STUDY ON THE BEHAVIOUR OF HIGH STRENGTH PALM OIL FUEL ASH (POFA) CONCRETE

OMAR ELMUKHTAR AHMED ELDAGAL

UNIVERSITI TEKNOLOGI MALAYSIA

STUDY ON THE BEHAVIOUR OF HIGH STRENGTH PALM OIL FUEL ASH (POFA) CONCRETE

OMAR ELMUKHTAR AHMED ELDAGAL

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of engineering *(Civil-Structure)*

Faculty of Civil Engineering
Universiti Teknologi Malaysia

NOVEMBER 2008

ABSTRACT

Many researchers have studied the use of agro-waste ashes as constituents in concrete. These agro-waste ashes contained an amount of silica which could be used as a pozzolanic material. Palm Oil Fuel Ash (POFA) is a by-product produced in palm oil mills. This ash has pozzolanic properties that not only enables the replacement of cement but also plays an important role in making strong and durable concrete. Collected POFA was dried and then sieved through a 300 μm sieve. Ashes passing through 300 μm sieve were ground in a modified Los Angeles abrasion test machine. The fineness of the POFA was checked by sieving through 45μm sieve at every half an hour grinding. For this research, total of five mixes were made of OPC as a control mix, OPC replaced with 20% and 30 % of POFA 10 μm and OPC replaced with 20 and 30 % of POFA 45 μm respectively. For compressive strength, six cubes of 100 mm tested at 7, 28, and 90 days. For flexural strength, three prisms of 100 x 100 x 500 mm were tested at 28 days. Five cylinders of 100 x 200 mm were tested for indirect tensile strength at 28 days for each mix. The slump test and compacting factor test were employed in measuring the fresh concrete. POFA concrete exhibit lower value of slump compared to slump of OPC concrete. Among POFA results, the finer the POFA, the lower the slump and hence lower degree of compaction. Although strength of POFA concrete did not exceed that of OPC, 58 MPa was achieved when using 20 % of POFA 10 μm. The flexural strength of POFA concrete is slightly lower than that of OPC. The higher was the replacement of OPC; the lower the flexural strength. Like that of flexural strength, indirect tensile strength of concrete containing POFA developed in a similar way. TG Analysis lead to the fact that the amount of $Ca(OH)_2$ increased with curing age indicating the progress of cement hydration reaction. And reduction in weight loss attributed to dehydroxylation of calcium hydroxide, and subsequent increase in compression is indicative of pozzolanic reaction. From the microstructural analysis (FESEM), radiating clusters of C-S-H gel have lead to a densification of the structure, and an increase in strength. Hexagonal platelets of $Ca(OH)_2$ could be observed in some samples.

ABSTRAK

Banyak penyelidik telah mengkaji penggunaan abu yang merupakan sisa industri sebagai bahan dalam pembuatan konkrit. Abu ini mengandungi silica yang membolehkan ia digunakan sebagai bahan pozolana. Abu kelapa sawit (POFA) adalah bahan buangan yang dijana oleh kilang memproses kelapa sawit. Abu ini memiliki sifat-sifat pozolana yang bukan sahaja membolehkan ia berfungsi sebagai bahan pengganti simen tetapi turut memainkan peranan penting dalam menghasilkan konkrit yang kuat dan tahan lasak. POFA yang diambil dari kilang telah dikeringkan dan diayak melepasi ayak 300 μm seterusnya dikisar menggunakan mesin pengisar Los Angeles. Kehalusan POFA kemudian dikenalpasti dangan mengayak abu tersebut menerusi ayak 45 μm pada setiap setengah jam sepanjang pengisaran dijalankan. Dalam kajian ini, sebanyak lima bancuhan telah dihasilkan iaitu yang mengandungi simen Portland biasa (OPC) sebagai bancuhan kawalan, OPC yang diganti dengan 20 % dan 30 % POFA 10 μm dan OPC yang diganti dengan 20 % dan 30 % POFA 45 μm. Kekuatan mampatan diperolehi dengan menguji enam kiub bersaiz 100 mm pada 7, 28, dan 90 hari. Kekuatan lenturan pula ditentukan dengan menguji tiga prisma bersaiz 100 x 100 x 500 mm pada 28 hari. Lima silinder (100 x 200 mm) telah diuji untuk menentukan kekuatan tegangan pada 28 hari bagi setiap bancuhan. Ujian runtuhan dan ujian faktor pemadatan telah digunakan untuk menentukan sifat konkrit segar. Konkrit POFA menunjukkan nilai runtuhan yang rendah berbanding konkrit OPC. Daripada keputusan POFA, semakin halus POFA maka semakin rendah nilai runtuhan dan nilai pemadatan yang diperolehi. Walaupun kekuatan POFA tidak mengatasi OPC, kekuatan 58 MPa dapat dicapai apabila menggunakan 20 % POFA 10 μm. Nilai kekuatan lenturan bagi konkrit POFA adalah sedikit rendah daripada OPC. Semakin tinggi nilai penggatian OPC; semakin rendah kekuatan lenturan. Kekuatan tegangan konkrit POFA menunjukkan corak sama seperti yang didapati dalam kekuatan lenturan. Analisis TG yang menunjukkan kandungan $Ca(OH)_2$ meningkat dengan umur pengawetan membuktikan penghidratan simen terus berlaku. Pengurangan dalam kehilangan berat adalah disebabkan "dehydroxylation" kalsium hidroksida manakala peningkatan kekuatan mampatan membuktikan berlakuanya tindak balas pozolana. Berdasarkan analisis mikrostruktur (FESEM), perkembangan dalam kelompok C-S-H gel telah membawa kepada pemadatan struktur dan meningkatkan kekuatan.

CONTENT

CHAPTER I

INTRODUCTION

1.1 Introduction

Concrete is one of the oldest manufactured construction material used in construction of various structures around the world. However, continuous research in the area of concrete material has resulted in production of many types of concrete known in various names each having a unique characteristic to fulfill the current construction industry demand. One of the concrete that become famous nowadays is high strength concrete due to its strength and durability (Abdullah and Hussin, 2006).

Although high strength concrete is often considered a relatively new material, its development has been gradual over many years. As the development has continued, the definition of high-strength concrete has changed. In the 1950s, concrete with a compressive strength of 34 MPa was considered high strength. For many years, concrete with compressive strength in excess of 41 MPa was available at only a few locations. However, in recent years, the applications of high-strength concrete have increased, and high strength concrete has now been used in many parts of the world (ACI, 1992).

In order to achieve high strength concretes, several methods can be applied. In general, high strength concrete contains strong aggregates, a higher Portland cement content and low water cement or water cementitious ratio. The addition of water reducing admixtures, superplasicizers, blast furnace slag, or silica fume is common today (Nawy, 1996).

Savings in overall cost of concrete structural systems are achieved by the use of higher strength concretes. Components of structure become smaller, thereby reducing the weight of the system with the resulting reduction in size and then cost of all components. The use of cement replacement materials in producing high strength concrete also encouraged sustainable development as it reduces the cement usage. As some cement replacement materials are obtained from agricultural wastes, it also helps recycling the by-products (Nawy, 1996).

1.2 Background of Research

Palm oil has been gaining increasing importance as cash crop in several tropical countries among which Malaysia is the largest producer of palm oil products. To date there are more than two hundred mills operating in this country (Hussin and Awal, 1997).

The palm oil industry is one of the major agro-industries in Malaysia. The commercial palm oil production is mainly located in Peninsular Malaysia and date back to the 1960s. During the period between 1990 and 2002, palm oil production was nearly doubled from 6,094,622 to 11,880,000 ton per year, making Malaysia the biggest palm oil producer worldwide (Vijayaraghavan, 2007).

It has been reported that the production of palm oil per month is over 435000 tons, 10 % of which is waste by-product of milling process in the form of palm oil fibre and palm oil shell as shown in Figure (1.1). These by-products are commonly known as palm oil fuel ash (POFA), are disposed without any commercial return. It has been identified that this ash has pozzolanic properties that not only enables the replacement of cement but also plays an active role in making strong and durable concrete (Hussin and Awal, 1997).

a) Palm oil shell

b) Palm oil fibre

Figure 1.1: Palm oil shell and fibre

1.3 Objectives of Research

The main objective of this present research is to study the behavior of high strength concrete by using palm oil fuel ash (POFA) in different fineness as partial replacement of ordinary Portland cement. In addition to this, study the effect of POFA on the workability of concrete.

1.4 Scope and Limitation

All test specimens are made up of concrete where Ordinary Portland cement is replaced with 20 % and 30 % of POFA 10 μm, and 20 % and 30 % of POFA 45 μm. Compressive, flexural, and tensile strengths are the major tests considered for determining the strength of concrete. Slump and compacting factor, on the other hand, are the tests to measure the workability of the concrete.

1.5 Importance of Research

The accelerated developments in concrete research over the past 20 years have opened new and more proficient utilization of components available in nature, including industrial waste. The thrust in this accelerated activity has been made or justified because of the economical gains in producing stronger structures that are smaller in component dimensions while larger in resulting space availability. Cost analysis of the use of high strength concrete as compared to normal strength concrete justifies its viability and utility (Nawy, 1996).

In recent years, studies have been carried out by various researchers in using wastes generated from the agricultural and industrial activities as concrete making materials (Tay and Show, 1994).

Many researchers have studied the use of agro-waste ashes as constituents in concrete. Their results have revealed that these agro-waste ashes contain high amount of silica in amorphous form and could be used as a pozzolanic material (Tangchirapat and Saeting, 2007). Utilization of palm oil fuel ash (POFA) is minimal and unmanageable, while its quantity increases annually and most of the POFA are disposed of as waste in landfills causing environmental and other problems (Tangchirapat and Saeting, 2007). To solve the energy problems, solid wastes from palm oil residue are used as fuel to produce steam for electricity generation. After burning, an ash by-product is produced. As a solution to the disposal problem of the ash derived from palm oil, research studies have been carried out to examine the feasibility of using the ash as cement replacement materials (Tay and Show, 1994).

1.5.1 Advantages of High Strength Concrete

The advantages of using high strength concrete often balance the increase in material cost. The following are some advantages that can be accomplished (Nawy, 1996):

1. Reduction in member size, resulting in an increase in rentable space and reduction in the volume of produced concrete with the accompanying saving in construction time.
2. Superior long-term service performance under static, dynamic, and fatigue loading.
3. Low creep and shrinkage.

4. Greater stiffness as a result of a higher modulus of elasticity.
5. Higher resistances to freezing and thawing, chemical attack, and significantly improve long-term durability and crack propagation.

REFERENCES

Abdullah, K. and Hussin, M.W. (2006), POFA: A Potential Partial Cement Replacement Material in Aerated Concrete, *Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference*. 5-6 September. Kuala Lumpur, Malaysia. 132- 140

Abu, Z (1990), *The Pzzolanicity of Some Agricultural fly ash and their Use in Cement Mortar and Concrete*. Master of Civil Engineering thesis, Universiti Teknologi Malaysia.

ACI Committee 363, (1992), State of the Art Report on High Strength Concrete, American Concrete Institute.

Adesanya, D. A. and Raheem A. A. (2009), a study of the workability and compressive strength characteristics of corn cob ash blended cement concrete, *Construction and Building Materials,* Vol. 23, 311–317.

Al-Oraimi, S.K. Taha,R. Hassan, H.F., (2006), The effect of the mineralogy of coarse aggregate on the mechanical properties of high-strength concrete. *Construction and Building Materials*. Vol. 20, 499–503.

ASTM Designation (2007): *C127* Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate, Book of Standards Volume: 04.02, American Society for Testing and Materials

ASTM Designation (2007): *C128* Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate, Book of Standards Volume: 04.02, American Society for Testing and Materials.

ASTM Designation (2006): *C 136* Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, Book of Standards Volume: 04.02, American Society for Testing and Materials.

ASTM Designation (2007): *C150* Standard Specification for Portland Cement, Annual Book of ASTM Standards, American Society for Testing and Materials

ASTM Designation (2008): *C172* Standard Practice for Sampling Freshly Mixed Concrete**,** Annual Book of ASTM Standards, American Society for Testing and Materials**.**

ASTM Designation (2008): *C494* Standard Specification for Chemical Admixtures for Concrete. Annual Book of ASTM Standards, American Society for Testing and Materials

ASTM Designation (2004): *C 566* Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying, Book of Standards Volume: 04.02, American Society for Testing and Materials

ASTM Designation (1994): *C618* Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as Mineral Admixture in Portland Cement Concrete, Annual Book of ASTM Standards, American Society for Testing and Materials

Awal, A.S.M., (1998), *A Study of Strength and Durability Performances of Concrete Containing Palm Oil Fuel Ash*, PhD Thesis, Universiti Teknologi Malaysia.

Hussin, M. W. and Awal, A. S. M. (1996), Influence of Palm Oil Fuel Ash on Strength and durability of concrete, *Proceedings of the 7th International conference on the DBMC*, Stockholm Sweden Vol.1, 291-298

Awal, A. S. M., and Hussin, M. W, (1997), Some Aspects of Durability Performances of Concrete Incorporating Palm Oil Fuel Ash, *Proceedings of 5th International Conference on Structural Failure, Durability and Retrofitting*, Singapore, 210-217

BS 882: (1992), Specification for aggregates from natural sources for concrete , British Standard Institution.

BS 1881: Part 102 (1983), Testing concrete: method for determination of slump, British Standard Institution.

BS 1881: Part 103 (1993), Testing concrete: method for determination of compacting factor, British Standard Institution.

BS 1881-Part 116, (1983), Testing concrete: Method for determination of compressive strength of concrete cubes, British Standard Institution.

BS 1881-Part 117, (1983), Testing concrete: Method for determination of tensile splitting strength, British Standard Institution.

BS 1881-Part 118, (1983), testing concrete: Method for determination of flexural strength, British Standard Institution.

Conner, J.R. (1990), Chemical *Fixation and Solidification of Hazardous Waste*, Van Nostrand. Reinhold, New York.

Department of Environment (1992), Design of Normal Concrete Mixes, Building Research Establishment, UK.

Awal A.S.M, and Hussin M.W. (1997), Properties of fresh and hardened concrete containing Palm Oil Fuel Ash, *proceeding the 3rd Asia Pacific Conference on Structural Engineering and Construction*, Johor Bahru, 17th-18th June 359-367

Illston, J. M. and Domone, P. L. J (2001), *Construction Materials; Their nature and Behavior*, First Edition, Taylor & Francis e-Library

James, J. and Rao, M.S. (1986). Reaction product of lime and silica from rice husk ash, *Cement and Concrete Research*, 16, 67 – 73.

Mahmud, H. B. and, Hamid, N. B.A.A. and Chia, B.S.(1996), High strength rice husk ash concrete – a preliminary investigation, *proceeding of the third Asia Pacific Conference on Structural Engineering and Construction (APSEC '96*), Johor Bahru, Malaysia, Ed: M. W. Hussin, pp. 383-390

Massaza, F. (1993), Pozzolanic cement, *Cement and Concrete Composites*, Vol. 15, 185-214

Nawy, E. G. *Fundamentals of high strength high performance concrete*, Essex, Eng: Longman, 1996

Neville, A. M. *Properties of Concrete*. 4th edition. Prentice Hall, (2005).

Pacewska, B. and Wilinska, I, (2002), Effect of waste aluminosilicate material on cement hydration and properties of cement mortar, *Cement and Concrete Research,* Vol. 32, 1823-1830.

Roger, R. and Noel, M. *Chemical Admixtures for Concrete*, Taylor & Francis e-Library, 2002.

Sumadi, S. R. and Hussin, M.W. (1993), Agricultural Ash (AA) – Construction Material for the Future, *Kongres Sains & Teknologi Malaysia, COSTAM 93,* 11-14, August, Kuala Lumpur.

Sumadi, S.R. and Hussin, M.W. (1995), Palm Oil Fuel Ash (POFA) As a Future Partial Cement Replacement Material In Housing Construction, *Journal of Ferrocement,* Vol.25, No.1, 25-34.

Tangchirapat, W. and Seating, T, (2007), Use of waste ash from palm oil industry in concrete, *Waste Management*, Vol. 27, (2007), pp.81–88

Tay, G. H, and Show K. Y. (1995), Use of ash Derived From Oil Palm Waste Incineration as a Cement Replacement Material, *Journal of Resources, Conservation and Recycling,* Vol. 13, 27-36.

Taylor, H. F. W., *Cement chemistry*, Academic Press Inc., New York. (1990).

Vijayaraghavan, K. and Ahmad D., (2007), Aerobic treatment of palm oil mill effluent, *Journal of Environmental Management*, Vol. 82, 24–31.

Yetgin, S. and Ahmet, C. (2006), Study of Effects of Natural Pozzolan on Properties of Cement mortars, *Journal of Materials in Civil Engineering, ASCE* / November/December, 815.