THERMAL AND MECHANICAL PROPERTIES OF PREPACKED CONCRETE CONTAINING PALM OIL FUEL ASH

ABDOLHAMID VAHEDI

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

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JANUARY 2015

To my Beloved Wife

ACKNOWLEDGEMENT

First and foremost I wish to glorify almighty ALLAH the most gracious the most merciful by the saying of ALLHAMDULLILAHI RABILALIMIN, for benefit of wisdom and power he has provided without expecting anything in return. These provisions of Allah (SW) have made it possible to come this long in academic pursuit.

I would like to express my sincere thanks to my advisor Assoc. Prof. Dr. A.S.M. Abdul Awal for his motivation, inspiration, encouragement, and unstinted guidance. The trust, patients, great insight, modesty and friendly personality demonstrated by him have always been my source of inspiration. I also extend my thanks to Prof. Dr. Mohammd Ismail, Dr. Mohd Yunus Ishak, and Dr. Abdullah Zawawi Awang for serving as my thesis committee and providing critical review on my thesis.

The author is greatly indebted to Faculty of Civil Engineering (FKA) for the support and facilities provided to carry out the experimental work. Same goes to the academic and non-academic staff of the faculty for their support, assistance and friendly treatment that facilitated the work. I would also like to acknowledge the University Technology Malaysia Research Lab Manger Mr. Nawawi Mohd Salleh Staffs for his help in my experiments.

I earnestly thank my family, especially to my sickly wife Shahnaz Ghafarzadeh who is always supportive to my study and work. I need to thank my kindly father and my lovely son Shahin for their love, support and patience during the development of this work. This work is also for my ever-beloved mother in heaven.

ABSTRACT

This research work outlines thermal and mechanical properties of prepacked concrete containing Palm Oil Fuel Ash (POFA). Prepacked aggregate concrete (PAC) is a special kind of concrete which is produced by first placing the coarse aggregates inside the molds followed by injection of grout by using pump or gravity method. The grout consists of sand, cement and water plus chemical and mineral admixtures. POFA is a mineral admixture which can be used as a supplementary cementitious material. This study determines the heat of hydration, heat transfer and mechanical properties of PAC with POFA replaced in different percentages of 0%, 10%, 20% and 30% by weight of cement. Along with thermal properties, properties of grout and strength of concrete were also investigated. The result obtained in this study demonstrated that the partial replacement of cement by POFA is advantageous and has very good potential to control the heat of hydration in prepacked concrete.

ABSTRAK

Kerja penyelidikan ini menggariskan sifat haba oleh konkrit prepacked yang mengandungi Palm Oil Fuel Ash (POFA). Konkrit agregat Prepacked (PAC) adalah sejenis konkrit khas yang dihasilkan dengan meletakkan agregat kasar terlebih dahulu ke dalam acuan diikuti dengan suntikan grout dengan menggunakan pam atau kaedah graviti. Grout terdiri daripada pasir, simen dan air serta bahan tambah kimia dan mineral. POFA adalah bahan tambah mineral yang boleh digunakan sebagai bahan gantian simen. Kajian ini menentukan haba penghidratan dan haba pemindahan oleh PAC dengan POFA digantikan dalam peratusan yang berbeza 0%, 10%, 20% dan 30% mengikut berat simen. Bersama-sama dengan sifat haba, sifat grout dan kekuatan konkrit juga telah disiasat. Keputusan yang diperolehi dalam kajian ini menunjukkan bahawa gantian separa simen oleh POFA adalah berfaedah dan mempunyai potensi yang sangat baik untuk mengawal haba penghidratan dalam konkrit prepacked.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
OPC	-	Ordinary Portland Cement
PAC	-	Prepacked Aggregate Concrete
POFA	-	Palm Oil Fuel Ash
UPVC	-	Unplasticized Poly Vinyl Chloride (pipe)
SP	-	Super Plasticizer
SSD	-	Saturated Surface Dry

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Construction of pre-packed concrete dates back to 1937 when Lee Turzillo and Louis S. Wertz applied this method in construct Santa Fe railroad near Martiez, California. Like the rest of the scientific, process of pre-packed concrete starting development. This investigation continued by Professor Raymond E. Davis in more practical. Pre-packed aggregate concrete gain its sole nature from its special placement which the coarse aggregate are placed first in the cast and grout is injected from under cast or top cast inside the matrix. Conventional concrete is placed as a composite aggregate and cement-grout mixture. This means the aggregate and cementitious grout components are combined before the concrete is placed into formwork. Prepacked aggregate concrete is different than conventional concrete methods because its components are placed in separate steps.

The most properties of pre-packed concrete depend on coarse aggregate because the superabundance of coarse aggregate inside the matrix is more than traditional concrete. Arrangement of aggregates which are point-to-point can be influence in all properties such as compressive strength and tensile strength, and even bending moment properties. In retrofitting structures, when pre-packed aggregate concrete in use, the bond between the traditional concrete and old concrete and the new pre-packed aggregate concrete is wonderful. Nowadays the most of using pre-packed concrete in repair of masonry structure, underwater construction and retrofitting structures, where placement by traditional method is extremely difficult and in mass concrete such as dams where low thermal hydration are required, and structure of tunnels and sluiceway plugs to comprise water at high pressure and in construction of atomic radiation are used as coarse aggregate commonly. Like the name implies, the aggregates are placed before the grout mixture. This leads to several advantages.

Because the aggregate is washed and placed into the formwork before the grout is injected, the aggregate-to-cement ratio is maximized. According to the American Concrete Institute this reduces shrinkage which can lead to higher bond ability with existing concrete surfaces. Higher bond ability and less shrinkage results in less cracking. Another advantage is that PAC disallows material separation when being placed, especially when the formwork is partially or fully submerged in water. Once the aggregate is placed, grout injection begins at the bottom of the formwork, and progresses vertically at separate injection points. Any water in the formwork is displaced as the grout fills all the voids between the aggregate, creating a homogenous mixture. A homogenous mixture leads to a stronger repair. Finally, when placing prepacked aggregate concrete, there is little need for heavy equipment. The aggregate can literally be washed into place using a sluice pipe. Then grout can be injected using a grout pump. This is especially beneficial on small bridge pier or dam repair projects because most of the equipment can be left onshore. Materials are transported to the repair site through temporary PVC sluice pipes and grout hoses. Fewer pieces of equipment will lead to a lower cost repair.

Pre-packed aggregate concrete is a special method of construction in Civil Engineering. Though it is a unique in nature but it has its own advantages and disadvantages. One of the advantage is close contact of coarse aggregate can be an excellent result in compressive strength compared to normal concrete. This will lead to a higher modulus of elasticity. Apparently pre-packed aggregate concrete is like normal concrete. From the literature, available to date, it has different properties compare to conventional concrete. It is essential that, to obtain the proper ratio of water to cement and ratio of sand to cement for a mass material with good flow. Also amount of POFA which can be used to decrease thermal hydration of concrete is very important. A Pozzolan is essentially a siliceous or siliceous and aluminous material which has little or no cementitious value but to change fine and mix to water have properties like cement. The broad definition of a Pozzolan imparts no bearing on the origin of the material, only on its capability of reacting with calcium hydroxide and water. A quantification of this capability is comprised in the term Pozzolanic activity. One such Pozzolanic material is Palm Oil Fuel Ash (POFA) which is a byproduct of burning of palm oil husk and palm kernel shell in palm oil mill boilers. All material has properties same Pozzolanic material can be a suitable material which makes it a good alternative for fly ash both to experimental test in lab and practical projects. Until now data on the thermal behavior of Prepacked concrete using POFA is very limited. Considering the availability of POFA, this research project has considered studying thermal behavior and transfer heat of Prepacked Concrete contained Palm Oil Fuel Ash.

1.2 Problem Statement

Dumping of palm oil fuel ash (POFA) not only occupies land but also creates environmental pollution and health hazard. These problems can be reduced to a large extent by using POFA in prepacked aggregate concrete. A number of research works have been carried out to investigate the potential use of POFA as a supplementary cementing material for normal, high-strength, and aerated concretes.

Either by experiment or by theory the heat of hydration of mass concrete are very high grade because of the huge cement. Increase the heat of hydration which can be damaging to the structure. Hydration of cementitious materials generates heat for several days after placement in all prepacked aggregate concrete members. This heat dissipates quickly in thin sections and causes no problems. In thicker sections, the internal temperature rises and drops slowly, while the surface cools rapidly to ambient temperature. Surface contraction due to cooling is restrained by the hotter interior concrete that doesn’t contract as rapidly as the surface. This restraint creates tensile stresses that can crack the surface concrete as a result of this uncontrolled temperature difference across the cross section. In most cases thermal cracking occurs at early ages. In rare instances thermal cracking can occur when concrete surfaces are exposed to extreme temperature rapidly. Concrete prepacked aggregate members will expand and contract when exposed to hot and cold ambient temperatures, respectively. Cracking will occur if this bulk volume change resulting from temperature variations is restrained. This is sometimes called temperature cracking and is a later age and longer term issue. The main concern with prepacked aggregate concrete is a high thermal surface gradient and resulting restraint. These conditions can result during the initial stages due to heat of hydration and during the later stages due to ambient temperature changes. Another factor is a temperature differential between an old concrete member and injecting elements in repair concerts. As the mass member cools from its peak temperature, the contraction is restrained by the element it is attached to, resulting in cracking.

The key to reducing thermal or temperature-related cracking is to recognize when it might occur and to take steps to minimize it. A thermal control plan that is tailored to the specific requirements of the project specification is recommended. Typical specifications for mass concrete include a maximum temperature and a maximum temperature differential. The maximum temperature addresses the time it takes for the concrete member to reach a stable temperature and will govern the period needed for protective measures. Excessively high internal concrete temperatures also have durability implications. A temperature differential limit attempts to minimize excessive cracking due to differential volume change. A limit of 30ºC is often used. However, concrete can crack at lower or higher temperature differentials. Temperature differential is measured using electronic sensors embedded in the interior and surface of the concrete.

However it can have a correct or incorrect procedure to use pump the grout. All mass concrete which make with prepacked aggregate concrete has a big problem. It is high thermal hydration in concrete. POFA can be improving the high heat of thermal. Avoid of blockage of pipe during the concreting operations. The important items to reduce the bleeding of grout and POFA use of consistency in the grout of pre-packed aggregate concrete to reduce the cement consumption and consequently thermal of hydration. These are all issues that scientists have been searching from long time to find solves to. In this investigation is to study the construction of appropriate grout for pre-packed aggregate concrete using different POFA to improve heat of hydration and transfer heat in pre-packed aggregate concrete. It also involves experiments to study the hypothesis of hydration and transfer temperature in prepacked concrete with difference percent of POFA. Hence, pre-packed aggregate concrete or another mass concrete require to replace material which decrease heat of hydration in the reaction between water and cement. Also amount of POFA which can be used to decrease thermal hydration of concrete is very important.

1.3 Aims and Objectives

The objectives of this study are listed as following:

1. To determine the fresh properties of grout incorporating POFA (bleeding and density).
2. To make prepacked aggregate concrete (pumping and gravity) specimens and compare their mechanical properties like compressive and tensile strength.
3. To find an optimum percentage of POFA in the grout for the purposes of having reduced heat of hydration consumption.
4. To find the best mixture proportions for the purpose of having the save energy (heat transfer).

1.4 Scope and Limitations

The scope of this investigation can be categorized as follows:

1. Making workable, consistent grouts using POFA as a pozzolanic material conforming to the regulations of ASTM C937-10 and ASTM C940-10a and ASTM C939-10.

2. The mix proportioning of prepacked concrete for 1 cubic meter are as follows:
    - Coarse aggregate 1320 kg
    - Fine aggregate 550 kg
    - Cement 378 kg
    - water 189 kg
3. Curing the cylinders according to ASTM C31/C31M – 12.
4. Calculating the compressive and tensile strength of prepacked aggregate concrete in conformance with ASTM C943-10.
5. Calculating the heat of hydration and transfer heat concrete in conformance with ASTM. C186/C186-05.

1.5 Significant of Study

To achieve the objectives of the study, it is needed to conduct some laboratory works. At the early stage of the research, select the POFA which are going to use in this research. In this research it used production POFA from the palm oil plant residues. Then the mechanical properties and thermal properties of prepacked aggregate concrete have to be justifying by conducting tensile and density tests. The concrete grade to be used is M30. Tests required for this research to achieve its objectives are: compression, tension, thermal hydration and transfer heat temperature tests of prepacked concrete containing POFA. The percentages of total POFA in this research are: 0%, 10%, 20%, and 30%. The cylindrical size will be used 300×150 mm, and for pumping grout prepacked aggregate concrete size used will be 150×1000 mm, size will be used for compressive test and 150 mm diameter with 300 mm height cylinder will be used for heat of hydration and transfer heat test. The specimens will be tested on 28 days of curing, therefore every category of POFA percent will have 3 samples of cylindrical size of 1000×150 mm and 3 samples of cylindrical with size of 300×150 mm.

POFA is a waste material which is found abundantly in Malaysia, Thailand and many other countries. These materials are mostly landfill or burn and effected on the surrounded environment. The significant of this study is to develop new technology in measure transfer heat temperature in prepacked aggregate concrete which can use as structural or non-structural members. From this study also, optimum percentage volume POFA that is suitable for expected quality of concrete will be justified so that it can be widely used as different applications such as concrete dams, restraining walls or any other concrete construction field based on its properties. POFA will help in decrease heat of hydration in concrete during action between cement and aggregate.

REFERENCES

Abdelgader, H. S. (1999). How to design concrete produced by a two-stage concreting method. *Cement and concrete research, 29*(3), 331-337.

Abdelgader, H. S., and Najjar, M. F. (2009). *Advances in concreting methods.* Paper presented at the International conference on sustainable built environment infrastructures in developing countries, Algeria.

Abdelgader, H. S., Najjar, M. F., and Azabi, T. M. (2010). Study of underwater concrete using two-stage (preplaced aggregate) concrete in Libya. *Structural Concrete, 11*(3), 161-165.

ACI Committee 304-R, . (1997). Proposed Revision of: Placing Concrete with Belt Conveyors. *ACI Materials Journal, 91*(6).

Akroyd, T. N. W. (1962). *Concrete: properties and manufacture*: Pergamon Press Oxford.

Association, Portland Cement. (1984). *Thickness design for concrete highway and street pavements*: Portland Cement Association.

Awal, A. S. M. A. (1984). Manufacture and properties of prepacked aggregate concrete. M. Eng. Sc. Thesis, University of Melbourne.

Awal, A. S. M.A. (1988). Failure mechanism of prepacked concrete. *Journal of Structural Engineering, 114*(3), 727-732.

Awal, A. S. M. A, and Warid, H. M. (1997). The effectiveness of palm oil fuel ash in preventing expansion due to alkali-silica reaction. *Cement and Concrete Composites, 19*(4), 367-372.

Awal, A. S. M. A. (1998). A study of strength and durability performances of concrete containing palm oil fuel ash. *PhD Thesis,* Universiti Teknologi Malaysia.

Awal, A. S. M. A, and Nguong, S. K. (2010). A Short-Term Investigation on High Volume Palm Oil Fuel Ash (POFA) Concrete. *Proceedings of the 35th Conferenece on our World in Concrete and Structure,* Singapore, 185-192.

Awal, A. S. M.A and Warid, H. M. (2011). Effect of palm oil fuel ash in controlling heat of hydration of concrete. *Procedia Engineering, 14,* 2650-2657.

Awal, A. S. M. A, and Shehu, I. A. (2013). Evaluation of heat of hydration of concrete containing high volume palm oil fuel ash. *Fuel, 105*, 728-731.

Basri, G., and Martín, E. L. (1999). PPL 15: the first brown dwarf spectroscopic binary. *The Astronomical Journal, 118*(5), 2460.

Brandt, J. H., Meyer, R. T., and Plank, B. N. (1998). *U.S. Patent No. 5,797,358*. Washington, DC: U.S. Patent and Trademark Office.

Champion, J. V, and Davis, I. D. (1970). Light scattering by solutions of flexible macromolecules subjected to flow. *The Journal of Chemical Physics, 52*(1), 381-385.

Chandara, C., Mohd Azizli, K. A., Ahmad, Z. A., Saiyid Hashim, S. F., and Sakai, E. (2012). Heat of hydration of blended cement containing treated ground palm oil fuel ash. *Construction and Building Materials, 27*(1), 78-81.

Chefdeville, M. J. (1963). Prepacked Aggregate Concrete and Activated Mortars. *DSIR, Building Research Station, Library Communication LC1190*.

Chindaprasirt, P. J. C., and Sinsiri, T. (2005). Effect of fly ash fineness on compressive strength and pore size of blended cement paste. *Cement and Concrete Composites, 27*(4), 425-428.

Chindaprasirt, P., and Rukzon, S. (2008). Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar. *Construction and Building Materials, 22*(8), 1601-1606.

Chusilp, N. J. C., and Kiattikomol, K. (2009). Utilization of bagasse ash as a pozzolanic material in concrete. *Construction and Building Materials*, *23*(11), 3352-3358.

Davis, R. E. (1960). Prepakt method of concrete repair. In *ACI Journal Proceedings* (Vol. 57, No. 8). ACI.

Gajda, J., and Vangeem, M. (2002). Controlling temperatures in mass concrete. *Concrete international*, *24*(1), 58-62.

Gambhir, M. L. (2013). *Concrete Technology: Theory and Practice*: Tata McGraw-Hill Education.

Hussin, M., and Abdullah, K. (2009). Properties of palm oil fuel ash cement based aerated concrete panel subjected to different curing regimes. *Malaysia Journal of Civil Engineering, 21*(1), 17-31.

Hussin, M. W., & Awal, A. S. M. A. (1996). *Influence of palm oil fuel ash on strength and durability of concrete.* Paper presented at the Proceedings of the

7th International Conference on Durability of Building Materials and Component, Stockholm.

Jaturapitakkul, C. K. T. W., and Saeting, T. (2007). Evaluation of the sulfate resistance of concrete containing palm oil fuel ash. *Construction and Building Materials, 21*(7), 1399-1405.

Lamond, J. F., and Pielert, J. H. (2006). *Significance of tests and properties of concrete and concrete-making materials* (Vol. 169): ASTM International.

Luikov, A. V. (1975). Systems of differential equations of heat and mass transfer in capillary-porous bodies (review). *International Journal of Heat and mass transfer, 18*(1), 1-14.

Malley, J., and Abdelgader, H. S. (2010). Investigation into viability of using two-stage (pre-placed aggregate) concrete in Irish setting. *Frontiers of Architecture and Civil Engineering in China*, *4*(1), 127-132.

Malhotra, V. M., and Mehta, P. K. (1996). *Pozzolanic and cementitious materials*(Vol. 1). Taylor & Francis.

Nanayakkara, S. M. A. (2011). Importance of controlling temperature rise due to heat of hydration in massive concrete elements. In*Proceedings of the IESL-SSMS Joint International Symposium on Social Management Systems*.

Neville, Adam. (1995). Chloride attack of reinforced concrete: an overview. *Materials and Structures, 28*(2), 63-70.

Ramachandran, N., and Shetty, D. K. (1991). Rising Crack-Growth-Resistance (R-Curve) Behavior of Toughened Alumina and Silicon Nitride. *Journal of the American Ceramic Society*, *74*(10), 2634-2641.

Ramachandran, V. S., and Cobb, S. (1995). Touching the phantom limb. *Nature, 377*(6549), 489-490.

Rukzon, S., and Mahachai, R. (2009). Effect of grinding on chemical and physical properties of rice husk ash. *International Journal of Minerals, Metallurgy and Materials, 16*(2), 242-247.

Sata, V., Jaturapitakkul, C., and Kiattikomol, K. (2004). Utilization of palm oil fuel ash in high-strength concrete. *Journal of Materials in Civil Engineering, 16*(6), 623-628.

Shannag, M. J. (2002). High-performance cementitious grouts for structural repair. *Cement and Concrete Research*, *32*(5), 803-808.

Sooraj, V. M. (2013). Effect of palm oil fuel ash (POFA) on strength properties of concrete. *International journal of Scientific and Research Publications*, *3*(6).

Standard, ASTM. *C33 /*C33M – 13. *Standard Specification for Concrete Aggregates, 2013*, American Society for Testing and Materials: Philadelphia, USA.

Standard, ASTM. C39/C39M-04. *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. 2004*, American Society for Testing and Materials: Philadelphia, USA.

Standard, ASTM. C150/C150-05. *Standard Specification for Portland Cement. 2005*, American Society for Testing and Materials: Philadelphia, USA.

Standard, ASTM. C186/C186-05. *Standard Test Method for Heat of Hydration of Hydraulic Cement. 2005*, American Society for Testing and Materials: Philadelphia, USA.

Standard, ASTM. *C192 /*C192M – 12. *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory, 2012*, American Society for Testing and Materials: Philadelphia, USA.

Standard, ASTM. *C496 /*C496M – 11. *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, 2004*, American Society for Testing and Materials: Philadelphia, USA.

Standard, ASTM. C618/C618-12A. *Standard Specification for Coal Fly Ash and Raw for Use in Concrete, 2012*, American Society for Testing and Materials: Philadelphia, USA.

Standard, ASTM. C938 – 10. *Standard Practice for Proportioning Grout Mixtures for Preplaced-Aggregate Concrete, 2002*, American Society for Testing and Materials: Philadelphia, USA.

Standard, ASTM. C939 – 10. *Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete, 2010*, American Society for Testing and Materials: Philadelphia, USA.

Standard, ASTM. C940 – 10. *Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory, 2010*, American Society for Testing and Materials: Philadelphia, USA.

Standard, ASTM. C943 – 10. *Standard Practice for Making Test Cylinders and Prisms for Determining Strength and Density of Preplaced-Aggregate Concrete in the Laboratory 2010*, American Society for Testing and Materials: Philadelphia, USA.

Sturrup, V. R., and Hooton, R. D. (1983). Durability of fly ash concrete. *ACI Special Publication, 79*.

Tangchirapat, W. (2009). Compressive strength and expansion of blended cement mortar containing palm oil fuel ash.*Journal of Materials in Civil Engineering*, *21*(8), 426-431.

Tang, I. N. (1977). Aerosol growth studies—III ammonium bisulfate aerosols in a moist atmosphere. *Journal of Aerosol Science*, *8*(5), 321-330.

Tay, J. H. (1990). Ash from oil-palm waste as a concrete material. *Journal of Materials in Civil Engineering*, *2*(2), 94-105.

Taylor, S. R. (1965). Geochemical analysis by spark source mass spectrography. *Geochimica et cosmochimica acta, 29*(12), 1243-1261.