STRENGTH DEVELOPMENT OF FLY ASH CONCRETE INCORPORATING GRAPHENE NANOPLATELETS

FARIZAN BINTI ZAKARIA

A dissertation submitted in partial fulfilment of the
requirements for the award of the degree of
Master of (Civil Engineering)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JUNE 2017

ACKNOWLEDGEMENT

Thanks to Allah Almighty for establishing me to complete this project report. The writing and completion of this project report would not have been possible without the assistance, support, and guidance of a few very special people in my life.

First of all, I would like to express my gratitude to Associate Professor Dr Norhazilan B Md. Noor, who encouraged me to pursue this project report. I am extremely grateful and indebted to him for his expertise, sincere and valuable guidance and encouragement extended to me.

I would like to thank to En. Amran B Alang Ahmad, from GB Quarry Kuala Dipang because providing me with the necessary materials.

I also thanks to all my colleagues and others who have provided assistance and support.

My deepest appreciation belongs to my lovely husband, Mohd Norman, and my kids, Nur Irdina Safiyya, Nur Insyirah Syafiqah, and Muhammad Adam Mikhail for their patience and understanding.

ABSTRACT

Concrete is the most popular building material in the world. As the requirement for development in infrastructure increases, the demand for the Ordinary Portland Cement concrete also increases. Furthermore, there are many demands on the innovative concrete, which is stronger, and cheaper than the conventional concrete. Thus, Graphene Nanoplatelets additive comes forward to overcome strength problems. As known, Graphene Nanoplatelets is sulphate material which has good electrical conductivity and ultrafiltration, strong, stiff, very light and more durable. It has been used as an alternative to improve the strength of fly ash concrete. In this study, the effects of graphene are evaluated for two different percentages which are 0.05% and 0.10%. Fly ash is waste material used as replacement to reduce the usage of cement and to predict positive strength of the concrete for it has pozzolan characteristics. Furthermore, it has been proven that concrete strength is increased when fly ash is used between 15-25%. Laboratory testing is the main method and is conducted to analyse the performance of graphene on fly ash concrete. It is based on BS 5328: Part 1:1991 and BS1881:1983. Grade 25N/mm^2 is designed for concrete mixture 0.5 water to cement ratio. There are 60 samples tested, which are 36 cube and 24 prismatic samples with dimension of 100mmx100mmx100mm and 100mmx100mmx500mm respectively. Tests are performed on the 7th and 28th day of water curing. Results show that the workability of concrete is reduced with increased graphene but the mechanical characteristic of concrete is increased. From the result obtained, the optimum value occurs on day 28 with 0.05% of graphene. The optimum values of compressive and flexural strength are 25.031MPa and 4.72MPa respectively. In conclusion, as an additive, Graphene Nanoplatelets improves the strength development of fly ash concrete by increasing its strength and enhancing other characteristics.

ABSTRAK

Konkrit merupakan bahan binaan utama di dunia dan digunakan dalam bidang Seiring dengan kepesatan pembangunan, permintaan terhadap konkrit juga meningkat. Tambahan pula terdapat banyak permintaan terhadap konkrit inovatif yang kuat dan lebih murah daripada konkrit konvensional seperti *Ordinary Portland Cement*. Oleh itu, Graphene Nanoplatelets telah digunakan sebagai bahan tambah bagi meningkatkan kekuatan konkrit abu terbang tersebut. Graphene Nanoplatelets merupakan bahan sulfat yang mempunyai sifat konduksi elektirk yang baik, kuat, keras, ringan dan lebih tahan lama. Kajian ini telah menggunakan 0.05% dan 0.10% graphene bagi melihat keberkesanannya terhadap kekuatan konkrit abu terbang. Abu terbang merupakan bahan buangan yang digunakan sebagai bahan ganti simen kerana ianya mempunyai ciri-ciri pozzolan. Tambahan pula terdapat kajian yang membuktikan bahawa penggunaan abu terbang di antara 15-25% dapat meningkatkan kekuatan konkrit. Ujian makmal merupakan kaedah utama digunakan di dalam kajian ini bagi menganalisis prestasi graphene terhadap konkrit abu terbang dengan menggunakan BS 5328: Part 1:1991 dan BS1881:1983 sebagai rujukan. Rekabentuk campuran konkrit gred 25N/mm^2 direkabentuk dengan nilai nisbah air 0.5 terhadap konkrit. Terdapat 60 sample yang akan duji iaitu 36 kiub dan 24 prismatik sampel, masing-masing bersaiz 100mm x100mm x100mm dan 100mm x100mm x500mm. Ujian terhadap sampel akan dilaksanakan pada hari ke 7 dan 28. Keputusan ujian menunjukkan peningkatan graphene telah mengurangkan kebolehkerjaan konkrit tetapi telah meningkatkan ciri-ciri mekanikal konkrit. Dari keputusan yang diperolehi menunjukkan nilai optimum berlaku pada hari ke-28 dengan nilai 0.05% graphene. Nilai optimum kekuatan mampatan dan lenturan yang diperolehi adalah 25.031MPa dan 4.72MPa. Kesimpulannya, sebagai bahan tambah, graphene dapat meningkatkan kekuatan serta sifat konkrit abu terbang.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

mm	-	millimetre
μm	-	Micrometre
nm	-	Nanometre
MPa	-	Mega Pascal
J	-	Joule
min	-	minutes
ml	-	millilitres
W	-	Watt
N	-	Newton
m	-	Meter
kg	-	kilo gram
l	-	Litre
ρ	-	Density
°	-	Degree
C	-	Celsius
F	-	Load
b	-	Width
d	-	Depth
L	-	Length
%	-	Percentage
WA	-	Water Absorption
W_1	-	Dry Mass
W_2	-	Wet Mass

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete is the most popular building material in the world. Nowadays, all construction works have been using cement as the main material in concrete mixture design. Ordinary Portland Cement (OPC) is generally used as the primary binder of the concrete in construction including coarse aggregates, fine aggregates and water. As the requirement for development in infrastructure increases, the demand for the OPC concrete also increases. However, there are more demands on the innovative concrete, which is stronger and cheaper than the conventional concrete. Thus, carbon nanotubes additive comes forward to meet the demand.

With the development of nano materials, carbon nano-fibers such as carbon nanotubes and Graphene Nanoplatelets are gradually studied. Graphene is a thin layer of pure carbon which is composed of single, tightly packed layer of carbon atoms that are bonded together in a hexagonal honeycomb lattice. It is a two dimensional carbon molecule in which the structure is quite similar to graphite. According to Antonio *et al*. (2016), Graphene Oxide has generated an interest since it acts as a supplement in the concrete mixture and a precursor to increase the strength and to enhance other characteristics of concrete. Furthermore, it has been proven that the concrete compression could be improved from 5% to 40% when enriched by graphene nano materials merely from 0.01% to 1% of OPC weight. Thus, this technology is widely applied in construction.

Fly-ash has the characteristic of cement known as pozzolan, it little possess itself because it has siliceous material or no cementitious value. It is known from the last century (Anon, 1974) that fly ash has the potential as a supplementary cementitious material in concrete. Furthermore, fly-ash is a form of waste material produced during manufacturing process from quarry industry. This waste material affects the environment directly and may cause environmental problems. Therefore, it is very important to minimize the environmental effects by using fly ash as an alternative to replace cement in the concrete mixture.

There are many researches done on the performance of the fly ash on workability and strength of concrete but it depends on the application, properties of the fly ash as well as specification limit. Historically, 15% to 25% mass of fly ash has been used as cementitious materials component in concrete (Thomas, 2007).

1.2 Problem Statement

The use of fly ash in concrete mixture has a limitation. It may decrease the mechanical properties of concrete such as strength, durability, porosity and others. Most researchers have finds that the usage of 15-25% of fly ash can help improve the strength of the concrete (Naik *et al.*, 2003; Poon *et al.*, 2004; Thomas, 2007; Feng and Clark, 2011; Bhaskar and Sathyam, 2014; and Shakir *et al.*, 2014). However, there is no exact percentage to improve the performance of the concrete. Thus, the effectiveness of mixture design depends on several factors including the type and quantity of cement, fly ash and additive. Hence, to overcome these problems, sulphate materials are used to improve the performance of the concrete. Graphene Nanoplatelets one of sulphate materials used as an additive to fly ash concrete. It has been used as an alternative to increase the strength (Pan, 2012; Shenghua *et al.*, 2013; Sedaghat *et al.*, 2014; and Devasena *et al.*, 2015). However, to what extent does graphene improve the performance of fly ash concrete.

1.3 Research Aim and Objectives

The main aim of this research is to study the effects of graphene against workability, water absorption, compression strength and flexural strength of graphene fly ash concrete. This study has 3 objectives:

i. To determine the characteristics of Graphene.
ii. To calculate the mixture design of graphene for fly ash concrete.
iii. To identify the effect of graphene on physical and mechanical properties of fly ash concrete.

1.4 Scope of Work

Scope of work covers the strength development of Fly Ash Concrete incorporating Graphene Nanoplatelets. It is done to identify the workability, density, water absorption, compression, and flexural strength of concrete on day 7 and day 28 of curing. Only compression and flexural tests are covered for mechanical performance because compressive strength of concrete is the most important characteristic. As known, an increase in compressive strength will improve concrete's mechanical properties.

Referring to BS 5328: Part 1:1991 and BS1881:1983, the 25N/mm^2 concrete mixture is designed with 0.5 water to cement ratio. 25% of fly ash replaced with graphene with percentages of 0%, 0.05% and 0.1% as an additive is studied. The fresh properties of Graphene Fly Ash concrete are determined through the slump test.

The experimental programs are prepared with two sizes of samples which are cube sizes (100mmx100mmx100mm) to test for water absorption and compressive strength, and prismatic samples (100mmx100mmx500mm) for the flexural test. Every test is conducted on 3 samples per testing for Graphene- Fly Ash Concrete.

1.5 Significance of Study

In the construction industry, cement is used as an important building material. There are many waste materials produced from quarry industry such as fly ash, quarry dust and others that can replace a certain portion of the cement. These waste materials are causing degradation to the environment as well as to flora and fauna.

The choice of fly ash as the replacement of cement has been supported in the previous studies and has obtained positive results. Therefore, the use of 25% of fly ash as a replacement will reduce the usage of cement and contribute in the good strength of the concrete. The significance of this study is to get the minimum percentage of Graphene Nanoplatelets to improve the strength of fly ash concrete.

REFERENCES

Antonio, C. N., Francisco, G., and Peres, N. M.(2006). *Drawing conclusions from graphene.* Physics World, 19(11):33

Ambra, R., Paola, g., Leigi, B., Marco, G. (2015) *Graphene Oxode as a Cement Reinforcing Additive.* Politecnico Milano. School of Industrial and Information Engineering. Master of Science in Materials Engineering and nanotechnology.

Anon (1974). *An Investigation of the Pozzolanic Nature of Coals Ashes*. Engineering News, Volume 71. Pages 1334-1335.

Antonio, V.R.J., German, C.S., Raymundo, M. M. E.(2016). *Optimising Content Graphene in High Strength Concrete*. International Journal of Scientific Research and Management. Volume 4, ISSN (e) 2321-3418, Page 4324

ASTM International *(2008). ASTM C618 - 08 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. Retrieved 2008-09-18.*

Benjamin C B. (1898). *On the atomic weight of graphite*. Philosophical Transactions of the Royal Society of London, pages 249–259, 1859. [60] L Staudenmaier. Method for the preparation of graphitic acid. Ber Dtsch Chem Ges, 31:1481–1487

Bhaskar Desai, V., and Satyam, A.(2014). *A Study on Partial Replacement of natural Granite Aggregate with Pelletized Fly Ash Aggregate.* International Journal of Computational: ISSN(e):2250-3005 Issue, 12, December 2014

British Standards Institution (1983). *Methods for determination of slump*. London: (BS1881: Part 102).

British Standards Institution (1983). *Methods for determination of water absorption.* London: (BS1881: Part 122).

British Standards Institution (1983). *Method for determination of compressive strength of concrete cubes*. London: (BS1881: Part 116).

British Standards Institution (1983). *Method for determination of flexural strength*. London:(BS1881: Part 117).

Carolyne, N. and Rebecca, A. A.(2009). *Optimization of Fly Ash in Concrete: High lime Fly Ash as a Replacement for Cement and Filler materials.* World of Coal Ash Conferences. May 4-7.

Daniela, C. M., Dmitry, V. K., Jacob, M. B., Alexander, S. Zhengzong, S. , Alexander, S., Lawrence, B. A., Lu, W. and James M. T.(2010). *Improved synthesis of graphene oxide*. ACS nano, 4(8):4806–4814.

Devasena, M., Karthikeyan, J. (2015). *Investigation on Strength properties of Graphene Oxide Concrete.* International Journal of Engineering Science Invention Research & Development; Vol. I Issue VIII February 2015 www.ijesird.com e-ISSN: 2349-6185.

Fakhim, B., Hassani A. R., and Ghodousi, P.(2014). *Preparation and mechanical properties of graphene oxide: cement nanocomposites*. The Scientific World Journal.

Felix Kala, T. (2013). *Effect of Granite Powder on Strength Properties of Concrete.* International Journal of Engineering and Science, Volume 2, ISSN (e) 2278-4721.

Feng, X. and Clark, B.(2011). *Evaluation of the Physical and Chemical properties of Fly Ash Products for use in Portland Cement Concrete*. Paper presented at the World of Coal Ash (WOCA).

Folliard, K.J. and Barborak, R.(2006). *Preventing ASR/DEF in New Concrete. Final Report*. Report No. FHWA/TX-.6/0-4085-5, Center for Transportation Research at the University of Texan at Austin.

Gong, K. , Pan, Z., Korayem, A.H., Qui, L., Li, D., Collins, F. (2014). *Reinforcing effects of graphene oxide on Portland Cement Paste*. J Mater Civil Engineering. A4014010.

Hae, K. J., Yun, P. L., Mei, H.J., Eun, S. K., Jung, J. B., and Young, H. L. (2009). *Thermal stability of graphite oxide*. Chemical physics letters, 470(4):255–258.

Haque, M.N. and Kayali, O.(1998). *Properties of high-strength concrete using a fine fly ash.* Cement and Concrete Research, 1445 – 1452.

Hossein, R. M., Vahid, H., Khezrollah, K., and Mehdi, S.K.(2014). *Polystyrene-grafted graphene nanoplatelets with various graft densities by atom transfer radical polymerization from the edge carboxyl group.* RSC Advances, 4(47):24439–24452.

Hofmann, U and Holst, R.(1939). *The acid nature and methylation of graphitic oxide*. Ber.Dtsc. Chem. Ges, 72:754–771

Hou, D., Ma, H., Zhu, Y., Li, Z. (2014). *Calcium silicate hydrate from dry to Saturated state: Structure, dynamics and mechanical properties*, Acta Mater. 67 81–94.

Hummers, W. S. and Offeman, R. E.(1958). Preparation *of graphitic oxide*. Journal of the American Chemical Society, 80(6):1339.

Kapgate, S.S., and Satone, S.R.(2013). *Effect of quarry dust as partial replacement of sand in concrete.* Indian Streams Res. J. 3(5), 1–8

Kostya, S. N., Geim, K., Morozov, S.V., Jiang, D., Y.Zhang, D., Dubonos, S.V. , Grigorieva, I.V., and Firsov, A.A. (2004). *Electric field effect in atomically thin carbon films*. science, 306(5696):666–669.

Lakshmidevi, K., Narasimha, A.V. (2015). *Effect of Fly Ash and Quarry Dust on Properties of Concrete.* International Journal of Innovative Research in Science, Engineering and TechnologyVol. 4, Issue 9, September 2015

Latifee, E. R. (2016). *An Experimental Factorial Design for ASR Mitigation with Fly Ash*. Malaysia Journal of Civil Engineering 28(1): 124-138.

Li, H., Xiao, H.G., Yuan, J., Ou, J.P.(2004). *Microstructure of cement mortar with nano-particles.* Composite part B, 35(B), 185-18

Lu, Z., Hou, D., Ma, H., Fan, T., Li, Z. (2016). *Effect of graphene Oxide on the Properties and Microstructures of the Magnesium Potassium Phosphate Cement paste.* Construction and Building Materials 119, Page 107-112

Lu, Z., Chen, G., Hao, W., Sun, G., Li, Z. (2015). *Mechanism of UV-assisted iO2/reduced graphene oxide composites with variable photo degradation of methyl orange,* RSC Adv. 5 (89) (2015) 72916–72922.

Naik, T. R., Ramme, B. R. & Kraus, R. N., and Siddique, R. (2003). *Long Term Performance of High Volume Fly Ash Concrete Pavement.* ACI Material Journal, Vol.92, No.2, pages 150-155.

Narayanan, N. and Ramamurthy, K. (2000). *Structure and Properties of Aerated Concrete: a review*. Cement and Concrete Composites, Vol. 22, no. 5, pp.321-329

Obla, K. H., Hill, R. L., & Martin, R. S.(2003). *HVFA Concrete an Industry Perspective.* Concrete International, August, Page 29 to 33

Ondova, M., Stevulava, N., Estokova, A. (2012*). The Study of the Properties of Fly Ash Based Concrete composites with various Chemical Admixtures.* 20th International Congress of Chemical and Process Engineering CHISA 2012. Prague, Czech Republic.

Ooi, W. H. (2014). *Physical and Mechanical Properties of Concrete using Fly Ash and Recycle Concrete Aggregate*. Master, Universiti Teknologi Malaysia, Skudai.

Pan, Z. (2012). *Graphene oxide reinforced cement and concrete*. WO Patent App. PCT/AU2012/001,582.

Poon, C. S., Lam, L., Fok, H., Kou, S.C.(2004). *Influence of moisture states of natural and recycled aggregates on the slump and compressive strength of concrete.* Cement and Concrete Research, Vol. 34, No. 1, 31-36.

Rao, N., Ramana, G., Desai, V. and Swamy, B.(2011). *Properties of Lightweight Aggregate Concrete with Cinder and Silica Fume Admixture.* International Journal of Earth Sciences and Engineering, ISSN 0974-5904, Vol.4, no. 6.

Sedaghat, A., Ram, M.K., Zayed, A., Kamal, R., Shanahan, N. (2014). *Investigation of Physical Porperties of Graphene Cement Composite for Structural Applications.* Open Jurnal of Composite Materials, 04(01), 12-21, doi:10.4236/ojcm.2014.41002

Shakir, A.A., Naganathan, S., Mustapha, K.N.(20140. *Effect of quarry dust and billet scale additions on the properties of fly ash bricks.* IJST, Trans. Civil Eng. 38(1), 51–60.

Shenghua, Lv., Yujuan, M., Chaochao, Q., Ting, S., Jingjing, L., and Qingfang, Z.(2013). *Effect of graphene oxide nanosheets of microstructure and mechanical properties of cement composites.* Construction and building materials, 49:121–127.

Sridhar Kumaar, A.A. , Saravanan, P.(2015). *An Experimental Study on Fly Ash Blended Cement Concrete with Partial Replacement of Quarry Sand*. International Journal on Applications in Civil and Enviornmental Engineering Volume 1: Issue 2: February 2015, pp 1-3.

Sobolev K, Gutierrez MF.(2005). *How Nanotechnology can Change the Concrete World.* Am Ceram Soc Bull 2005;84(11):16–9.

Staudenmaier, L. (1898). *Method for the preparation of graphitic acid*. BerDtsch Chem Ges, 31:1481–1487.

Subramani, T., and Ramesh, K.S.(2015). *Experimental Study On Partial Replacement Of Cement With Fly Ash And Complete Replacement Of Sand With M sand.* International Journal of Application or Innovation in Engineering & Management . Volume 4, Issue 5, May 2015

Tehmina, A., Sadaqat, U. K., Fareed, A. M. (2014). *Mechanical Characteristics of Hardened Concrete with Different Mineral Admixtures.* The Scientific World Journal, Volume 2014, Article ID 875082

Thomas, M. (2007). *Optimising the Use of Fly Ash in Concrete*. Portland Cement Association

Zhou, F., M. S. (2014). *Investigation on Properties of Cementittious materials Reinforced by Graphene.* University of Pittsburgh.