UNIVERSITI PUTRA MALAYSIA

OiI PALM KERNEL SHELL CONCRETE MIX DESIGN AND BOND STRENGTH

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By

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May 2012

Chair: Prof. Dato' Ir. Mohd Saleh Jaafar, PhD

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Malaysia has been known for years to produce more than half of the world's output of palm oil and produces approximately 3.13 million tonnes as wastes in the form of oil palm shells (PKS) every year. A multitude of efforts have been made in the direction of waste management, and one of these plans are the use of PKS as a lightweight aggregate that can be used for construction purposes. However, the properties of Lightweight OPS concrete depend on the mix proportions, type of sand and the physical properties of the materials used.

In order to ensure that PKS concrete can be used for structural purposes the compressive strength should be at least 25 Mpa. The physical and mechanical properties of PKS concrete showed that the densities and the 28-day compressive strengths of the concrete vary in range from 1750-2050 kg/m^3 and 12-24 N/mm^2, respectively, which are not acceptable to be utilized in structural application. Therefore, this project focuses on strength performance of PKS concrete by finding optimized mix design as well as the bond strength between concrete and steel bars. This work started by choosing a suitable mix to be used for PKS concrete design. ACI 211.2-98 and ASTM C 330-00 have been chosen in order to start conducting trial mixes and to prepare the materials used in optimized mix design. Metakaolin has been used as a mineral admixture to ascertain its contribution in improving the properties of PKS concrete. Tests on the mechanical properties were conducted and the relationship between mechanical properties was analysed. PKS concrete containing 10% metakaolin showed a stronger bond and an increase of 28-day compressive strength by almost 25%. The splitting tensile strengths and modulus of rupture of PKS concrete were found to be 7% and 20% of their compressive strengths. The modulus of elasticity was found to be around 12KN/mm^2 which is higher than values found in the previous studies. Higher experimental bond strengths were recorded for PKS concrete compared to predicted values and bond strengths were found to be approximately 18% and 9% of compressive strength for deformed and plain bars respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

REKAAN DAN KEKUATAN IKATAN KONKRIT CAMPURAN TEMPURUNG KELAPA SAWIT

Oleh

ASAD MOHAMED ELMAGARHE

Mai 2012

Chair: Prof. Dato' Ir. Mohd Saleh Jaafar, PhD

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Malaysia telah terkenal dalam penghasilan lebih daripada separuh pengeluaran minyak kelapa sawit sedunia dan menghasilkan anggaran 3.14 juta tan bahan buangan dalam bentuk tempurung kelapa sawit (TKS) setiap tahun. Pelbagai usaha telah dilakukan terhadap pengurusan bahan buangan, dan salah satu daripadanya adalah penggunaan TKS sebagai agregat ringan bagi tujuan pembinaan. Walaubagaimanapun, sifat konkrit TKS ringan bergantung kepada kadar campuran, jenis pasir dan sifat fizikal bahan yang digunakan.

Untuk menentukan bahawa konkrit TKS boleh digunakan untuk pembinaan, kekuatan mampatannya sepatutnya sekurang-kurangya 25 Mpa. Sifat fizikal dan mekanikal konkrit TKS menunjukkan bahawa ketumpatan dan kekuatan mampatan 28-hari konkrit tersebut berubah dalam julat 1750-2050 kg/m^3 dan 12-24 N/mm^2 masing-masing. Ia masih belum boleh diterima untuk penggunaan dalam pembinaan. Oleh itu, projek ini menumpu kepada prestasi kekuatan konkrit TKS dengan menemukan rekaan campuran yang optima sekaligus dengan kekuatan ikatan di antara konkrit dan batang keluli. Penyelidikan ini dimulakan dengan memilih campuran yang sesuai untuk rekaan konkrit TKS. AC 211.2-98 dan ASTM C 330-00 dipilih untuk menjalankan campuran ujian dan menyediakan bahan untuk digunakan dalam rekaan campuran yang optima. Metakaolin telah digunakan sebagai galian campuran untuk menentukan sumbangannya dalam memperbaikkan sifat konkrit TKS. Ujian ke atas sifat mekanikal dan modulus elastik telah dijalankan dan perkaitan di antara sifat mekanikal telah dikaji. Konkrit TKS yang mengandungi 10% metakaolin menunjukkan ikatan yang lebih kuat serta peningkatan kekuatan mampatan 28-hari hampir 25%. Kekuatan tegangan pecah dan modulus pecah bagi TKS konkrit didapati 7% dan 20% daripada kekuatan mampatannya. Modulus elastik didapati di sekitar 12 N/mm2 iaitu lebih tinggi daripada nilai yang ditemui dalam kajian sebelumnya. Kekuatan ikatan teruji yang lebih tinggi telah direkod untuk konkrit TKS berbanding dengan nilai ramalan dan kekuatan ikatan didapati lebih kurang 18% dan 9% daripada kekuatan mampatan untuk batang terubah dan juga batang biasa.

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I thank all my friends who have given me emotional support. Special thanks are given to my parents and my brothers and sisters for their love.

APPROVAL

I certify that a Thesis Examination Committee has met on (**to be announced by GSO**) to conduct the final examination of Asad Mohamed Elmagarhe on his thesis entitled "**Optimizing the Mix Design of Oil Palm Shell Concrete**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the University Putra Malaysia [P.U. (A) 106] 15 March 1998. The committee recommends that the student be awarded the Thesis of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at University Putra Malaysia or at any other institution.

ASAD MOHAMED ELMAGARHE
Date: 22 May 2012

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LIST OF ABBREVIATIONS

FA	:Fly Ash
HRM	:High Reactivity Metakaolin
HSC	:High Strength Concrete
LVDT	:Linear Variable Differential Transformer
LWA	:Lightweight Aggregate
LWAC	:Lightweight aggregate Concrete
MK	:Metakaolin
MOR	:Modulus of Rupture
NA	:Not available
NWC	:Normal Weight Concrete
OPC	:Ordinary Portland Cement
OPS	:Oil Palm Shell
PFA	:Pulverized fuel ash
PKS	:Palm Kernel Shell
PKSC	:Palm Kernel Shell Concrete
SEM	:Scanning Electron Microscopy
SF	:Silica Fume
SLWAC	:Structural Lightweight Aggregate Concrete
SP	:Superplasticizer
SSD	:Saturated Surface Dry

DEDICATION

This thesis is dedicated to my family who have always given me emotional support.

CHAPTER 1

INTRODUCTION

1.1 General

The use of agro-waste materials in construction is becoming more popular due to current economic and environmental concerns. Large amount of agro-waste materials or green materials such as sawdust ash, vegetables fibers, palm oil kernel shells, rice husk ash, etc. are being utilized as raw materials for blended components in concrete. However, broad utilization of green materials is still limited due to excessive treatments that may be required before they can be effectively used with cement [1].

Malaysia, Nigeria, Thailand and Indonesia are the countries that produce the largest quantities of palm oil. Consequently, they are also processing a large amount of industrial waste, which is dumped in factory yards. Over the last 30 years, awareness has grown particularly in Malaysia and Nigeria regarding disposal management strategies. One of the successful strategies is the potential of utilizing agricultural and industrial waste as construction materials. Thus, the use of waste materials, particularly in the manufacture of Lightweight Aggregates (LWA) is considered productive and vital. The PKS production in Malaysia is shown in Figure 1.1.

For this research, palm kernel shell (PKS), sometimes referred to as oil palm shells (OPS) is the industrial waste used as a LWA. Okpala [2] stated that the African people had used PKS in the past to build their mud houses and even nowadays the reaming is still in good condition. Teo et al [3] reported that in Malaysia, PKS was implemented in the construction of low-cost houses by using PKS hollow blocks for the walls and PKS concrete for the footings. He also expressed that lintels and beams showed acceptable performance with no serious structural problems during sustained load.

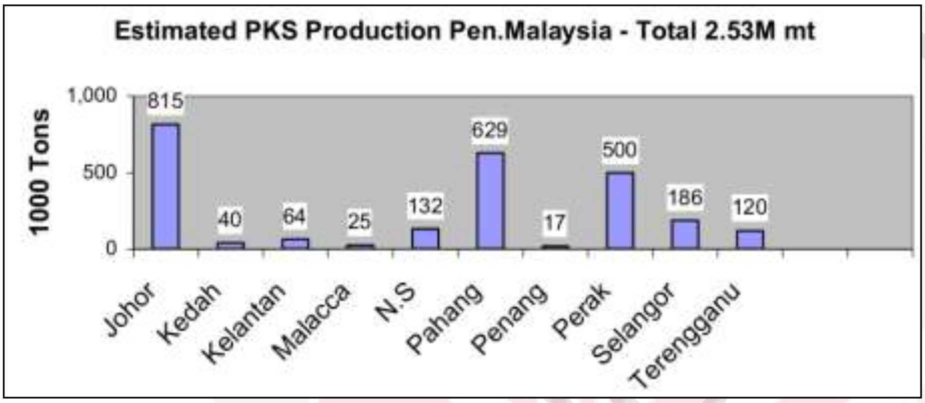

Figure 1.1: PKS Production in Peninsula Malaysia (By State) in 2004, (Dit, 2007) [4]

1.2 Problem statement

1.2.1 Mix design of Palm Kernel Shell concrete

There were several preliminary investigations done by Mannan and Ganapathy [5] to identify an appropriate mix design for palm kernel shell concrete. Three different methods were followed, ACI mix design method for normal weight concrete and the mix design method mentioned in references [5, 6]. None of these procedures as presented in their findings achieved the targeted compressive strength of 25 N/mm^2. The maximum compressive strength that was gained was around 14 N/mm^2, which is also below the minimum strength of structural lightweight concrete; 17 N/mm^2 [8]. Finally, Mannan and Ganapathy [5] concluded that PKS mix design should be subjected to a trial-and error method in order to obtain a proper mix proportion.

Another mix design approach was presented by Alengaram et al [9] and Shafigh et al [10] as their mixes displayed high compressive strengths of 37 and 45 N/mm^2, respectively. Nevertheless, both mixes contain high cement content, (535 kg/m^3) for Alengaram and (550 kg/m^3) for Shafigh. Thus, using high cement content with aggregates classified as waste materials will achieve a low-cost concrete. Hence, for this study the optimized mix design focuses on lowering the cement content, which will has tremendous effect on the cost besides achieving an acceptable compressive strength for LWAC.

1.2.2 **Using the metakaolin as mineral admixtures in PKS concrete**

Generally, according to previous researches, the failure of PKSC is controlled by two things, i.e., the failure of the shell itself or by the bond between PKS and cement matrix. This problem has been addressed by a couple of researchers by adding the mineral admixtures such as fly ash and silica fume to the PKSC. Basri et al [11] proved that using fly ash (FA) with class F as a mineral admixture in PKSC did not achieve the desired outcome to optimize compressive strength. Moreover, they indicated a reduction in compressive strength of almost 25% by using 15% fly ash as a cement replacement.

Alengaram et al [12] used silica fume (SF) as a cement additive. They found that the 28-day compressive strength was around 37 N/mm^2. This finding gave evidence that the weaker zone, i.e. the zone between the aggregate and cement's interface was strengthened by utilizing SF. Hence, eventually, the bond strength increased to produce a higher compressive strength.

PKS has a flaky and irregular shape so it has an explicit effect on workability. According to Alengaram et al [9], SF should be used between 8% and 10% in order to cover the entire shell's surface. Consequently, using 10% SF as a cement additive combined with the irregularity shape effect of the shells will cause a high demand for water to maintain workability. Eventually, a special or high-water reducer (superplasticizer) will also be needed to make the concrete more workable.

In this research, 5 and 10% of metakaolin (MK) has been used as a cement replacement in order to optimize the mix design of PKSC. MK was chosen in this study rather than other types of supplementary materials for four important reasons:

- The reactivity of metakaolin was very high when compared with other types of pozzolanic materials. Metakaolin comprises the highest percentage of alumino-silicates between the pozzolanic materials, enabling it to maximise the durability of concrete binder [13]. Metakaolin extremely reacts with lime more athan flyash that its reaction with lime in concrete may take up to two month [14], while metakaolin, the reaction may occur within two weeks [15].

- Metakaolin has a low specific gravity in the range of 2.10 to 2.60 compared to other types of supplementary materials such as fly ash, 2.6 to 3.0, and blast furnace slag, 2.80 to 2.95. Therefore, using metakaolin to replace the cement that has a specific gravity in the range of 3.0 to 3.10 will has tangible effect upon density. This fact was approved from Al-Sibahy and Edward [16] who used the metakaloin to replace cement for lightweight concrete contained a recycled glass. According to their findings they noticed that by increasing the percentage of metakaloin from 0, 5 and 10% as cement replacement, the density had a reduction around 1680, 1670 and 1620kg/m^3, respectively. Thus, using metakaolin instead of other types of supplementary materials not only will enhance the mechanical property of PKS concrete but also will provide more acceptable density for structural lightweight concrete.

- Another advantage is that metakaolin is not classified as a by-product, unlike other pozzolanic materials which their engineering properties cannot be control [17]. Therefore, implementing metakaolin will promise some benefits comparable to other supplementary materials. In this study, evaluation the performance of metakaolin-PKS concrete will be compared to other lightweight PKS concrete contains incorporation different supplementary materials from previous published work.

- Dubey and Banthia [18] reported that the slump values for concrete mixes comprised of 10% SF were found to be equal to half the values of mixes that contain the same proportion of MK. That means MK concrete requires less quantity of high water reducer compared to SF.
- There were no previous research studies investigating the effect of MK on the mechanical properties of PKSC.

1.2.3 **Utilization of Palm Kernel shell in structural applications**

In 1984, Abdullah [19] carried out a first study concerning usage of PKS as a lightweight aggregate to produce LWC. Abdullah proved from his findings that the resulting concrete has an air-dry density in the range of 1840-2050 kg/m^3 and 28-day compressive strength between 5 and 20 N/mm^2. However, most codes and standards require a specified minimum strength for structural lightweight aggregate concrete, for example, ASTM C330 [20] specified that the minimum strength for structural lightweight concrete is 17 N/mm^2. BS 5400 [21] required minimum allowable cube strength of 25 N/mm^2 for LWAC to be used in structural application such as reinforced concrete bridges. In this research the target strength of 30 N/mm^2 was allocated to ensure PKSC to be use in structural application. Shafigh et al [22] and Ng et al [23] did an investigation of in the structural integrity of palm kernel shell reinforced concrete, they reported that although PKSC has good mechanical properties such as perfect insulation, it still needs additional investigation for their structural behavior as the PKS concrete slap for instance failed to fulfilled the minimum strength requirement at the time of lifting, transporting and the time of service. Eventually, they concluded that a further tests regarding of structural behavior are required.

Another study was done by Alengaram et al. [12], who studied the effect of silica fume in the bond strength of PKSC beam, they observed that PKSC beam exhibited under ductile load several cracks with a very small crack width which gave an indication of strong bond between PKSC and reinforced bars. Eventually, they concluded that using silica fume as cement replacement enhanced the bond strength of PKS concrete. There are various factors that affect the bond strength of palm kernel shell concrete (PKSC) such as mix proportions, density and curing conditions. Thus, in this study metakaolin has been used as cement replacement not only to enhance the bond strength of PKSC but also by limiting the air-density to be in the margin of structural lightweight concrete. Herewith, the bond strength was chosen as the margin to indicate the development in the structural behavior for proposed mix designation.

1.3 Research objectives

The objectives of this study can be summarized as given below:

i) To determine the optimum mix design of PKSC by limiting the cement content between 400 to 480 kg/m^3 and To study the effect of metakaolin as a mineral admixture in PKS concrete.

ii) To identify the enhancement in the bond strength between PKSC and steel bar.

1.4 Scope of this research

The development of the mix design of PKSC was done by limiting the cement content to be in the range of 400 to 480 kg/m^3. Also, this research work addressed the potentiality of using high reactive metakaolin (HRM) as a supplementary cementitious material in PKS concrete mixes. Four different mixes were used and every mix proportion was incorporated with 0, 5 and 10% of high-reactivity metakaolin (HRM) in order to optimize the compressive strength and mechanical properties of PKSC. The PKS aggregate for the four mixes was fully replaced with granite aggregate and nominated as the control mix.

The fresh and hardened concrete properties of PKSC were chosen to be the base of this study, by analyzing and comparing the behaviors for each concrete mix. Slump and compacting factor test was chosen to evaluate the workability of concrete mixes. All concrete samples were cured under water tank regimes for almost one month. The mixes that incorporated 10% metakaolin showed the highest compressive strength of more than 30 N/mm^2. One mix that is considered as an optimized mix was selected according to its low cement content and high compressive strength. The mechanical properties of the selected mix was investigated and compared with the same concrete mix but fully replaced with granite aggregate. The bond stress of the selected mix of PKSC was compared to a similar grade of NWC. Twenty-one cylindrical concrete reinforced with plain and deformed bars of different sizes was tested and compared concerning its bond strength behaviour.

However, some limitations were set which would not cover for this study:

- Studies related to durability and thermal conductivities are not included.
- No studies on long term properties such as shrinkage and creep.

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