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DEVELOPMENT OF HIGH VOLUME POFA SELF- COMPACTING CONCRETE USING COLLOIDAL NANO SILICA AS A VISCOSITY MODIFYING AGENT

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By

SAMIRA JILANI KOJOURI

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Faculty : Engineering

This study delineates the effects of nano silica on self-compacting concrete (SCC) with high volume replacement of palm oil fuel ash (POFA). POFA is an agro waste found in hefty amounts in Malaysia. It is a by-product of burning residues of palm oil industry which reportedly has pozzolanic behavior. Pozzolanic mineral admixtures are used in concrete to enhance the mechanical properties and the durability. However, the addition of mineral admixtures especially in high volumes reduces the workability and increases the demand for superplasticizer. The negative effect of the explained phenomenon is of great importance in SCC in which high workability as well as cohesiveness is required. Furthermore, inclusion of mineral admixture as a replacement for cement brings about the delay in hydration for which unbound water increases in the matrix at early ages. This increases the risk of segregation and bleeding and as a result the hardened properties of concrete including the mechanical properties and the durability are disadvantageously overshadowed.
The overarching purpose of this study was to overcome the above mentioned demerits of inclusion of high volume POFA in the SCC matrix. Accordingly, cement was replaced with 20%, 30% and 50% of POFA to investigate the behavior and reactions at early and late age properties of SCC. Slump flow, J-ring, L-box, and sieve stability test were conducted to assess the fresh properties of SCC with POFA. Also, the compressive strength at ages of 1, 3, 7, 28, and 90 days were recorded. Moreover, the durability tests including chloride permeation, gas permeability, sulfate attack and drying shrinkage were conducted at late ages up to six months. The SEM, XRD, FTIR, TGA, DSC and calorimetry tests were also performed to study the underlying mechanism which the microstructure and chemical composition of samples were changed. The same tests were carried out for samples with 1% colloidal nano silica. For samples with the highest level of replacement (50% POFA), dosages of 0.5% and 1.5% colloidal nano silica were also used.

The results showed that the replacement of cement with more than 20% dosage of POFA notably increased the bleeding and segregation of the mixture. The chemical tests revealed that the delayed hydration increased the amount of free water in the matrix. The free water diffused out of the matrix and bleeding and segregation occurred consequently. However, when nano silica was added, the bleeding and segregation were controlled by accelerating the hydration through its pozzolanic and dissolving effects. Furthermore, results from the hardened properties showed that the addition of nano silica compensated the strength depletion caused by high volume of cement replacement, albeit, the target strength of 30 MPa was achieved at 90 days. Similarly, the addition of nano silica reduced the drying shrinkage, gas permeability, sulfate attack and chloride ingression in high volume POFA-SCC. In general, the results were conclusive that the addition of nano silica enhances the properties of self-compacting concrete with high volume of mineral admixture with low cementing properties.

Keywords: Self-compacting concrete, POFA, Colloidal nano silica, Stability, Compressive strength, Durability.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN KONKRIT PEMAMPATAN DIRI POFA BERISIPADU TINGGI MENGGUNAKAN NANO SILIKA BERKOLOID SEBAGAI EJEN MENGUBAHSUAI KELIKATAN

Oleh

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Kajian ini menggariskan kesan-kesan nano silica terhadap konkrit memadat-diri (SCC) dengan kandungar isipadu yang tinggi menggantikan abu sisa bahan api kelapa sawit (POFA). POFA merupakan sisa pertanian yang didapati dengan jumlah yang banyak di Malaysia. Ia adalah hasil sampingan pembakaran sisa industri minyak sawit yang dilaporkan mempunyai tingkah laku pozzolanik. Bahan tambah mineral pozzolanik digunakan dalam konkrit untuk meningkatkan ciri-ciri mekanikal dan ketahanlasakannya. Walau bagaimanapun, penambahan bahan tambah mineral terutama dalam jumlah yang tinggi mengurangkan kebolehkerjaan dan meningkatkan permintaan untuk superplasticizer. Kesan negatif fenomena yang dijelaskan adalah amat penting dalam SCC di mana kebolehkerjaan yang tinggi serta kejeleketan diperlukan. Tambahan pula, kemasukan bahan tambah mineral sebagai pengganti simen membawa lengah dalam penghidratan yang mana air tak terikat bertambah dalam matriks pada awal umur. Ini meningkatkan risiko pengasingan dan penjujuhan dan kesannya sifat konkrit terkeras termasuk sifat-sifat mekanikal dan ketahanlasakan dibayangi secara negatif.

Tujuan paling utama kajian ini adalah untuk mengatasi kelemahan yang dinyatakan di atas hasil kemasukan POFA berisipadu tinggi dalam matriks SCC. Oleh itu, simen telah digantikan dengan 20%, 30%, dan 50% POFA untuk menyiasat perilaka dan tindakbalas yang terhasil pada umur awal dan lewat dalam sifat-sifat SCC. Ujian-ujian aliran turunan, J-ring, kotak-L, dan ujian kestabilan ayak telah dijalankan untuk menilai sifat-sifat baru POFA SCC berisipadu tinggi. Kekuatan mampatan sampel pada umur 1, 3, 7, 28, dan 90 hari telah direkodkan. Selain itu, ujian ketahanlasakan termasuk penyerapan klorida, kebolehtelapan gas, serangan sulfat dan pengecutan keringan telah dijalankan pada umur lewat sehingga enam bulan. Ujian-ujian seperti SEM, XRD, FTIR, TGA, DSC, dan ujian kalorimeter juga telah dilakukan untuk mengkaji mekanisme yang mendasari di mana mikrostruktur dan kimia komposisi sampel telah berubah. Prosedur yang sama telah dijalankan untuk sampel dengan 1% nano silica berkoloid. Bagi sampel dengan tahap tertinggi penggantian (50% POFA), dos nano silika berkoloidal yang lain sebanyak 0.5% dan 1.5% juga digunakan.

Hasil kajian menunjukkan bahawa penggantian simen dengan POFA terutamanya pada dos yang lebih daripada 20% meningkatkan penjujuhan dan pengasingan. Ujian kimia mendedahkan bahawa penghidratan yang tertangguh meningkatkan jumlah air bebas di dalam matriks. Air bebas diresap daripada matriks dan penjujuhan dan menyebabkan pengasingan berlaku seterusnya. Walau bagaimanapun, apabila nano silika ditambah, penjujuhan dan pengasingan dapat dikawal dengan mempercepatkan penghidratan melalui kesan pozzolanik dan perlarutan. Tambahan pula, hasil daripada sifat keras konkrit menunjukkan bahawa penambahan nano silika menyebabkan kekurangan kekuatan yang disebabkan oleh isipadu penggantian simen yang tinggi walaupun kekuatan sasaran 30 MPa dicapai pada 90 hari. Begitu juga penambahan nano silika mengurangkan pengecutan terkering, kebolehtelapan gas, serangan sulfat dan kemasukan klorida dalam POFA-SCC berisipadu tinggi. Secara umumnya, keputusan menunjukkan bahawa penambahan nano silika meningkatkan sifat-sifat SCC dengan bahan tambah mineral berisipadu tinggi dengan sifat-sifat penyimenan yang rendah.

Kata Kunci: Konkrit memadat-diri, POFA, Nano silica berkoloid, Kestabilan, Kekuatan mampatan, ketahanlasakan

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I certify that a Thesis Examination Committee has met on 6 May 2016 to conduct the final examination of Samira Jilani Kojouri on her thesis entitled "Development of High Volume POFA Self-Compacting Concrete using Colloidal Nano Silica as a Viscosity Modifying Agent" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS AND ACRONYMS

SCC	Self- compacting concrete
NVC	Normal vibrated concrete
POFA	Palm oil fuel ash
OPC	Ordinary Portland cement
SP	Superplasticizer
PNS	Polynaphtalane sulforlate
PCE	polycarbxylate ether
PA	Polyacrylate
VMA	Viscosity modifying admixtures
NS	Nano silica
CNS	Colloidal nano silica
Ctr	Control
C_3S	Tricalcium silicate
C_2S	Dicalcium silicate
C-S-H	Calcium silicate hydrate
CH	Calcium hydroxide
ITZ	Interfacial transition zone
AFm	Alumina, Ferric oxide, monosulfate
W/b	Water to binder ratio
TGA	Thermo gravimetric analysis
FTIR	Fourier transforms infrared spectroscopy
SEM	Scanning electron microscope
XRD	X-Ray Diffraction Analysis
DSC	Differential scanning calorimeter
RCPT	Rapid chloride penetration test

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is the most used building material in the world and reportedly more than 10 billion tons are produced annually (Mehta, 2002). Being easily engineered for different purposes and its rather cheap and available constituents are major success keys in its mass production around the world. Many forms of concrete, so far, have been proposed and cast adaptable to its use and the required strength, namely, self-compacting concrete, ductile concrete, and foam concrete. Of all types of concrete being introduced to construction industry, self-compacting concrete (SCC) or also known as self-consolidating concrete, has a great importance due to its high workability and viscosity which eases up the pouring and cast in members with congested reinforcement, foundations, and underwater concreting. Furthermore, removal of the vibration process cuts off the labour and hence the costs are reduced extensively.

All the above mentioned advantages of SCC comes with a requirement of high volume of cement (up to 600 kg/m^3) to achieve an appropriate matrix cohesiveness to hold the aggregates, which is known as stability. Production of cement is believed to trigger more than 7% of emitted carbon dioxide to the atmosphere (Huntzinger and Eatmon, 2009). Furthermore, high volume of cement induces thermal crack and also jeopardizes dimensional stability of concrete due to mechanisms such as shrinkage and creep (Rozière et al., 2007). Experts have proposed usage of viscosity modifying agents to reduce the cement content and to control the stability. On the other hand, mineral admixtures are suggested into the matrix to lessen the amount of cement through cement replacement. Admixing mineral admixtures not only reduces the cement content but enhances the qualities of concrete such as mechanical properties and the durability. However, only limited amounts of replacement are suggested in order to maintain the appropriate stability and avoid the strength depletion of samples (Hassan et al., 2012, Sheinn et al., 2003).

One of the mineral admixtures is palm oil fuel ash (POFA) which is the residue from burning shells and fibres of palm fruit and is produced in hefty amounts in Malaysia. Based on statistics of Malaysian Palm Oil Board (2015), more than 5.6 million hectares of land are occupied with palm plants in Malaysia that produce approximately 15 million tons of POFA annually. Many studies suggest that POFA has pozzolanic behavior and hence can lead to formation of secondary C-S-H and strengthen the matrix. Also, different works verified that POFA can enhance the durability of concrete in terms of chloride and sulfate resistance (Jaturapitakkul et al., 2007, Johari et al., 2012). However, a comprehensive study on application of high volumes of POFA in self-compacting concrete is indispensable.

The other recently exploited mineral admixture is nano silica which is available in two forms of powder and colloidal gel. In general, nano silica influences the cement matrix by its pozzolanic behavior originated from its amorphous nature of nano sized SiO_2

(Björnström et al., 2004). Its nano size particle boosts up its effectiveness compared to silica fume, albeit at a shorter duration also the addition of nano-TiO_2, nano-Al_2O_3 and nano silica to the self-compacting mortar showed that among all samples, nano silica increased the strength to a higher level compared to other nano materials (Mohseni et al., 2015). Furthermore, high surface energy of particles can enhance the dissolution of cement compounds to render higher amounts of hydration products at very early stages of hydration. The hydration products can later envelop the nano particles which act as nuclei for a better distribution of C-S-H all over the matrix (Said et al., 2012). The mentioned phenomena besides nano filling effect of nano silica can further densify the matrix. Studies show that nano silica can enhance both mechanical properties and the durability of cement based materials.

1.2 Problem Statement

One of the major problems with self-compacting concrete is the usage of high content of cement in the matrix (Okamura and Ouchi, 1998). Cement should be used in high amounts to create enough cohesiveness in the matrix to hold the aggregates together as well as to facilitate its flow ability which consequently causes higher rate of shrinkage and induces cracks in the matrix especially in the perimeter of the aggregates (Persson, 2001). To solve the problem, experts have proposed usage of viscosity modifying agents (Domone, 2007).

Cement replacement especially in high volumes is suggested since cement production is merely responsible for 7% of increasing carbon footprint into the ecosystem (Huntzinger and Eatmon, 2009). However, addition of mineral admixtures as cement replacement increases the water demand and reduces the workability. So, superplasticizers are added to overcome the reduced workability. The addition of high volume of mineral admixtures and superplasticizers negatively affects the hydration evolution and in some cases chemically conflicts the viscosity modifying agent. The delayed hydration may cause the bleeding and segregation of the fresh concrete which depletes the strength of hardened matrix later and lowers the durability qualities. The delayed hydration is not only as a result of superplasticizer but also can be caused by high volume replacement of cement with mineral admixtures especially with the one's with lower cementitous qualities such as POFA.

According to the statistics of Malaysian palm oil board (Malaysian Palm Oil Board, 2015), it is predicted that production of palm oil is increasing on an annual basis. POFA a by-product of palm oil plantation in Malaysia is dumped in landfills as a waste without any profitable return and causes environmental problems. Nevertheless, Awal and Hussin (2011) reported that the use of ground POFA as a supplementary cementing material due to its high content of SiO_2 is accepted. Due to low reactivity of POFA comparing other mineral admixtures such as silica fume and its porous morphology, POFA can facilitate and control stability of fresh SCC by delaying the hydration at lower contents of replacement.

Farzadnia et al. (2015) reported that porous surface of POFA imbibes water and consequently, increases the water demand at high content of replacement. However, the solution to dispose POFA as a highly produced agro waste is a core motive for researcher to come up with scientific solutions to use POFA as a cement replacement in concrete especially in high volume. However, Tangchirapat et al. (2009a) mentioned that only up to 30% of POFA can be used as a cement replacement.

Based on this information, this study is carried out with a hypothesis that nano silica can facilitate use high volume of POFA as a cement replacement in SCC. Hypnotically nano silica reduce the water absorbed in POFA by filling it pore structure. The excessive water can be released over time causing segregation and bleeding at high content of POFA. Furthermore, the amount of available water for hydration depletes which delays the hydration rate remarkably. Nano silica can accelerate hydration by its dissolution effect on C_3S. On the other hand, POFA was selected due to its low cementing and pozzolanic properties which accentuates the negative effect of high volume use. Besides, its hybrid effect with nano silica in SCC is not known yet.

In this study, nano modification of POFA is used to overcome the disadvantage of POFA and to change it to an advantage. Nano sized silica with high surface energy accelerates the hydration at the very first moments of contact with cement particles (Said et al., 2012), which is beneficial to the matrix in order to use it as a viscosity modifying agent. Other additives that have the same potential used are silica fume, limestone and metakaolin, however the reactivity of these materials are reported to initiate at later age of concrete i.e. up to three days from mixing (Wild et al., 1996). This is further reported by Jiang et al. (2015), whom investigated the pozzolanic reactivity of metakaolin and silica fume and concluded that most part of CH has not react with metakaolin and silica fume at first 3 days of curing due to their lower pozzolanic reactivity and lower surface area.

Based on above mentioned researches, nano particles are chosen because it increases the packing density of particles as a wider range of sizes are exploited in the matrix. Also, the pore structure of POFA can be modified in favour of segregation and bleeding when high volume of POFA is used. Besides, the gradual release of free water can render higher rate of C-S-H in long run especially with presence of POFA, for which the pozzolanic reactivity initiates at ages as late as 14 to 28 days of curing (Altwair et al., 2011). This can enhance the durability of high volume POFA- SCC as well as compensate the strength loss at later ages.

The aim of this study is to exploit nano silica as a modifying agent to overcome the delayed hydration due to either high volume replacement of cement with POFA or the increased demand for superplasticizers in order to control the stability. Furthermore, nano silica hypothetically, can compensate the depleted compressive strength caused by high volume of replacement and can enhance the durability issues of SCC.

1.3 Research Questions

Although the advantages of incorporation of low content of POFA in concrete is well investigated, Chindaprasirt et al. (2007a) agree that using POFA in high replacement levels negatively affect fresh properties, especially in self-compacting concrete in which the stability is highly influenced by cement content. The partial replacement of cement with POFA can beneficially reduce thermal cracking due to excessive heat augmentation, however, reduction in the peak temperature and also the hydration delay at peak temperature may disadvantageously change the fresh properties of concrete and may cause bleeding and segregation, so addition of appropriate viscosity modifying agents can help to enhance the fresh properties of SCC and consequently improve the hardened properties of SCC. Nevertheless additions of chemical viscosity modifying agents are not beneficial as they may conflict with superplasticizers. So, introducing a viscosity modifying agent with enhancing effects on properties of self-compacting concrete such as stability, early age strength, and durability in long run is indispensable.

This study focused on effects of nano silica as a viscosity modifying agent on chemical and physical characteristics of self-compacting concrete with high volume POFA. This study tents to answer the following questions;

1. What are the effects of high volume replacement of POFA on early age and late age properties of SCC?
2. How can physical and chemical properties of nano silica affect the fresh properties of high volume POFA self-compacting concrete?
3. To what extent can nano silica compensate the possible shortcoming caused by high volume cement replacement in terms of mechanical properties and durability?
4. What is the governing mechanism when the binary mix of nano silica and high volume POFA is used in the SCC matrix?

1.4 Objectives

The main aim of this research is to overcome the negative effects of high volume replacement of POFA on fresh and hardened properties of self-compacting concrete by addition of nano silica. The enhancement in the durability of the proposed concrete such as drying shrinkage, chloride ingression, and sulfate attack and gas permeability was also investigated. This was realized through the following four objectives;

1. To determine the stability, fresh properties, and early and late age compressive properties of high volume POFA self-compacting concrete with Colloidal Nano Silica (CNS).

2. To ascertain the durability behaviour of high volume POFA-SCC with Colloidal Nano Silica (CNS).

3. To determine the microstructure and chemical composition of high volume of POFA-SCC with Colloidal Nano Silica (CNS)

1.5 Significance of the Study

This study intended to use nano silica as a viscosity modifying agent in high volume POFA self-compacting concrete. The replacement of cement with high volume of POFA reduces the carbon dioxide footprint to a great extent. Furthermore, it solves the environmental problem caused by hefty amount of agro waste in Malaysia. Nano silica can control the bleeding and segregation caused by high volume replacement of POFA due to its high surface energy and chemical reactivity. The advantage of nano silica over other viscosity modifying agents is that there is no conflicting effect with the superplasticizers. Furthermore, unlike other viscosity modifying agents, nano silica can compensate the strength loss caused by replacement of cementing materials with low cementitous properties. In addition, this study unveils the mechanisms by which nano silica interacts with POFA which is considered as a low cementitous material due to a low content of Ca and Al.

1.6 Scope and Limitations of the Study

This study focused on cement replacement with up to 50% POFA. The 50% is considered as a high volume for mineral admixtures with low cementitous properties due to its low contents of Ca and Al ions. The ground POFA was used to increase the reactivity of its particles. On the other hand nano silica in colloidal state dosage was limited to 1% for mixtures 20 and 30% POFA; and up to 1.5% for 50% replacement of POFA. The volume of water and the type of aggregate were constant throughout the study.

In the first phase of the study the fresh properties of SCC are determined from slump flow, J-ring, L-box, and sieve stability test. However, to optimize the workability, the dosage of superplasticizer was varying with constant W/b ratio. The maximum amount of superplasticizer used is 8%. In the second stage of the study, the compressive strength of SCC was measured and reported at ages of 1, 3, 7, 28 and 90 days. The target strength of control samples was set to be 30MPa. To investigate the underlying mechanism by which POFA and nano silica modify the SCC matrix, the following tests were conducted: XRF, XRD, TGA, SEM, FTIR, and DSC tested and qualitatively analysed. On the other hand, , the durability of high volume POFA self-compacting concrete with and without nano silica was evaluated through permeability tests, shrinkage, chloride ingression, and attack at ages for a period of six month. The growing use of SCC in infrastructures especially underwater structures and foundations, which exposes SCC to environments, necessitated the performance assessment of samples against attack over other durability issues such as carbonation hence less focus on the later are made in this research. The energy consumption, CO_2 emission, cost analysis and carbonation were not investigated in this study.

1.7 Overview of the Thesis

The thesis encompasses four chapters to report and discuss the research work done in this study as follows;

Chapter two initially introduces the history, characteristics and properties of self-compacting concrete. Modification of SCC matrix using mineral admixture at different replacement levels including low and high volume is also discussed. Following the given reviews on SCC, the POFA and its chemical and physical properties are presented and its effects on concrete are reviewed. In the final section of the chapter, properties of nano silica and mechanisms by which it enhances the cement based materials are discussed. Chapter two is finally ended with concluding remarks to help readers better comprehend the purpose of the dissertation.

Chapter three describes the methodology and the approach used to achieve the objectives of the study. It consists of introduction of materials, sample preparation, testing procedure as well as the purpose behind the selection of the tests. Flowcharts are provided to depict the methodology step by step.

Chapter four comprises of three sections; the fresh properties, the hardened properties and the durability of the high volume POFA SCC with/without nano silica. The orders of sections are arranged according to the objectives of the study for more clarification. The mechanism by which POFA and nano silica influenced the matrix has been discussed along the chapter.

Finally, Chapter 5 provides a summary and conclusion of the study and suggests some recommendation for further research in this area of knowledge.

REFERENCES

ACI Committee 2005. Building Code Requirements for Structural Concrete (Aci 318-05) and Commentary (Aci 318r-05). American Concrete Institute.

Aıtcin, P. 2003. The Durability Characteristics of High Performance Concrete: A Review. *Cement and Concrete Composites,* 25**,** 409-420.

Aldahdooh, M., Bunnori, N. M. & Johari, M. M. 2013. Development of Green Ultra-High Performance Fiber Reinforced Concrete Containing Ultrafine Palm Oil Fuel Ash. *Construction and Building Materials,* 48**,** 379-389.

Alonso, C., Fernandez, L. 2004. Dehydration and Rehydration Processes of Cement Paste Exposed to High Temperature Environments. *Journal of Materials Science,* 39**,** 3015-3024.

Altwair, N. M., Johari, M. A. M. & Hashim, S. F. S. 2011. Strength Activity Index and Microstructural Characteristics of Treated Palm Oil Fuel Ash. *Structure,* 5**,** 6.

Aly, M., Hashmi, M., Olabi, A., Messeiry, M., Abadir, E. & Hussain, A. 2012. Effect of Colloidal Nano-Silica on the Mechanical and Physical Behaviour of Waste-Glass Cement Mortar. *Materials & Design,* 33**,** 127-135.

Aprianti, E., Shafigh, P., Bahri, S. & Farahani, J. N. 2015. Supplementary Cementitious Materials Origin from Agricultural Wastes–a Review. *Construction and Building Materials,* 74**,** 176-187.

Assaad, J., Khayat, K. H. & Daczko, J. 2004. Evaluation of Static Stability of Self-Consolidating Concrete. *ACI Materials Journal,* 101**,** 207-215.

ASTM 490/C490M 2012. *Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete.* West Conshohocken, Pennsylvania; .

ASTM C39 2014. *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.*

ASTM C127 1993. *Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate.* American Society for Testing and Materials Philadelphia, PA.

ASTM C128 2004. *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate.* West Conshohocken, PA 19428-2959, United States.

ASTM C157/ C157M 2004. *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete.*

ASTM C469 2008. Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. *Section 04.02.* Washington.

ASTM C511 2005. *Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes.* Annual Book of ASTM Standards.

ASTM C596 2001. American Society for Testing and Materials. *Standard Test Method for Drying Shrinkage of Mortar Containing Hydraulic Cement.*

ASTM C618 2004. American Society for Testing and Materials,. *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete.*

ASTM C1012 2004. American Society for Testing and Materials,. *Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution.* West Conshohocken, PA 19428-2959, United States.

ASTM C1202 2010. American Society for Testing and Materials,. *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.*

ASTM C1611/C 1611M 2005. American Society for Testing and Materials,. *Standard Test Method for Slump Flow of Self-Consolidating Concrete.* US: ASTM Intemational.

ASTM C1679 2008. *Standard Practice for Measuring Hydration Kinetics of Hydraulic Cementitious Mixtures Using Isothermal Calorimetry, Annual Book of ASTM Standards.* West Conshohocken, PA 19428-2959, United States.

Atiş, C. D. 2002. Heat Evolution of High-Volume Fly Ash Concrete. *Cement and Concrete Research,* 32**,** 751-756.

Awal, A. A. & Hussin, M. W. 1997. The Effectiveness of Palm Oil Fuel Ash in Preventing Expansion Due to Alkali-Silica Reaction. *Cement and Concrete Composites,* 19**,** 367-372.

Awal, A. A. & Hussin, M. W. 2011. Effect of Palm Oil Fuel Ash in Controlling Heat of Hydration of Concrete. *Procedia Engineering,* 14**,** 2650-2657.

Awal, A. A. & Shehu, I. 2013. Evaluation of Heat of Hydration of Concrete Containing High Volume Palm Oil Fuel Ash. *Fuel,* 105**,** 728-731.

Azmi, A. E. 2008. *The Properties and Flexural Behaviour of Self Compacting Concrete Using Palm Oil Fuel Ash and Admixture.* Universiti Teknologi Malaysia, Faculty of Civil Engineering.

Bartos, P. J. & Yu, Z. Testing-Scc: Towards New European Standards for Fresh Scc. Proceedings of the First International Symposium on Design, Performance and Use of Self-Consolidating Concrete, Changsha, Hunan, Kina, 2005. 25-46.

Bassuoni, M. & Nehdi, M. 2009a. Durability of Self-Consolidating Concrete to Different Exposure Regimes of Sodium Sulfate Attack. *Materials and Structures,* 42**,** 1039-1057.

Bassuoni, M. & Nehdi, M. 2009b. Durability of Self-Consolidating Concrete to Sulfate Attack under Combined Cyclic Environments and Flexural Loading. *Cement and Concrete Research,* 39**,** 206-226.

Bazant, Z. P., Sener, S. & Kim, J.-K. 1987. Effect of Cracking on Drying Permeability and Diffusivity of Concrete. *ACI Materials Journal,* 84**,** 351-357.

Beigi, M. H., Berenjian, J., Omran, O. L., Nik, A. S. & Nikbin, I. M. 2013. An Experimental Survey on Combined Effects of Fibers and Nanosilica on the Mechanical, Rheological, and Durability Properties of Self-Compacting Concrete. *Materials & Design,* 50**,** 1019-1029.

Belkowitz, J. S., Belkowitz, W. B., Nawrocki, K. & Fisher, F. T. 2015. Impact of Nanosilica Size and Surface Area on Concrete Properties. *ACI Materials Journal,* 112.

Benaicha, M., Roguiez, X., Jalbaud, O., Burtschell, Y. & Alaoui, A. H. 2015. Influence of Silica Fume and Viscosity Modifying Agent on the Mechanical and Rheological Behavior of Self Compacting Concrete. *Construction and Building Materials,* 84**,** 103-110.

Berra, M., Carassiti, F., Mangialardi, T., Paolini, A. & Sebastiani, M. 2012. Effects of Nanosilica Addition on Workability and Compressive Strength of Portland Cement Pastes. *Construction and Building Materials,* 35**,** 666-675.

Bhatty, J. I. & Reid, K. J. 1985. Use of Thermal Analysis in the Hydration Studies of a Type 1 Portland Cement Produced from Mineral Tailings. *Thermochimica Acta,* 91**,** 95-105.

BIBM, C. & ERMCO, E. 2005. Efnarc. *The European Guidelines for Self-Compacting Concrete: Specification, Production and Use, The Self-Compacting Concrete European Project Group.*

Bid, S. & Pradhan, S. 2002. Preparation and Microstructure Characterization of Ball-Milled Zro2 Powder by the Rietveld Method: Monoclinic to Cubic Phase Transformation without Any Additive. *Journal of Applied Crystallography,* 35**,** 517-525.

Björnström, J., Martinelli, A., Matic, A., Börjesson, L. & Panas, I. 2004. Accelerating Effects of Colloidal Nano-Silica for Beneficial Calcium–Silicate–Hydrate Formation in Cement. *Chemical Physics Letters,* 392**,** 242-248.

Boukendakdji, O., Kadri, E.-H. & Kenai, S. 2012. Effects of Granulated Blast Furnace Slag and Superplasticizer Type on the Fresh Properties and Compressive Strength of Self-Compacting Concrete. *Cement and Concrete Composites,* 34**,** 583-590.

Bouzoubaa, N. & Lachemi, M. 2001. Self-Compacting Concrete Incorporating High Volumes of Class F Fly Ash: Preliminary Results. *Cement and Concrete Research,* 31**,** 413-420.

Brandt, A. M. 2009. Cement Based Composites. *Europe,* 10**,** 29.20.

Brooks, J. & Johari, M. M. 2001a. Effect of Metakaolin on Creep and Shrinkage of Concrete. *Cement and Concrete Composites,* 23**,** 495-502.

Brooks, J. & Johari, M. M. 2001b. Long-Term Deformations of High-Strength Concrete Containing Silica Fume and Metakaolin. *Special Publication,* 200**,** 97-112.

Chandara, C., Azizli, K. A. M., Ahmad, Z. A., Hashim, S. F. S. & Sakai, E. 2012. Heat of Hydration of Blended Cement Containing Treated Ground Palm Oil Fuel Ash. *Construction and Building Materials,* 27**,** 78-81.

Cheng, A., Huang, R., Wu, J.-K. & Chen, C.-H. 2005. Influence of Ggbs on Durability and Corrosion Behavior of Reinforced Concrete. *Materials Chemistry and Physics,* 93**,** 404-411.

Chindaprasirt, P., Homwuttiwong, S. & Jaturapitakkul, C. 2007a. Strength and Water Permeability of Concrete Containing Palm Oil Fuel Ash and Rice Husk–Bark Ash. *Construction and Building Materials,* 21**,** 1492-1499.

Chindaprasirt, P., Jaturapitakkul, C. & Sinsiri, T. 2005. Effect of Fly Ash Fineness on Compressive Strength and Pore Size of Blended Cement Paste. *Cement and Concrete Composites,* 27**,** 425-428.

Chindaprasirt, P., Jaturapitakkul, C. & Sinsiri, T. 2007b. Effect of Fly Ash Fineness on Microstructure of Blended Cement Paste. *Construction and Building Materials,* 21**,** 1534-1541.

Chindaprasirt, P., Rukzon, S. & Sirivivatnanon, V. 2008. Resistance to Chloride Penetration of Blended Portland Cement Mortar Containing Palm Oil Fuel Ash, Rice Husk Ash and Fly Ash. *Construction and Building Materials,* 22**,** 932-938.

Chopra, D. & Siddique, R. 2015. Strength, Permeability and Microstructure of Self-Compacting Concrete Containing Rice Husk Ash. *Biosystems Engineering,* 130**,** 72-80.

Collepardi, M., Olagot, J. O., Skarp, U. & Troli, R. Influence of Amorphous Colloidal Silica on the Properties of Self-Compacting Concretes. Proceedings of the International Conference in Concrete Constructions, 2002. 473-483.

Danner, T., Justnes, H., Geiker, M. & Lauten, R. A. 2015. Phase Changes During the Early Hydration of Portland Cement with Ca-Lignosulfonates. *Cement and Concrete Research,* 69**,** 50-60.

Dehn, F., Holschemacher, K. & Weiße, D. 2000. Self-Compacting Concrete (Scc) Time Development of the Material Properties and the Bond Behaviour. *Selbstverdichtendem Beton*.

Detwiler, R. J., Bhatty, J. I. & Battacharja, S. 1996. *Supplementary Cementing Materials for Use in Blended Cements*.

Dinakar, P., Reddy, M. K. & Sharma, M. 2013. Behaviour of Self Compacting Concrete Using Portland Pozzolana Cement with Different Levels of Fly Ash. *Materials & Design,* 46**,** 609-616.

Domone, P. 2007. A Review of the Hardened Mechanical Properties of Self-Compacting Concrete. *Cement and Concrete Composites,* 29**,** 1-12.

Farzadnia, N., Abdullah Abang, A. A. & Ramazan, D. Development of Nanotechnology in High Performance Concrete. Advanced Materials Research, 2012. Trans Tech Publ, 115-118.

Farzadnia, N., Ali, A. A. A., Demirboga, R. & Anwar, M. P. 2013. Characterization of High Strength Mortars with Nano Titania at Elevated Temperatures. *Construction and Building Materials,* 43**,** 469-479.

Farzadnia, N., Noorvand, H., Yasin, A. M. & Aziz, F. N. A. 2015. The Effect of Nano Silica on Short Term Drying Shrinkage of Pofa Cement Mortars. *Construction and Building Materials,* 95**,** 636-646.

Felekoglu, B. 2007. Utilisation of High Volumes of Limestone Quarry Wastes in Concrete Industry (Self-Compacting Concrete Case). *Resources, Conservation and Recycling,* 51**,** 770-791.

Feys, D., Verhoeven, R. & De Schutter, G. 2007. Evaluation of Time Independent Rheological Models Applicable to Fresh Self-Compacting Concrete. *Applied Rheology,* 17**,** 56244-57190.

Gesoğlu, M., Güneyisi, E. & Özbay, E. 2009. Properties of Self-Compacting Concretes Made with Binary, Ternary, and Quaternary Cementitious Blends of Fly Ash, Blast Furnace Slag, and Silica Fume. *Construction and Building Materials,* 23**,** 1847-1854.

Ghafari, E., Costa, H., Júlio, E., Portugal, A. & Durães, L. 2014. The Effect of Nanosilica Addition on Flowability, Strength and Transport Properties of Ultra High Performance Concrete. *Materials & Design,* 59**,** 1-9.

Givi, A. N., Rashid, S. A., Aziz, F. N. A. & Salleh, M. A. M. 2010. Experimental Investigation of the Size Effects of Sio_2 Nano-Particles on the Mechanical Properties of Binary Blended Concrete. *Composites Part B: Engineering,* 41**,** 673-677.

Givi, A. N., Rashid, S. A., Aziz, F. N. A. & Salleh, M. A. M. 2011. The Effects of Lime Solution on the Properties of Sio_2 Nanoparticles Binary Blended Concrete. *Composites Part B: Engineering,* 42**,** 562-569.

Global palm oil production. 2015. http://www.globalpalmoilproduction.com/previous-year.asp.

Golop, R. & Taylor, H. 1995. Microstructural and Microanalytical Studies of Sulfate Attack, Iii. Sulfate Resisting Portland Cement: Reaction with Sodium and Magnesium Sulphate Solutions. *Cement and Concrete Research,* 25**,** 1581-1590.

Gomes, P. C., Gettu, R., Agullo, L. & Bernad, C. Experimental Optimization of High-Strength Self-Compacting Concrete. Proceedings of Second International Symposium on SCC, Kochi, 2001. 377-386.

Gonzalez, M. & Irassar, E. 1997. Ettringite Formation in Low C 3 a Portland Cement Exposed to Sodium Sulfate Solution. *Cement and Concrete Research,* 27**,** 1061-1072.

Gopalan, M. 1993. Nucleation and Pozzolanic Factors in Strength Development of Class Fly Ash Concrete. *Materials Journal,* 90**,** 117-121.

Güneyisi, E., Gesoglu, M., Al-Goody, A. & İpek, S. 2015. Fresh and Rheological Behavior of Nano-Silica and Fly Ash Blended Self-Compacting Concrete. *Construction and Building Materials,* 95**,** 29-44.

Han, F., Liu, R., Wang, D. & Yan, P. 2014. Characteristics of the Hydration Heat Evolution of Composite Binder at Different Hydrating Temperature. *Thermochimica Acta,* 586**,** 52-57.

Han, L.-H. & Yao, G.-H. 2004. Experimental Behaviour of Thin-Walled Hollow Structural Steel (Hss) Columns Filled with Self-Consolidating Concrete (Scc). *Thin-Walled Structures,* 42**,** 1357-1377.

Hassan, A. A., Lachemi, M. & Hossain, K. M. 2012. Effect of Metakaolin and Silica Fume on the Durability of Self-Consolidating Concrete. *Cement and Concrete Composites,* 34**,** 801-807.

Hill, R. & Howard, C. 1987. Quantitative Phase Analysis from Neutron Powder Diffraction Data Using the Rietveld Method. *Journal of Applied Crystallography,* 20**,** 467-474.

Hobbs, D. & Taylor, M. 2000. Nature of the Thaumasite Sulfate Attack Mechanism in Field Concrete. *Cement and Concrete Research,* 30**,** 529-533.

Horta, A. 2005. Evaluation of Self-Consolidating Concrete for Bridge Structure Applications.

Hou, P., Kawashima, S., Kong, D., Corr, D. J., Qian, J. & Shah, S. P. 2013. Modification Effects of Colloidal Nanosio 2 on Cement Hydration and Its Gel Property. *Composites Part B: Engineering,* 45**,** 440-448.

Hou, P., Wang, K., Qian, J., Kawashima, S., Kong, D. & Shah, S. P. 2012. Effects of Colloidal Nanosio2 on Fly Ash Hydration. *Cement and Concrete Composites,* 34**,** 1095-1103.

Huntzinger, D. N. & Eatmon, T. D. 2009. A Life-Cycle Assessment of Portland Cement Manufacturing: Comparing the Traditional Process with Alternative Technologies. *Journal of Cleaner Production,* 17**,** 668-675.

Ibrahim, R. K., Hamid, R. & Taha, M. R. 2012. Fire Resistance of High-Volume Fly Ash Mortars with Nanosilica Addition. *Construction and Building Materials,* 36**,** 779-786.

Irassar, E. 2002. Sulphate Attack and Sulphate Resistant Cements. *Advances in Cement Technology: Chemistry, Manufacture and Testing, Thec Book Int., India***,** 595-629.

Irassar, E. 2009. Sulfate Attack on Cementitious Materials Containing Limestone Filler—a Review. *Cement and Concrete Research,* 39**,** 241-254.

Isaia, G. C., GASTALDInI, A. L. G. & Moraes, R. 2003. Physical and Pozzolanic Action of Mineral Additions on the Mechanical Strength of High-Performance Concrete. *Cement and Concrete Composites,* 25**,** 69-76.

Ismail, M., Ismail, M. E. & Muhammad, B. 2011. Influence of Elevated Temperatures on Physical and Compressive Strength Properties of Concrete Containing Palm Oil Fuel Ash. *Construction and Building Materials,* 25**,** 2358-2364.

Itim, A., Ezziane, K. & Kadri, E.-H. 2011. Compressive Strength and Shrinkage of Mortar Containing Various Amounts of Mineral Additions. *Construction and Building Materials,* 25**,** 3603-3609.

Jalal, M., Fathi, M. & Farzad, M. 2013. Effects of Fly Ash and Tio_2 Nanoparticles on Rheological, Mechanical, Microstructural and Thermal Properties of High Strength Self Compacting Concrete. *Mechanics of Materials,* 61**,** 11-27.

Jalal, M., Mansouri, E., Sharifipour, M. & Pouladkhan, A. R. 2012. Mechanical, Rheological, Durability and Microstructural Properties of High Performance Self-Compacting Concrete Containing Sio_2 Micro and Nanoparticles. *Materials & Design,* 34**,** 389-400.

Jalal, M., Pouladkhan, A., Harandi, O. F. & Jafari, D. 2015. Comparative Study on Effects of Class F Fly Ash, Nano Silica and Silica Fume on Properties of High Performance Self Compacting Concrete. *Construction and Building Materials,* 94**,** 90-104.

Jaturapitakkul, C., Kiattikomol, K., Tangchirapat, W. & Saeting, T. 2007. Evaluation of the Sulfate Resistance of Concrete Containing Palm Oil Fuel Ash. *Construction and Building Materials,* 21**,** 1399-1405.

Jaturapitakkul, C., Tangpagasit, J., Songmue, S. & Kiattikomol, K. 2011. Filler Effect and Pozzolanic Reaction of Ground Palm Oil Fuel Ash. *Construction and Building Materials,* 25**,** 4287-4293.

Ji, T. 2005. Preliminary Study on the Water Permeability and Microstructure of Concrete Incorporating Nano-Sio 2. *Cement and Concrete Research,* 35**,** 1943-1947.

Jiang, G., Rong, Z. & Sun, W. 2015. Effects of Metakaolin on Mechanical Properties, Pore Structure and Hydration Heat of Mortars at 0.17 W/B Ratio. *Construction and Building Materials,* 93**,** 564-572.

Jo, B.-W., Kim, C.-H., Tae, G.-h. & Park, J.-B. 2007. Characteristics of Cement Mortar with Nano-Sio 2 Particles. *Construction and Building Materials,* 21**,** 1351-1355.

Johari, M. M., Zeyad, A., Bunnori, N. M. & Ariffin, K. 2012. Engineering and Transport Properties of High-Strength Green Concrete Containing High Volume of Ultrafine Palm Oil Fuel Ash. *Construction and Building Materials,* 30**,** 281-288.

Kanellopoulos, A., Petrou, M. F. & Ioannou, I. 2012. Durability Performance of Self-Compacting Concrete. *Construction and Building Materials,* 37**,** 320-325.

Kannan, V. & Ganesan, K. 2014. Chloride and Chemical Resistance of Self Compacting Concrete Containing Rice Husk Ash and Metakaolin. *Construction and Building Materials,* 51**,** 225-234.

Kashima, S., Kanazawa, K., Okada, R. & Yoshikawa, S. Application of Self-Compacting Concrete Made with Low-Heat Cement for Bridge Substructures of Honshu-Shikoku Bridge Authority. Proceedings of the International Workshop on Self-Compacting Concrete, 1999. 255-261.

Khatib, J. M. 2008. Performance of Self-Compacting Concrete Containing Fly Ash. *Construction and Building Materials,* 22**,** 1963-1971.

Khayat, K. H. & Feys, D. 2010. *Design, Production and Placement of Self-Consolidating Concrete: Proceedings of Scc2010, Montreal, Canada, September 26-29, 2010*, Springer Science & Business Media.

Khayat, K. H. & Guizani, Z. 1997. Use of Viscosity-Modifying Admixture to Enhance Stability of Fluid Concrete. *ACI Materials Journal,* 94**,** 332-340.

Kim, J.-K. & Lee, C.-S. 1998. Prediction of Differential Drying Shrinkage in Concrete. *Cement and Concrete Research,* 28**,** 985-994.

Klimesch, D. S. & Ray, A. 1996. The Use of Dta/Tga to Study the Effects of Ground Quartz with Different Surface Areas in Autoclaved Cement: Quartz Pastes. Part 1: A Method for Evaluating Dta/Tga Results. *Thermochimica Acta,* 289**,** 41-54.

Kong, D., Su, Y., Du, X., Yang, Y., Wei, S. & Shah, S. P. 2013. Influence of Nano-Silica Agglomeration on Fresh Properties of Cement Pastes. *Construction and Building Materials,* 43**,** 557-562.

Kontoleontos, F., Tsakiridis, P., Marinos, A., Kaloidas, V. & Katsioti, M. 2012. Influence of Colloidal Nanosilica on Ultrafine Cement Hydration: Physicochemical and Microstructural Characterization. *Construction and Building Materials,* 35**,** 347-360.

Kroehong, W., Sinsiri, T. & Jaturapitakkul, C. 2011a. Effect of Palm Oil Fuel Ash Fineness on Packing Effect and Pozzolanic Reaction of Blended Cement Paste. *Procedia Engineering,* 14**,** 361-369.

Kroehong, W., Sinsiri, T., Jaturapitakkul, C. & Chindaprasirt, P. 2011b. Effect of Palm Oil Fuel Ash Fineness on the Microstructure of Blended Cement Paste. *Construction and Building Materials,* 25**,** 4095-4104.

Kronlöf, A., Leivo, M. & Sipari, P. 1995. Experimental Study on the Basic Phenomena of Shrinkage and Cracking of Fresh Mortar. *Cement and Concrete Research,* 25**,** 1747-1754.

Kumar, M., Singh, S. K. & Singh, N. 2012. Heat Evolution During the Hydration of Portland Cement in the Presence of Fly Ash, Calcium Hydroxide and Super Plasticizer. *Thermochimica Acta,* 548**,** 27-32.

Lachemi, M., Hossain, K., Lambros, V., Nkinamubanzi, P.-C. & Bouzoubaa, N. 2004. Performance of New Viscosity Modifying Admixtures in Enhancing the Rheological Properties of Cement Paste. *Cement and Concrete Research,* 34**,** 185-193.

Land, G. & Stephan, D. 2012. The Influence of Nano-Silica on the Hydration of Ordinary Portland Cement. *Journal of Materials Science,* 47**,** 1011-1017.

Langan, B., Weng, K. & Ward, M. 2002. Effect of Silica Fume and Fly Ash on Heat of Hydration of Portland Cement. *Cement and Concrete Research,* 32**,** 1045-1051.

Latifi, M., Guefrech, A., Mounanga, P. & Khelidj, A. 2011. Experimental Study of the Effect of Addition of Nano-Silica on the Behaviour of Cement Mortars. *Procedia Engineering,* 10**,** 900-905.

Łaźniewska-Piekarczyk, B. 2012. The Influence of Selected New Generation Admixtures on the Workability, Air-Voids Parameters and Frost-Resistance of Self Compacting Concrete. *Construction and Building Materials,* 31**,** 310-319.

Leemann, A., Münch, B., Gasser, P. & Holzer, L. 2006. Influence of Compaction on the Interfacial Transition Zone and the Permeability of Concrete. *Cement and Concrete Research,* 36**,** 1425-1433.

Leemann, A. & Winnefeld, F. 2007. The Effect of Viscosity Modifying Agents on Mortar and Concrete. *Cement and Concrete Composites,* 29**,** 341-349.

Li, G. 2004. Properties of High-Volume Fly Ash Concrete Incorporating Nano-Sio 2. *Cement and Concrete research,* 34**,** 1043-1049.

Libre, N. A., Khoshnazar, R. & Shekarchi, M. 2010. Relationship between Fluidity and Stability of Self-Consolidating Mortar Incorporating Chemical and Mineral Admixtures. *Construction and Building Materials,* 24**,** 1262-1271.

Lim, S. K., Tan, C. S., Lim, O. Y. & Lee, Y. L. 2013. Fresh and Hardened Properties of Lightweight Foamed Concrete with Palm Oil Fuel Ash as Filler. *Construction and Building Materials,* 46**,** 39-47.

Long, G., Gao, Y. & Xie, Y. 2015. Designing More Sustainable and Greener Self-Compacting Concrete. *Construction and Building Materials,* 84**,** 301-306.

Lothenbach, B., Scrivener, K. & Hooton, R. 2011. Supplementary Cementitious Materials. *Cement and Concrete Research,* 41**,** 1244-1256.

Lutterotti, L., Matthies, S., Wenk, H.-R., Schultz, A. & Richardson Jr, J. 1997. Combined Texture and Structure Analysis of Deformed Limestone from Time-of-Flight Neutron Diffraction Spectra. *Journal of Applied Physics,* 81**,** 594-600.

Madandoust, R., Mohseni, E., Mousavi, S. Y. & Namnevis, M. 2015. An Experimental Investigation on the Durability of Self-Compacting Mortar Containing Nano-Sio_2, Nano-Fe_2o_3 and Nano-Cuo. *Construction and Building Materials,* 86**,** 44-50.

Madandoust, R. & Mousavi, S. Y. 2012. Fresh and Hardened Properties of Self-Compacting Concrete Containing Metakaolin. *Construction and Building Materials,* 35**,** 752-760.

Madandoust, R., Ranjbar, M. M. & Mousavi, S. Y. 2011. An Investigation on the Fresh Properties of Self-Compacted Lightweight Concrete Containing Expanded Polystyrene. *Construction and Building Materials,* 25**,** 3721-3731.

Malaysian Palm Oil Board, M. 2015. *Economic and Statistic* [Online]. Available: http://econ.mpob.gov.my/economy/annual.

Malhotra, V. M. & Mehta, P. K. 1996. *Pozzolanic and Cementitious Materials*, Taylor & Francis.

Mardani-Aghabaglou, A., Tuyan, M., Yılmaz, G., Arıöz, Ö. & Ramyar, K. 2013. Effect of Different Types of Superplasticizer on Fresh, Rheological and Strength

Properties of Self-Consolidating Concrete. *Construction and Building Materials,* 47**,** 1020-1025.

Mazzotti, C. & Ceccoli, C. Creep and Shrinkage of Self Compacting Concrete: Experimental Behavior and Numerical Model. Proc. of the Eighth International Conference on Creep, Shrinkage, and Durability of Concrete and Concrete Structures, 2008. 667-673.

Mehta, P. K. 1999. Advancements in Concrete Technology. *Concrete International-Detroit-,* 21**,** 69-76.

Mehta, P. K. 2002. Greeningof the Concrete Industry for Sustainable Development. *Concrete international,* 23.

Mehta, P. K. & Monteiro, P. J. 2006a. Concrete–Microstructure, Properties, and Materials (International Editions 2006). McGraw-Hill Education (Asia), Taiwan.

Mehta, P. K. & Monteiro, P. J. 2006b. Concrete: Microstructure, Properties, and Materials, Vol. 3mcgraw-Hill. *New York*.

Memon, S. A., Shaikh, M. A. & Akbar, H. 2011. Utilization of Rice Husk Ash as Viscosity Modifying Agent in Self Compacting Concrete. *Construction and building materials,* 25**,** 1044-1048.

Mitchell, D., Hinczak, I. & Day, R. 1998. Interaction of Silica Fume with Calcium Hydroxide Solutions and Hydrated Cement Pastes. *Cement and Concrete Research,* 28**,** 1571-1584.

Mohamed, H. A. 2011. Effect of Fly Ash and Silica Fume on Compressive Strength of Self-Compacting Concrete under Different Curing Conditions. *Ain Shams Engineering Journal,* 2**,** 79-86.

Mohammadi, M., Hesaraki, S. & Hafezi-Ardakani, M. 2014. Investigation of Biocompatible Nanosized Materials for Development of Strong Calcium Phosphate Bone Cement: Comparison of Nano-Titania, Nano-Silicon Carbide and Amorphous Nano-Silica. *Ceramics International,* 40**,** 8377-8387.

Mohseni, E., Miyandehi, B. M., Yang, J. & Yazdi, M. A. 2015. Single and Combined Effects of Nano-Sio 2, Nano-Al 2 O 3 and Nano-Tio 2 on the Mechanical, Rheological and Durability Properties of Self-Compacting Mortar Containing Fly Ash. *Construction and Building Materials,* 84**,** 331-340.

Moslemi, A. M., Khosravi, A., Izadinia, M. & Heydari, M. Application of Nano Silica in Concrete for Enhanced Resistance against Sulfate Attack. Advanced Materials Research, 2014. Trans Tech Publ, 874-878.

Nagaratnam, B. H., Rahman, M. E., Mirasa, A. K., Mannan, M. A. & Lame, S. O. 2016. Workability and Heat of Hydration of Self-Compacting Concrete

Incorporating Agro-Industrial Waste. *Journal of Cleaner Production,* 112**,** 882-894.

Naik, T., Singh, S. & Hossain, M. 1993. Abrasion Resistance of High-Volume Fly Ash Concrete Systems. *A Final Progress Prepared for EPRI, CBU Report*.

Nath, P. & Sarker, P. 2011. Effect of Fly Ash on the Durability Properties of High Strength Concrete. *Procedia Engineering,* 14**,** 1149-1156.

Nazari, A. & Riahi, S. 2011a. The Effects of Sio 2 Nanoparticles on Physical and Mechanical Properties of High Strength Compacting Concrete. *Composites Part B: Engineering,* 42**,** 570-578.

Nazari, A. & Riahi, S. 2011b. Splitting Tensile Strength of Concrete Using Ground Granulated Blast Furnace Slag and Sio 2 Nanoparticles as Binder. *Energy and Buildings,* 43**,** 864-872.

Nehdi, M. & Bassuoni, M. 2008. Durability of Self-Consolidating Concrete to Combined Effects of Sulphate Attack and Frost Action. *Materials and structures,* 41**,** 1657-1679.

Nehdi, M., Pardhan, M. & Koshowski, S. 2004. Durability of Self-Consolidating Concrete Incorporating High-Volume Replacement Composite Cements. *Cement and Concrete Research,* 34**,** 2103-2112.

Noorvand, H., Ali, A. A. A., Demirboga, R., Noorvand, H. & Farzadnia, N. 2013. Physical and Chemical Characteristics of Unground Palm Oil Fuel Ash Cement Mortars with Nanosilica. *Construction and Building Materials,* 48**,** 1104-1113.

Okamura, H. & Ouchi, M. 1998. Self-Compacting High Performance Concrete. *Progress in structural Engineering and Materials,* 1**,** 378-383.

Okamura, H. & Ozawa, K. Mix Design Method for Self-Compactable Concrete. Proceedings-Japan Society Of Civil Engineers, 1994. Dotoku Gakkai, 1-1.

Ozbay, E., Oztas, A., Baykasoglu, A. & Ozbebek, H. 2009. Investigating Mix Proportions of High Strength Self Compacting Concrete by Using Taguchi Method. *Construction and Building materials,* 23**,** 694-702.

Page, C., Short, N. & El Tarras, A. 1981. Diffusion of Chloride Ions in Hardened Cement Pastes. *Cement and Concrete Research,* 11**,** 395-406.

Panesar, D. & Shindman, B. 2012. The Effect of Segregation on Transport and Durability Properties of Self Consolidating Concrete. *Cement and Concrete Research,* 42**,** 252-264.

Pentti, G. H.-E. P. Properties of Scc-Especially Early Age and Long Term Shrinkage and Salt Frost Resistance. Proceedings of the 1 st International Rilem

Symposium on Self-compacting Concrete, Stockholm, Sweden. Rilem, Bagneux, France, 1999. 211-225.

Persson, B. 2001. A Comparison between Mechanical Properties of Self-Compacting Concrete and the Corresponding Properties of Normal Concrete. *Cement and Concrete Research,* 31**,** 193-198.

Petersson, O. & Billberg, P. Investigation on Blocking of Self-Compacting Concrete with Different Maximum Aggregate Size and Use of Viscosity Agent Instead of Filler. Proceedings of the First International RILEM Symposium Self-Compacting Concrete, Stockholm, Sweden, 1999. 333-344.

Petit, J.-Y., Wirquin, E. & Helnan-Moussa, B. 2011. Effect of W/C and Superplasticizer Type on Rheological Parameters of Scc Repair Mortar for Gravitational or Light Pressure Injection. *Cement and Concrete Composites,* 33**,** 1050-1056.

Pierre-Claude, C. A. 1990. Principles Underlying Production of High-Performance Concrete. *Cement, Concrete and Aggregates,* 12**,** 70-78.

Pierre-Claver, N. & Pierre-Claude, A. 2004. Cement and Superplasticizer Combinations: Compatibility and Robustness. *Cement, Concrete and Aggregates,* 26**,** 1-8.

Prakash, N. & Santhanam, M. 2006. A Study of the Interaction between Viscosity Modifying Agent and High Range Water Reducer in Self Compacting Concrete. *Measuring, Monitoring and Modeling Concrete Properties.* Springer.

Qing, Y., Zenan, Z., Deyu, K. & Rongshen, C. 2007. Influence of Nano-Sio 2 Addition on Properties of Hardened Cement Paste as Compared with Silica Fume. *Construction and building materials,* 21**,** 539-545.

Quercia, G., Hüsken, G. & Brouwers, H. 2012. Water Demand of Amorphous Nano Silica and Its Impact on the Workability of Cement Paste. *Cement and Concrete Research,* 42**,** 344-357.

Raghavan, K., Sarma, S. & Chattopadhyay, D. Creep, Shrinkage and Chloride Permeability Properties of Self-Consolidating Concrete. First North American Conference on the Design and Use of Self-Consolidating Concrete 12-13 November 2002, 2003. 307-312.

Rahman, M. E., Muntohar, A. S., Pakrashi, V., Nagaratnam, B. H. & Sujan, D. 2014. Self Compacting Concrete from Uncontrolled Burning of Rice Husk and Blended Fine Aggregate. *Materials & Design,* 55**,** 410-415.

Regourd, M., Hornain, H. & Mortureux, B. 1980. Microstructure of Concrete in Aggressive Environments. *Durability of Building Materials and Components.* ASTM International.

Rizwan, S. & Bier, T. A. High Performance Self-Compacting Mortars Containing Pozzolanic Powders. BMC-8, The Eight International Symposium on Brittle Matrix Composites, 2006. 23-25.

Rols, S., Ambroise, J. & Pera, J. 1999. Effects of Different Viscosity Agents on the Properties of Self-Leveling Concrete. *Cement and Concrete Research,* 29**,** 261-266.

Roy, D. M. 1999. Alkali-Activated Cements Opportunities and Challenges. *Cement and Concrete Research,* 29**,** 249-254.

Rozière, E., Granger, S., Turcry, P. & Loukili, A. 2007. Influence of Paste Volume on Shrinkage Cracking and Fracture Properties of Self-Compacting Concrete. *Cement and concrete composites,* 29**,** 626-636.

Sabet, F. A., Libre, N. A. & Shekarchi, M. 2013. Mechanical and Durability Properties of Self Consolidating High Performance Concrete Incorporating Natural Zeolite, Silica Fume and Fly Ash. *Construction and Building Materials,* 44**,** 175-184.

Sabir, B., Wild, S. & Bai, J. 2001. Metakaolin and Calcined Clays as Pozzolans for Concrete: A Review. *Cement and Concrete Composites,* 23**,** 441-454.

Safiuddin, M., Abdus Salam, M. & Jumaat, M. Z. 2011. Utilization of Palm Oil Fuel Ash in Concrete: A Review. *Journal of Civil Engineering and Management,* 17**,** 234-247.

Safiuddin, M., Salam, M. A. & Jumaat, M. Z. 2013. Key Fresh Properties of Self-Consolidating High-Strength Pofa Concrete. *Journal of Materials in Civil Engineering,* 26**,** 134-142.

Safiuddin, M., West, J. & Soudki, K. 2012. Properties of Freshly Mixed Self-Consolidating Concretes Incorporating Rice Husk Ash as a Supplementary Cementing Material. *Construction and Building Materials,* 30**,** 833-842.

Şahmaran, M., Christianto, H. A. & Yaman, İ. Ö. 2006. The Effect of Chemical Admixtures and Mineral Additives on the Properties of Self-Compacting Mortars. *Cement and Concrete Composites,* 28**,** 432-440.

Said, A. M., Zeidan, M. S., Bassuoni, M. & Tian, Y. 2012. Properties of Concrete Incorporating Nano-Silica. *Construction and Building Materials,* 36**,** 838-844.

Sakai, E., Kasuga, T., Sugiyama, T., Asaga, K. & Daimon, M. 2006. Influence of Superplasticizers on the Hydration of Cement and the Pore Structure of Hardened Cement. *Cement and Concrete Research,* 36**,** 2049-2053.

Santhanam, M., Cohen, M. D. & Olek, J. 2001. Sulfate Attack Research—Whither Now? *Cement and Concrete Research,* 31**,** 845-851.

Sata, V., Jaturapitakkul, C. & Kiattikomol, K. 2004. Utilization of Palm Oil Fuel Ash in High-Strength Concrete. *Journal of Materials in Civil Engineering,* 16**,** 623-628.

Sata, V., Jaturapitakkul, C. & Kiattikomol, K. 2007. Influence of Pozzolan from Various by-Product Materials on Mechanical Properties of High-Strength Concrete. *Construction and Building Materials,* 21**,** 1589-1598.

Sata, V., Jaturapitakkul, C. & Rattanashotinunt, C. 2010. Compressive Strength and Heat Evolution of Concretes Containing Palm Oil Fuel Ash. *Journal of Materials in Civil Engineering,* 22**,** 1033-1038.

Schonlin, K. & Hilsorf, H. 1988. Permeability as a Measure of Potential Durability of Concrete--Development of a Suitable Test Apparatus. *Special Publication,* 108**,** 99-116.

Sedran, T., De Larrard, F., Hourst, F. & Contamines, C. Mix Design of Self-Compacting Concrete (Scc). RILEM Proceedings, 1996. 439-450.

Senff, L., Hotza, D., Repette, W. L., Ferreira, V. M. & Labrincha, J. A. 2010. Mortars with Nano-Sio 2 and Micro-Sio 2 Investigated by Experimental Design. *Construction and Building Materials,* 24**,** 1432-1437.

Senff, L., Labrincha, J. A., Ferreira, V. M., Hotza, D. & Repette, W. L. 2009. Effect of Nano-Silica on Rheology and Fresh Properties of Cement Pastes and Mortars. *Construction and Building Materials,* 23**,** 2487-2491.

Senhadji, Y., Escadeillas, G., Mouli, M. & Khelafi, H. 2014. Influence of Natural Pozzolan, Silica Fume and Limestone Fine on Strength, Acid Resistance and Microstructure of Mortar. *Powder Technology,* 254**,** 314-323.

Sha, W., O'Neill, E. & Guo, Z. 1999. Differential Scanning Calorimetry Study of Ordinary Portland Cement. *Cement and Concrete Research,* 29**,** 1487-1489.

Shaikh, F. U. A. & Supit, S. W. 2015. Chloride Induced Corrosion Durability of High Volume Fly Ash Concretes Containing Nano Particles. *Construction and Building Materials,* 99**,** 208-225.

Sheinn, A., Ho, D., Tam, C., Wallevik, O. & Nielsson, I. Effect of Particle Shape on Paste Rheology of Scc. International RILEM Symposium on Self-Compacting Concrete, 2003. RILEM Publications SARL, 232-239.

Shen, L., Jovein, H. B. & Li, M. 2014. Measuring Static Stability and Robustness of Self-Consolidating Concrete Using Modified Segregation Probe. *Construction and Building Materials,* 70**,** 210-216.

Shiqun, L., Della M, R. & Amithaba, K. 1985. Quantitative Determination of Pozzolans in Hydrated Systems of Cement or Ca (Oh) 2 with Fly Ash or Silica Fume. *Cement and Concrete Research,* 13**,** 1079-1086.

Siad, H., Lachemi, M., Bernard, S. K., Sahmaran, M. & Hossain, A. 2015. Assessment of the Long-Term Performance of Scc Incorporating Different Mineral Admixtures in a Magnesium Sulphate Environment. *Construction and Building Materials,* 80**,** 141-154.

Siddique, R. 2004. Performance Characteristics of High-Volume Class F Fly Ash Concrete. *Cement and Concrete Research,* 34**,** 487-493.

Skarendahl, A. & Petersson, Ö. 2000. State-of-the-Art Report of Rilem Technical Committee 174-Scc, Self-Compacting Concrete. *SARL, Paris: RILEM Publ***,** 17-22.

Sobolev, K., Flores, I., Hermosillo, R. & Torres-Martínez, L. M. 2006. Nanomaterials and Nanotechnology for High-Performance Cement Composites. *Proceedings of ACI Session on Nanotechnology of Concrete: Recent Developments and Future Perspectives***,** 91-118.

Sobolev, K., Flores, I., Torres-Martinez, L., Valdez, P., Zarazua, E. & Cuellar, E. 2009. Engineering of Sio2 Nanoparticles for Optimal Performance in Nano Cement-Based Materials. *Nanotechnology in Construction 3.* Springer.

Sonebi, M. 2004. Medium Strength Self-Compacting Concrete Containing Fly Ash: Modelling Using Factorial Experimental Plans. *Cement and Concrete research,* 34**,** 1199-1208.

Sonebi, M. & Bartos, P. 2002. Filling Ability and Plastic Settlement of Self-Compacting Concrete. *Materials and Structures,* 35**,** 462-469.

Su, N., Hsu, K.-C. & Chai, H.-W. 2001. A Simple Mix Design Method for Self-Compacting Concrete. *Cement and Concrete Research,* 31**,** 1799-1807.

Sukumar, B., Nagamani, K. & Srinivasa Raghavan, R. 2008. Evaluation of Strength at Early Ages of Self-Compacting Concrete with High Volume Fly Ash. *Construction and Building Materials,* 22**,** 1394-1401.

Tangchirapat, W. & Jaturapitakkul, C. 2010. Strength, Drying Shrinkage, and Water Permeability of Concrete Incorporating Ground Palm Oil Fuel Ash. *Cement and Concrete Composites,* 32**,** 767-774.

Tangchirapat, W., Jaturapitakkul, C. & Chindaprasirt, P. 2009a. Use of Palm Oil Fuel Ash as a Supplementary Cementitious Material for Producing High-Strength Concrete. *Construction and Building Materials,* 23**,** 2641-2646.

Tangchirapat, W., Jaturapitakkul, C. & Kiattikomol, K. 2009b. Compressive Strength and Expansion of Blended Cement Mortar Containing Palm Oil Fuel Ash. *Journal of Materials in Civil Engineering,* 21**,** 426-431.

Tangchirapat, W., Khamklai, S. & Jaturapitakkul, C. 2012. Use of Ground Palm Oil Fuel Ash to Improve Strength, Sulfate Resistance, and Water Permeability of

Concrete Containing High Amount of Recycled Concrete Aggregates. *Materials & Design,* 41**,** 150-157.

Tangchirapat, W., Saeting, T., Jaturapitakkul, C., Kiattikomol, K. & Siripanichgorn, A. 2007. Use of Waste Ash from Palm Oil Industry in Concrete. *Waste Management,* 27**,** 81-88.

Tay, J. H. 1990. Ash from Oil-Palm Waste as a Concrete Material. *Journal of Materials in Civil Engineering,* 2**,** 94-105.

Taylor, H. F. 1997. *Cement Chemistry,* Thomas Telford.

Tobón, J., Payá, J., Borrachero, M. & Restrepo, O. 2012. Mineralogical Evolution of Portland Cement Blended with Silica Nanoparticles and Its Effect on Mechanical Strength. *Construction and Building Materials,* 36**,** 736-742.

Tongaroonsri, S. & Tangtermsirikul, S. 2009. Effect of Mineral Admixtures and Curing Periods on Shrinkage and Cracking Age under Restrained Condition. *Construction and Building Materials,* 23**,** 1050-1056.

Tragardh, J. Microstructural Features and Related Properties of Self-Compacting Concrete. Self-Compacting Concrete: Proceedings of the First International RILEM Symposium held in Stockholm, Sweden 13-14 September 1999, 1999. 175-186.

Türker, F., Aköz, F., Koral, S. & Yüzer, N. 1997. Effects of Magnesium Sulfate Concentration on the Sulfate Resistance of Mortars with and without Silica Fume. *Cement and concrete research,* 27**,** 205-214.

Uysal, M. & Sumer, M. 2011. Performance of Self-Compacting Concrete Containing Different Mineral Admixtures. *Construction and Building materials,* 25**,** 4112-4120.

Uysal, M., Yilmaz, K. & Ipek, M. 2012. The Effect of Mineral Admixtures on Mechanical Properties, Chloride Ion Permeability and Impermeability of Self-Compacting Concrete. *Construction and Building Materials,* 27**,** 263-270.

Valcuende, M., Marco, E., Parra, C. & Serna, P. 2012. Influence of Limestone Filler and Viscosity-Modifying Admixture on the Shrinkage of Self-Compacting Concrete. *Cement and Concrete Research,* 42**,** 583-592.

Van Tuan, N., Ye, G., Van Breugel, K. & Copuroglu, O. 2011. Hydration and Microstructure of Ultra High Performance Concrete Incorporating Rice Husk Ash. *Cement and Concrete Research,* 41**,** 1104-1111.

Vengala, J., Sudarshan, M. & Ranganath, R. 2003. Experimental Study for Obtaining Self-Compacting Concrete. *Indian concrete journal,* 77**,** 1261-1266.

Wild, S., Khatib, J. & Jones, A. 1996. Relative Strength, Pozzolanic Activity and Cement Hydration in Superplasticised Metakaolin Concrete. *Cement and Concrete Research,* 26**,** 1537-1544.

Xie, Y., Liu, B., Yin, J. & Zhou, S. 2002. Optimum Mix Parameters of High-Strength Self-Compacting Concrete with Ultrapulverized Fly Ash. *Cement and Concrete Research*, 32**,** 477-480.

Yahia, A., Tanimura, M. & Shimoyama, Y. 2005. Rheological Properties of Highly Flowable Mortar Containing Limestone Filler-Effect of Powder Content and W/C Ratio. *Cement and Concrete Research,* 35**,** 532-539.

Yu, P., Kirkpatrick, R. J., Poe, B., McMillan, P. F. & Cong, X. 1999. Structure of Calcium Silicate Hydrate (C-S-H): Near-, Mid-, and Far-Infrared Spectroscopy. *Journal of the American Ceramic Society,* 82**,** 742-748.

Zhang, M.-H. & Islam, J. 2012. Use of Nano-Silica to Reduce Setting Time and Increase Early Strength of Concretes with High Volumes of Fly Ash or Slag. *Construction and Building Materials*, 29**,** 573-580.

Zhang, M.-h. & Li, H. 2011. Pore Structure and Chloride Permeability of Concrete Containing Nano-Particles for Pavement. *Construction and Building Materials*, 25**,** 608-616.

Zhao, H., Sun, W., Wu, X. & Gao, B. 2015. The Properties of the Self-Compacting Concrete with Fly Ash and Ground Granulated Blast Furnace Slag Mineral Admixtures. *Journal of Cleaner Production,* 95**,** 66-74.

Zhu, W. & Bartos, P. J. 2003. Permeation Properties of Self-Compacting Concrete. *Cement and Concrete Research*, 33**,** 921-926.

Zyganitidis, I., Stefanidou, M., Kalfagiannis, N. & Logothetidis, S. 2011. Nanomechanical Characterization of Cement-Based Pastes Enriched with Sio 2 Nanoparticles. *Materials Science and Engineering: B,* 176**,** 1580-1584.