

UNIVERSITI TEKNOLOGI MALAYSIA

DECLARATION OF THESIS / UNDERGRADUATE PROJECT PAPER AND COPYRIGHT

Author's full name : YULIUS RIEF ALKHALY

Date of birth : 7th JULY 1971

Title : DEVELOPMENT OF LIGHTWEIGHT CONCRETE USING
HOLLOW SPHERES

Academic Session: 2008/2009

I declare that this thesis is classified as :

CONFIDENTIAL

(Contains confidential information under the Official Secret Act 1972)*

RESTRICTED

(Contains restricted information as specified by the organization where research was done)*

OPEN ACCESS

I agree that my thesis to be published as online open access (full text)

I acknowledged that Universiti Teknologi Malaysia reserves the right as follows:

1. The thesis is the property of Universiti Teknologi Malaysia.
2. The Library of Universiti Teknologi Malaysia has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.



SIGNATURE

B727676

(NEW IC NO. /PASSPORT NO.)

Date : 24th NOVEMBER 2008

Certified by :



SIGNATURE OF SUPERVISOR

DR. REDZUAN ABDULLAH

NAME OF SUPERVISOR

Date : 24th NOVEMBER 2008

NOTES : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

24th November 2008

Librarian
Perpustakaan Sultanah Zanariah
UTM, Skudai,
Johor

Sir,

CLASSIFICATION OF PROJECT REPORT AS RESTRICTED
- *DEVELOPMENT OF LIGHTWEIGHT CONCRETE USING HOLLOW SPHERES* -
By *YULIUS RIEF ALKHALY*

Please be informed that the above mentioned project report entitled "*DEVELOPMENT OF LIGHTWEIGHT CONCRETE USING HOLLOW SPHERES*" be classified as RESTRICTED for a period of three (3) years from the date of this letter. The reason for this classification is:

The project has a quality of new invention. We intent to file for a pattern

Thank you.

Sincerely yours,



Dr. Redzuan Abdullah
Faculty of Civil Engineering,
Universiti Teknologi Malaysia
81310 UTM Skudai, Johor.
Telephone: 07-5531591
: 019-7720622

I declare that I have read through this project and to
my opinion this report is adequate in term of scope and quality for
the purpose of awarding the degree of Master of Engineering (Civil – Structures)

Signature


:.....

Name of Supervisor

: Dr. REDZUAN ABDULLAH

Date

: NOVEMBER 2008

DEVELOPMENT OF LIGHTWEIGHT CONCRETE USING
HOLLOW SPHERES

YULIUS RIEF ALKHALY

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil-Structures)

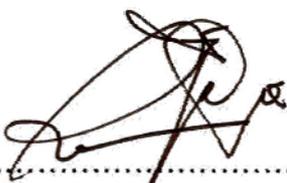
Faculty of Civil Engineering
Universiti Teknologi Malaysia

NOVEMBER 2008

I declare that this project report entitled “*Development of Lightweight Concrete Using Hollow Spheres*” is the result of my own research except as cited in references.

The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature



:

Name of Supervisor

: YULIUS RIEF ALKHALY

Date

: NOVEMBER 2008

*Specially for my beloved wife,
Dewi Andriana*

*To my children,
Siti Iffat Tabriza
Muhammad Rayyan Syauqy*

To Brothers and Sisters

ACKNOWLEDGEMENTS

Upon the accomplishment of this project, the author would like to express sincere gratitude and special appreciation to my supervisor Dr. Redzuan Abdullah, for his invaluable guidance, meaningful contributions and untiring efforts, advices and encouragements throughout this project. With his valuable suggestions, ideas, assistance, encouragement, comment and criticism, the author is able to complete the project on time.

I would also like to extend thanks to the local government of Nanggroe Aceh Darussalam, Indonesia, for funding and support two years of my study through a University of Malikussaleh scholarship. Outmost gratitude is extended to staff of the Faculty of Civil Engineering, Universiti Teknologi Malaysia, for their support and assistance during my study in the structures department. Special thanks to the technicians at structural laboratory and all those who helped directly or indirectly to make this project a success. My fellow postgraduate colleagues and many friends whom I met here during my study should be recognized for their continual support and encouragements.

Lastly, deepest appreciation and thanks to my beloved wife, children, brothers and sisters for their encouragement and moral support during preparation this project.

ABSTRACT

A new type lightweight concrete was produce using plastic and glass spheres, as a replacement to coarse aggregate. The new concrete was tested to determine compressive strength, density, water absorption, and stress-strain relationship. Twenty five samples of concrete specimen were prepared, nine of which were mix of normal concrete and cement mortar. The size of spheres of plastic were used of 6 mm, 14.5 mm and glass spheres were of 16 mm, 25 mm. In order to improve the interfacial strength between spheres and cement matrix, the surface of spheres was coated with sand using epoxy adhesive SIKADUR 330. It was found that by using plastic spheres as aggregate the density of the concrete was lowered significantly, while by using glass spheres the density of concrete was not reduced as low as that using plastic spheres. The strength of the concrete using both types of spheres was reduced compared to the concrete using natural coarse aggregate. The strength of concrete using sand coated plastic spheres was increased compared to that without sand coating. Due to insufficient bond strength of SIKADUR 330 on the surface of glass spheres, the concrete using sand coated glass sphere did not gain additional compressive strength. The capability of concrete using glass or plastic spheres to resist water absorption was as good as normal concrete. However, overall performance of concrete using plastic and glass spheres showed good result. The Compressive strength rages between 24 MPa to 29 MPa which is 66% - 77% of normal concrete strength, which indicate that the strength is sufficiently strong for use in structural element. The results of this study indicate that plastic and glass spheres may provide as a suitable alternative to produce structural lightweight concrete.

ABSTRAK

Suatu konkrit ringan jenis baru telah dihasilkan menggunakan sfera plastik dan kaca, sebagai pengganti batu baur kasar. Konkrit jenis baru ini telah diujikaji dengan ujian kekuatan mampatan, ujian kepadatan, ujian penyerapan air dan ujian tegasan-tarikan. Dua puluh lima buah konkrit spesimen telah diujikaji, termasuk didalamnya enam siri daripada konkrit biasa dan motar simen sebagai pembandingan. Saiz sfera plastic dan sfera kaca yang digunakan masing-masing iaitu 6 mm, 14.5 mm dan 16 mm, 25 mm. Untuk menaikkan kekuatan cengkaman antara permukaan sfera dan konkrit, penyapuan pasir dengan gam epoxy SIKADUR 330 digunakan. Penggunaan sfera plastik sebagai pengganti batu baur kasar menunjukkan penurunan pada kepadatan konkrit secara nyata, sedangkan dengan menggunakan sfera kaca tidak menunjukkan penurunan kepadatan seperti pada sfera plastik. Kedua-dua jenis sfera itu juga memberikan penurunan pada kekuatan mampatan konkrit. Kekuatan mampatan konkrit yang menggunakan sfera dengan sapuan pasir lebih baik dibandingkan dengan konkrit yang menggunakan sfera tanpa sapuan pasir. Oleh kerana lemahnya kekuatan cengkaman gam SIKADUR 330 pada permukaan sfera kaca, cara ini tidak memberikan tambahan pada kekuatan mamapatan konkrit yang menggunakan sfera kaca. Kemampuan konkrit yang berisi sfera kaca atau palstik untuk mengawal penyerapan air adalah sama serperti konkrit biasa. Walaubagaimanapun, keboleherjaan konkrit yang menggunakan sfera kaca dan sfera plastik menunjukkan hasil yang baik. Kekuatan mampatan boleh mencapai 24 MPa hingga 29 MPa atau sebesar 66% - 77% daripada kekuatan mampatan konkrit biasa dan layak digunakan pada unsur struktur. Keputusan ujikaji menunjukkan bahawa sfera plastik dan sfera kaca boleh dipakai sebagai pilihan untuk mewujudkan konkrit ringan pada unsur struktur.

TABLE OF CONTENT

CHAPTER	SUBJECT	PAGE
	CERTIFICATION OF THESIS	
	SUPERVISOR’S LETTER FOR RESTRICTED THESIS	
	CERTIFICATION BY SUPERVISOR	
	TITLE PAGE	i
	AUTHOR’S DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF SYMBOLS AND ABBREVIATIONS	xv
	LIST OF APPENDICES	xvii
CHAPTER 1	INTRODUCTION	1
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 Aims and Objectivities of Study	3
	1.4 Scope of Study	4
	1.5 Layout of Thesis	4

CHAPTER 2 LITERATURE REVIEW	5
2.1 Introduction	5
2.1.1 Definition of Lightweight Concrete	6
2.1.2 Type of Lightweight Concrete	7
2.1.3 Classification and Application of Lightweight Concrete	8
2.1.4 Advantages and Disadvantages of Lightweight Concrete	11
2.2 Aerated Concrete	12
2.2.1 Foamed Concrete	13
2.2.2 Gas Concrete	14
2.3 Lightweight Aggregate Concrete	14
2.3.1 Natural Aggregate	14
2.3.1.1 Mineral Aggregate	15
2.3.1.2 Organic Aggregate	16
2.3.2 Manufactured Aggregate	18
2.3.2.1 Sintered Fly Ash Aggregates	18
2.3.2.2 Expanded Perlite Aggregate	19
2.3.2.3 Foamed Blast-Furnace Slag Aggregate	19
2.3.2.4 Cenosphere Aggregates	20
2.3.2.5 Polystyrene Aggregates	21
2.4 No-Fine Concrete (Pervious Concrete)	22
2.5 Properties of Lightweight Concrete	23
2.5.1 Properties of Aerated Concrete	23
2.5.2 Properties of Lightweight Aggregate Concrete	26
2.5.3 Properties of No-Fine Concrete	28
2.6 Factors Effecting On Compressive Strength of Concrete	30
2.7 The Effect of Aggregate Strength on Lightweight Concrete	31
2.8 The Effect of Hollow Spherical Inclusion in Concrete	32

CHAPTER 3 RESEARCH METHODOLOGY	33
3.1 Introduction	33
3.2 Material Used and Preparation	33
3.3.1 Cement	34
3.3.2 Sand and Crushed Stone	34
3.3.3 Spheres and Epoxy Adhesive	36
3.3.4 Water	41
3.3 Mix Proportion	41
3.3.1 Trial Mix	42
3.3.2 Mixing Procedure	43
3.4 Preparation of Concrete Cube	47
3.5 Curing	48
3.6 Testing	49
3.6.1 Cube Compressive Strength	50
3.6.2 Density	50
3.6.3 Water Absorption	51
3.6.4 Strain-strain Relationship	52
CHAPTER 4 RESULTS AND DISCUSSION	54
4.1 Introduction	54
4.2 Compressive Strength	54
4.2.1 Comparison of Compressive Strength between Concrete Made with and without Sand Coated	57
4.2.2 Comparison of Compressive Strength between Sand Coated Sphere Concrete and Normal Concrete	67
4.3 Density	68
4.4 Water Absorption	71

4.5	Theoretical Density Reduction of Solid Glass Sphere to Form Hollow Glass Sphere	74
4.6	Stress-Strain Relationship	75
CHAPTER 4 CONCLUSIONS AND RECOMMENDATIONS		81
5.1	Conclusions	81
5.2	Recommendations	83
REFERENCES		84
APPENDICES		87

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Type of lightweight concrete	8
2.2	Lightweight concrete density classes	10
2.3	Classification of lightweight concrete	11
2.4	Some of the typical properties of lightweight aggregate concrete	27
3.1	Specific gravity data of sand	34
3.2	Specific gravity data of crushed stone	35
3.3	Physical data of spheres	36
3.4	Concrete mixes proportions	42
4.1	28 day compressive strength of cube specimens	55
4.2	Density of cube specimens	70
4.3	Water absorption of cube specimens	73
4.4	Modulus of elasticity and Poisson's ratio of concrete specimens	79

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Range in proportions of materials used in concrete, by absolute volume	6
2.2	Principle of producing lightweight concrete	7
2.3	Dome of Pantheon	9
2.4	Typical ranges of densities of lightweight concretes	10
2.5	Pumice rock	15
2.6	Scoria rock	16
2.7	Palm oil shells	17
2.8	Expanded perlite	19
2.9	Blast-furnace slag	20
2.10	Cenospheres	21
2.11	Polystyrene beads	22
2.12	No-Fine concrete	23
2.13	Relationships between the compressive strength and the density of aerated concrete	25
2.14	Influence of the water-cement ratio, entrained air, and cement content on concrete strength	30
2.15	Interplay of factors influencing the concrete strength	31
3.1	Gradation of sand	35
3.2	Gradation of crushed stone	35
3.3	Original types of spheres	37
3.4	Sphere of 25 mm size after sand coating	37
3.5	Sphere of 16 mm size (a) after sand coating	37
3.6	Sphere of 16 mm size (b) after sand coating	38

3.7	Sphere of 14.5 mm size after sand coating	38
3.8	Sphere of 6 mm size after sand coating	38
3.9	Coating process (a) Epoxy adhesive mix	39
3.10	Coating process (b) Spreading epoxy adhesive on rough surface plate and putting spheres on it.	39
3.11	Coating process (c) Mixing between spheres and epoxy adhesive	39
3.12	Coating process (d) Shacking spheres on sand	40
3.13	Adhesive epoxy of Sikadur 330	40
3.14	Slump test	43
3.15	Weighing of specimen to determine density of fresh concrete	43
3.16	Mixing process of normal concrete (a) Putting materials on pan	44
3.17	Mixing process of normal concrete (b) Dry mix	44
3.18	Mixing process of normal concrete (c) Wet mix	45
3.19	Mixing process of original sphere concrete (a) Putting materials on pan	45
3.20	Mixing process of original sphere concrete (b) Dry mix	45
3.21	Mixing process of original sphere concrete (c) Wet mix	46
3.22	Mixing process of sand coated sphere concrete (a) Putting materials on pan	46
3.23	Mixing process of sand coated sphere concrete (b) Dry mix	46
3.24	Mixing process of sand coated sphere concrete (c) Wet mix	47
3.25	Preparation of steel mould	47
3.26	Pouring of concrete specimens into mould	48
3.27	Remoulding of specimens after 1 day casting	48
3.28	Curing of specimens in water for 21 days	49
3.29	Curing of specimens in air for 7 days	49
3.30	ELE-ADR 2000 testing machine	50
3.31	Wiping of specimen with dam cloth and weighing in water to determine density of concrete	51
3.32	Drying of concrete specimens in the oven	52
3.33	Concrete specimens with patched strain gauges	53
3.34	Data logger apparatus	53
3.35	Equipment set up and fixing the cable	53
4.1	28 day average compressive strength of cube specimens	56
4.2	28 day average compressive strength of selected sphere concretes	58

4.3	Typical failure of mix C series cube specimens	59
4.4	Typical failure of mix D series cube specimens	60
4.5	Typical failure of mix E series cube specimens	61
4.6	Typical failure of mix F series cube specimens	62
4.7	Typical failure of mix G series cube specimens	63
4.8	Typical failure of mix CO series cube specimens	64
4.9	Typical failure of mix EO series cube specimens	65
4.10	Typical failure of mix GO series cube specimens	66
4.11	Variation of 28 day compressive strength of sand coated sphere concretes	67
4.12	Average air dry density of cube specimens	70
4.13	Average water absorption of cube specimens	73
4.14	Illustration of cross section of hollow sphere	75
4.15	Stress-Strain Relation of Normal Aggregate Concrete (Mix Ac1)	76
4.16	Stress-Strain Relation of Normal Aggregate Concrete (Mix Ac2)	76
4.17	Stress-Strain Relation of Sand Coated Sphere Concrete (Mix Dc1)	77
4.18	Stress-Strain Relation of Sand Coated Sphere Concrete (Mix Dc2)	77

LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Cross section of the specimen
AAC	-	Autoclaved aerated concrete
ACI	-	American Concrete Institute
Al	-	Aluminium
ASTM	-	American Standard Testing Materials
BS	-	British Standard
CEB	-	Comite' Euro-International du Beton
E	-	Experimental static modulus of elasticity
E_c	-	Theoretical static modulus of elasticity
ε	-	Longitudinal strain of specimen
ε_h	-	Circumferential strain of specimen
f_c	-	Compressive strength of concrete
H_2	-	Hydrogen
H_2O_2	-	Hydrogen Peroxide
γ_{ad}	-	Air dry density
γ_d	-	Oven dry density
Ma	-	Mass of the test specimen in air
Mi	-	Immersion mass of the test specimen
Mo	-	Oven dry mass of the test specimen
Mw	-	Mass of the test specimen in water
NAAC	-	Non autoclaved aerated concrete
O_2	-	Oxygen
P	-	The maximum load applied
ρ	-	Concrete density of cube specimen
ρ_w	-	density of water

s	-	Stress of specimen
V	-	Volume of the test specimen
v	-	Poisson's ratio
WO	-	Water absorption of the test specimen
Zn	-	Zink

LIST OF APPENDICES

APPENDICES NO.	TITLE	PAGE
A.1	Sieve Analysis of Fine Aggregate	87
A.2	Sieve Analysis of Coarse Aggregate	89
A.3	Fine and Coarse Aggregate Specific Gravity Data	90
A.4	Original Sphere Specific Gravity Data	91
A.5	Sand Coated Sphere Specific Gravity Data	92
A.6	Weight of Spheres per 100 pieces	94
A.7	Stress-strain Data	94

CHAPTER 1

INTRODUCTION

1.1 Background

The use of lightweight concrete in the construction industry has become popular in the past few decades due to its some benefits. The benefits of using lightweight concrete include: reduce dead load, improved resistance to cyclic loading, longer spans, better fire ratings, thinner structural members, less reinforcing steel, and lower foundation costs (Short and Kinniburgh, 1978).

There are four establish method that can be used to produce lightweight concrete: using air bubble; using hollow or porous aggregate; using solid lightweight material as coarse aggregate; and using coarse aggregates only to produce 'no-fines' concrete (Short and Kinniburgh, 1978; Teo, et al., 2006; and Ravindrarajah, et. al., 1993). Using these methods, lightweight concrete of wide range of density and strength have been produced for use in many civil work purposes.

Classification of lightweight concrete can be based on the density of the concrete. Generally, a low density concrete has low strength and a high density often

has high strength. Hence, the major problems of lightweight concrete are its low strength and high rate of water absorption due to its low density. However, if hollow spheres were to be used to replace the ordinary aggregate, the strength of concrete could be maintained as compared to lightweight concrete with air bubble. Agni Vickmeshwaran, (2007), reported that by inclusions of large hollow sphere, the original strength of concrete can be retained but density can be reduced. Thereby, there is possible to use spheres to replace coarse aggregate.

In this study a new method to produce lightweight concrete is proposed. The method uses hollow spheres to replace coarse aggregate or air bubbles. Spherical manufactured aggregate of different sizes of solid plastic and glass are used to produce concrete cube. The concrete with a particular of sphere that produces the highest strength is studied further to investigate stress-strain behaviour. It is expected that by replacing aggregate with hollows spheres, the density of concrete can be reduced and a new type of lightweight concrete can be developed.

1.2 Problem Statement

The lightweight concrete produced by using air bubble or porous/hollow aggregate method absorbs high amount of water. High air content results in lower densities and higher porosity hence consequently lower compressive strength (Kearsley, et. al, 2002; and Lo, et. al., 2004).

Highly permeable concrete either by using porous aggregate or large amount of air bubbles permit easy entry and ingress of water into concrete matrix which results in durability problems. Water is known to be a cause of many types of physical processes of degradation. As a transportation vehicle for aggressive ions, water can also be a source of chemical processes of degradation, such as sulphate and

chloride attack. Sulphate attack can result in the loss of strength and even cracking of concrete, while chloride can lower the pH value of concrete and consequently induce corrosion of reinforcement (Mehta and Monteiro, 2006).

Theoretically, the introduction of low-permeability aggregate particles in a high-permeability cement paste is expected to reduce the permeability of the system because the aggregate particles should intercept the channels of flow within the cement paste matrix (Mehta and Monteiro, 2006). Concrete made with non-absorbent material such as plastic and glass spheres as coarse aggregate can be used to produce a lightweight concrete to yield a better performance such as better compressive strength and low permeability. Thus the problem of air bubble or hollow and porous aggregate method can be solved.

1.3 Aims And Objectivities of Study

The aim of this research is to produce lightweight concrete using hollows spheres. In order to achieve this aim, several objectives are set out:

1. To develop a new method for producing lightweight concrete which maybe sufficiently strong for use in structural element.
2. To study the mechanical properties of new developed lightweight concrete in term of compressive strength, density, and water absorption. Type of sphere that produces the highest strength is studied further to investigate the stress-strain behaviour.

1.4 Scope of Study

This study concentrates mainly on the compressive strength of the concrete comprises plastic and glass spheres as coarse aggregate. Due to unavailability of strong hollow spheres in market, solid plastic balls of 6 mm diameter and solid plastic of 14.5 mm diameter with hole/core; and solid glass marbles of 16 and 25 mm diameter were used. The use of solid spheres may not produce the lightweight concrete as intended for. In this study, solid spheres were used merely to test the viability of concept of producing lightweight concrete using hollow spheres.

It has been observed that a concrete mixture containing a rough-textured or crushed aggregate would show somewhat higher strength than a corresponding concrete containing smooth or naturally weathered aggregate of similar mineralogy (Mehta and Monteiro, 2006). Thus, In order to improve bonding with cement matrix, epoxy adhesive was used to coat sand on the surface of spheres but its influence on stated properties will not be considered in this research. Comparison between the proposed lightweight concrete and normal concrete and cement mortar was also made in terms of compressive strength, density and water absorption.

1.5 Layout of Thesis

This thesis consists of 5 chapters. Following current chapter the comprehensive information on available literature of lightweight concrete are presented in chapter 2. Chapter 3 discusses the adoptive methodology used in this study, including design of mix proportion and design as well as preparation and casting of test specimens and detail of testing method .The results are presented in chapter 4 which consist of result of compressive strength, water adsorption and density of new lightweight concrete. Finally chapter 5 presents conclusions and recommendation for current and future experimental work.