densities.

1.3 Objectives

There are three objectives in this study:

- i. To determine the performance index of lightweight foamed concrete incorporated with sieved sand as filler with various densities.
- ii. To developed a guideline on lightweight foamed concrete's preparation and casting.
- iii. To propose the application of lightweight foamed concrete in accordance to compressive strength results.

1.4 Scope of Study

In this study, the lightweight foamed concrete is produced by mixing ordinary Portland cement, sand, water and synthetic-based foaming agent. The density of the lightweight foamed concrete is designed and targeted in 800, 1000, 1300, 1500 and 1700kg/m³ respectively. The mix proportion for cement-sand ratio is set as 1:1 while

the water-cement ratio (w/c) is depending on the flow table test of base mix (mortar) which the range value is set within 22cm to 23cm in diameter. The sand is sieved to obtain the particles size passing through 600 μ m sieve opening and oven dried at 105°C \pm 5°C for 24 hours to remove the total moisture content before casting. Total nine cubes (100 x 100 x 100mm in dimension) in accordance with BS EN 12390-1 (BSI, 2000) are casted for each density. The foamed concrete cubes are cured in water after un moulded and tested for compressive strength at 7,14 and 28 days. For the fresh properties, flow table test in accordance with ASTM C1437 (ASTM, 2007) is conducted to determine the workability of fresh base mix while inverted slump test in accordance with ASTM C1611 (ASTM, 2014) is carried out to obtain the consistency of fresh foamed concrete. For the mechanical properties, compressive strength test in accordance with BS EN 12390-3 (BSI, 2001) is conducted to obtain the compressive strength of concrete specimens. The strength performance index (PI) indicates proportion of the compressive strength corresponding to a unit density is determined and discussed. From the experimental, a guideline on lightweight foamed concrete's preparation and casting is developed. Lastly, the lightweight foamed concrete is proposed and discussed for their applications based on the compressive strength results.

1.5 Significance of Study

Through the experimental work, the mix proportion to manufacture the lightweight foamed concrete using sieved sand as filler at various density is obtained and the engineering properties of lightweight foamed concrete in term of compressive strength can be determined. Besides that, in this study, a guideline is also developed in order to provide the procedures of preparation and casting lightweight foamed concrete from beginning of preparation of base mix and foam until the mixture of base mix and foam to produce lightweight foamed concrete. Based on the compressive strength, the applications of lightweight foamed concrete with various density are proposed in civil and structure engineering areas.

1.6 Outline of Thesis

This project report contains 6 chapters. The general information of the research subject including background of the study, problem statement, objectives of the study, scope of work and significance of study are mentioned in Chapter 1. Chapter 2 is the literature review which review the detailed background of the foamed concrete and the research done by previous researchers. Chapter 3 discusses on the experimental works of lightweight foamed concrete incorporated sieved sand as filler. In the chapter, the fresh properties and mechanical properties of lightweight foamed concrete as well as the results and discussion on the mix design are discussed and delivered. From the experimental works, the guideline on lightweight foamed concrete's preparation and casting is observed, recorded, studied and discussed in Chapter 5. In Chapter 6, the application of lightweight foamed concrete incorporated sieved sand as filler at various density is proposed in accordance to their compressive strength requirement. The research works are summarized and concluded in Chapter 7. Moreover, the recommendation for future works also discussed in this chapter.

REFERENCES

- ACI (1999). ACI 213R-87. *Guide for Structural Lightweight Aggregate Concrete*. United State: American Concrete Institute.
- Aldridge, D (2015). Introduction to Foamed Concrete: What, Why, How? In Dhir, R.K., Newlands, M.D. and McCarthy, A. (Ed.) *Used of Foamed Concrete in Construction* (pp. 1-14) London: Thomas Telford.
- Amran, Y.H.M., Farzadnia, N., and Ali, A.A.A. (2015). Properties and Applications of Foamed Concrete; a Review. *Construction and Building Materials*. 101, 990-1005.
- ASTM (1999). ASTM C332. *Standard Specification for Lightweight Aggregates for Insulating Concrete*. United State: American Society for Testing and Materials.
- ASTM (2009). ASTM C330/C330M. *Standard Specification for Lightweight Aggregates for Structural Concrete*. United State: American Society for Testing and Materials.
- ASTM (2013). ASTM C1437-13. *Standard Test Method for Flow of Hydraulic Cement Mortar*. United States: American Society for Testing and Materials.
- ASTM (2014a). ASTM C1611-14. *Standard Test Method for Slump Flow of Self-Consolidating Concrete*. United State: American Society for Testing and Materials
- ASTM (2014b). ASTM C90-14. *Standard Specification for Loadbearing Concrete Masonry Units*. United State: American Society for Testing and Materials.
- ASTM (2014c). ASTM C129-14a. *Standard Specification for Nonloadbearing Concrete Masonry Units*. United State: American Society for Testing and Materials.

- Awang, H., Mydin, M.A.O., and Roslan, A.F. (2012). Effect of additives on mechanical and thermal properties of lightweight foamed concrete. *Advanced in Applied Science Research*. 3(5), 3326-3338.
- Bing, C., Zhen, W., and Ning, L (2012). Experimental research on properties of high-strength foamed concrete. *Journal of Materials in Civil Engineering*. 21(1), 113-118.
- Boughrarou, R. and Cale, S.A. (2005). Stabilisation of old mine workings: a case study of the use of foamed concrete in combe down stone mines. In Dhir, R.K., Newlands, M.D. and McCarthy, A. (Ed.) *Used of Foamed Concrete in Construction* (pp. 133-142) London: Thomas Telford.
- Brady, K.C., Watts, G.R.A. and Jones, M.R. (2001) *Specification for Foamed Concrete*. Project Report PR/IS/40/01. Crowthorne: TRL Limited.
- BSI (1996). BS 3892-2. *Pulverized-fuel ash; Specification for Pulverized Fuel Ash to be Used as a Type I Addition*. London: British Standard Institution.
- BSI (2000). BS EN 12390-1. *Testing Hardened Concrete Part 1: Shape, dimensions and other requirements for specimens and moulds*. London: British Standard Institution.
- BSI (2009). BS EN 12390-3. *Testing Hardened Concrete Part 3: Compressive Strength of Test Specimens*. London: British Standard Institution.
- BSI (2011) BS EN 197-1:2011. *Composition, specifications and conformity criteria for common cements*. London: British Standard Institution.
- Cong, M. and Bing, C (2015). Properties of a foamed concrete with soil as filler. *Construction and Building Materials*. 76, 61-69.
- Cox, L (2005). Major road and bridge projects with foam concrete. In Dhir, R.K., Newlands, M.D. and McCarthy, A. (Ed.) *Used of Foamed Concrete in Construction* (pp. 105-112) London: Thomas Telford.

- Dhir, R.K. and Jackson, N. (1996). *Part III Concrete*. In Jackson, N. and Dhir, R.K. (Ed.) *Civil Engineering Materials (5th ed.)* (pp. 163-195). London: Macmillan Press Ltd.
- Goh, C.H. (2011). *Strength Development of Lime and Cement Stabilized Clayey Soil*. Bachelor Degree Thesis. Universiti Teknologi Malaysia, Skudai.
- Jones, M.R., and McCarthy, A., (2005a). Behaviour and assessment of foamed concrete for construction applications. In Dhir, R.K., Newlands, M.D. and McCarthy, A. (Ed.) *Used of Foamed Concrete in Construction* (pp. 61-88) London: Thomas Telford.
- Jones, M.R. and McCarthy, A. (2005b). Preliminary Views on the Potential of Foamed Concrete as a Structural Material. *Magazine of Concrete Research*. 57(1), 21-31.
- Hamidah, M.S., Azmi, I., Ruslan, M.R.A., Kartini, K., and Fadhil, N.M (2005). Optimisation of foamed concrete mix of different sand-cement ratio. In Dhir, R.K., Newlands, M.D. and McCarthy, A. (Ed.) *Used of Foamed Concrete in Construction* (pp. 37-44) London: Thomas Telford.
- Highway Authorities and Utilities Committee (2010). *New Roads and Street Works Act 1991. Specification for the Reinstatement of Openings in Highways*. London: TSO.
- Hilal, A.A., Thom, N. H., and Dawson, A.R. (2015). On void structure and strength of foamed concrete made without/with additives. *Construction and Building Materials*. 85, 57-164.
- Kearsley, E.P., and Wainwright, P.J. (2001). The effect of high fly ash content on the compressive strength of foamed concrete. *Cement and Concrete Research*. 31, 105-112.
- Kearsley, E.P. and Mostert, H.F. (2005a). The Use of Foamed Concrete in Refractories. In Dhir, R.K., Newlands, M.D. and McCarthy, A. (Ed.) *Used of Foamed Concrete in Construction* (pp. 89-96) London: Thomas Telford.

- Kearsley, E.P. and Mostert, H.F. (2005b). Designing Mix Composition of Foamed Concrete with High Fly Ash Contents. In Dhir, R.K., Newlands, M.D. and McCarthy, A. (Ed.) *Used of Foamed Concrete in Construction* (pp. 29-36) London: Thomas Telford.
- Khaw, Y.H. (2010). *Performance of Lightweight Foamed Concrete using Laterite as Sand Replacement*. Bachelor Degree Thesis, Universiti Malaysia Pahang, Pekan.
- Lane, J. W. (2011). *Concrete Masonry Manual*. (9th ed.) Concrete Manufacturers Association.
- Lee, Y.L and Hung, Y.T (2005). Exploitation of solid wastes in foamed concrete: challenges ahead. In Dhir, R.K., Newlands, M.D. and McCarthy, A. (Ed.) *Used of Foamed Concrete in Construction* (pp. 15-22) London: Thomas Telford.
- Lee, Y.L. (2015). *Structural Behaviour of Slab Panel System with Embedded Cold-Formed Steel Skeletal Frame*. PhD Thesis. Universiti Teknologi Malaysia, Skudai.
- Liew, A.C.M (2005). New innovative lightweight foam concrete technology. In Dhir, R.K., Newlands, M.D. and McCarthy, A. (Ed.) *Used of Foamed Concrete in Construction* (pp. 45-50) London: Thomas Telford.
- Lim, S.K., Tan, C.S., Lim, O.Y., and Lee, Y.L. (2013). Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler. *Construction and Building Materials*. 46, 39-47.
- Lim, S.K., Tan, C.S., Zhao, X., and Ling, T.C. (2015). Strength and Toughness of Lightweight Foamed Concrete with Different Sand Grading. *KSCE Journal of Civil Engineering*. 19(7), 2191-2197.
- Makul, N. and Sua-iam, G. (2016) Characteristics and utilization of sugarcane filter cake waste in the production of lightweight foamed concrete. *Journal of Cleaner Production*. 126, 118-133.
- Maziah, M (2011). *Development of Foamed Concrete Enabling and Supporting Design*. PhD Thesis, University of Dundee

- McGovern, G. (2000). *Manufacture and Supply of Ready-mix Foamed Concrete*. One day awareness seminar on 'Foamed Concrete: Properties, Applications and Potential' held at University of Dundee. 12-25.
- Mehta, P. K. (2002) Greening of the Concrete Industry for Sustainable Development. *ACI Concrete International*, 24 (7), 23-28.
- Mindess, S., Young, J.F., and Darwin, D. (2003). *Concrete* (2nd ed.) Pearson Education Inc.: Prentice Hall
- Nambiar, E.K.K.K., and Ramamurthy, K. (2006). Influence of filler type on the properties of foam concrete. *Cement and Concrete Research*. 28, 475-480.
- Nawy, E.G. (2001). *Fundamentals of high-performance concrete*. (2nd ed.) New York: John Wiley & Sons, Inc. 2-11.
- Neville, A.M. and Brooks, J.J. (1987). *Concrete Technology*. England: Longman Scientific & Technical.
- Newman, J. and Owens, P. (2003). *Properties of lightweight concrete*. In Newman, J. and Ban, S.C. (Ed.) *Advanced Concrete Technology: Processes*. (pp. 2/3-2/25). Butterworth-Heinemann: Elsevier.
- Ramamurthy, K., Nambiar, and E.K.K.K, Ranjani, G.I.S. (2009). A classification of studies on properties of foam concrete. *Cement and Concrete Composites*. 31, 388-396.
- Schroeder, W.L., Dickenson, S.E. and Warrington, D.C. (2004). *Soils in Construction*. (5th ed.) New Jersey: Prentice Hall
- Transport Research Laboratory (2001). *Specification for Foamed Concrete*. Application Guide AG39
- Zhao, X., Lim, S.K., Tan, C.S., Li, B., Ling, T.C., Huang, R. and Wang, Q. (2015). Properties of Foamed Mortar Prepared with Granulated Blast-Furnace Slag. *Material*. 8, 462-473.