EFFECT OF POLYPROPYLENE FIBER ON THE PROPERTIES OF MORTAR CONTAINING SILICA FUME

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I hereby declare that all corrections and comments made by the supervisor(s) and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Satu kajian telah dijalankan bagi menentukan kesan penggunaan gentian polipropilena ke atas sifat-sifat mortar yang mengandungi wasap silika. Eksperimen ini terdiri daripada ujian mortar baru iaitu ujian meja aliran, serta mortar keras seperti kekuatan mampatan, kekuatan lenturan, halaju dedenyut ultrabunyi, keliangan, penyerapan air dan kebolehtelapan gas. Retak pengecutan plastik juga diuji dalam projek ini menggunakan acuan yang direka khas dan diperhatikan selepas 24 jam. Mortar gred 50 N/mm^2 digunakan dan diuji pada 7, 14 dan 28 hari. Wasap silika yang digunakan adalah 10% dan kandungan gentian polipropilena adalah 0.1%, 0.3% dan 0.5%. Bancuhan kawalan mengandungi wasap silika tanpa gentian polipropilena. Berdasarkan keputusan ujian mampatan, penambahan gentian tidak memberi kesan positif kepada kekuatan. Penambahan gentian kepada spesimen juga tidak menunjukkan kesan yang besar terhadap ujian lenturan. Struktur liang dan penyerapan air dalam spesimen meningkat disebabkan penambahan gentian polipropilena di dalam mortar. Kebolehtelapan dan keliangan mortar meningkat disebabkan peningkatan jumlah gentian dalam mortar tetapi menurun mengikut tempoh ujian yang berbeza. Kualiti spesimen terletak pada julat yang baik. Walau bagaimanapun, hasil gabungan 10% wasap silika dan 0.3% gentian polipropilena adalah campuran yang optimum.

ABSTRACT

An investigation has been performed to study the effect of polypropylene fiber on the properties of mortar containing silica fume. The experiment consists of testing of fresh mortar via flow table test, as well as hardened mortar such as compressive strength, flexural strength, ultrasonic pulse velocity (UPV), porosity, water absorption and gas permeability test. Plastic shrinkage cracking was also studied in this project using a specially fabricated mould and observed after 24 hours. Mortar sample with characteristic strength of 50 N/mm^2 was designed and tested at 7, 14 and 28 age days. Silica fume content used was 10% and polypropylene fiber volume fraction was 0.1%, 0.3% and 0.5%. The control mix was the mortar containing silica fume with no fiber. Based on the compressive strength result, the addition of fiber did not give positive impact on the compressive strength. The fiber addition also has no significant influence on the flexural strength of the mortars. The pore structure in the specimens increased due to the additional of fiber in the mortar. Permeability and porosity of the mortars increased due to the increase volume of fiber fraction but decreased with longer curing periods. The quality of specimens fall in the range of good quality. However, the combination of 10% of silica fume and 0.3% fiber results in optimum mixture design.

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LIST OF ABBREVIATIONS

GHG	**G**reen **H**ouse **G**ases
HPC	**H**igh **P**erformance **C**oncrete
SCM	**S**upplementary **C**ementitious **M**aterial
OPC	**O**rdinary **P**ortland Cement
SP	**S**uperplasticizer
SF	**S**ilica **F**ume
PPF	**P**olypropylene **F**iber
GGBS	**G**round **G**ranulated **B**last-Furnace **S**lag
ASTM	**A**merican **S**ociety for **T**esting and **M**aterials
ACI	**A**merican **C**oncrete **I**nstitute
UPV	**U**ltrasonic **P**ulse **V**elocity
PUNDIT	**P**ortable **U**ltrasonic **N**on-**D**estructive **I**ndicating **T**ester
BS	**B**ritish **S**tandard
BSI	**B**ritish **S**tandard **I**nstitute

CHAPTER 1

INTRODUCTION

1.1 General Introduction

According to the World Commission on Environment and Development of the United Nations, sustainability means "meeting the needs of the present without compromising the ability of the future generations to meet their own needs" (UNFCCC COP9 Rep., 2014). The sustainability of the cement and concrete industries is essential to the well-being of our planet and to human development (Naik, 2008).

However, the production of Portland cement, an essential constituent of concrete, leads to the release of significant amounts of CO_2, a greenhouse gas (GHG). The production of one ton of Portland cement produces about one ton of CO_2 and other GHGs. Presently, the annual worldwide concrete production is 12 billion tonnes, of which cement constitutes 1.6 billion tonnes. Production of 1 tonne of cement generates approximately 1 tonne of CO_2 with a requirement of 7,000 MJ of electrical power. Therefore, the concrete industry significantly impacts the ecology of the earth. The environmental issues associated with GHGs, in addition to natural resources issues, will play a leading role in the sustainable development of the cement and concrete industry during this century (Naik, 2008).

Portland cement is not considered as an environmentally friendly material, because its manufacture creates greenhouse gas emissions. Therefore, engineers must reduce the use of Portland cement in concrete (Malhotra, 2014). Supplementary cementitious materials (SCM) reduce the impact of cement through utilization of other waste stream products (Siddique and Kunal, 2016).

The use of SCM has significant environmental advantages in that it reduces energy usage and there are significant interests to utilize the waste products as a partial cement replacement, as in making the cement to be more sustainable and durable. Some examples are pozzolans, which are obtained as industrial by-products. When industrial by-products replace cement, even up to 70%, in concrete, the environmental impact improves along with the energy efficiency and durability of concrete (Naik et al., 2003). This is because plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking.

One of the examples of pozzolans which is obtained from industrial by-product is silica fume. Silica fume has been recognized as a pozzolanic admixture that is effective in enhancing the mechanical properties and improving the chemical durability of concrete (Siddique and Khan, 2011).

Silica fume was first used in shotcrete in Norway in the nineteen seventies where the country's rocky terrain facilitated the development of shotcrete tunnel lining (Wolsiefer and Morgan, 1993). It delivers greater economy with low costs, greater time savings and more efficient use of sprayed concrete. Silica fume has be used in a variety of cementitious repair products. Greater bonding strength assures of outstanding performance of both wet and dry process shotcreting with less rebound loss and thicker applications with each pass of the shotcrete nozzle (Rasol, 2015).

Silica fume has the ability to increase the surface adhesion of mortars or grouts. Silica fume significantly improves cohesiveness making it ideal for use in underwater grouts, decreases permeability in grouts used for post-tensioning applications and increases the resistance to aggressive chemicals (Rasol, 2015).

High Performance Concrete (HPC) containing silica fume; for bridges, parking decks, marine structures and bridge deck overlays which are subjected to constant deterioration caused by rebar corrosion current, abrasion and chemical attack problems (Rasol, 2015). Addition of silica fume to concrete improves its durability through reduction in the permeability and refined pore structure, leading to a reduction in the diffusion of harmful ions, reducing calcium hydroxide content, which results in a higher resistance to sulphate attack. Improvement in durability will also improve the ability of silica fume concrete in protecting the embedded steel from corrosion (King, 2012).

Internal micro cracks are inherently present in the poor quality concrete and its poor tensile strength is due to the propagation of such micro cracks, eventually leading to brittle fracture of the concrete (Damgir, 2011). Mortar containing silica fume increases the occurrence of plastic shrinkage cracking which takes place under tensile stress systems and hot weather condition.

Hence, silica fume shotcrete has been widely used in variety of construction often combined polypropylene fibers to control plastic shrinkage cracking. This will be the major reason for the growing interest in the performance of polypropylene fiber in cement based materials which is the desire to increase the toughness of the basic matrix. It is good to include polypropylene fibers which have a good tensile strength in mortar in order to improve the mechanical properties of the mortar. Polypropylene fibers have been widely used for the reinforcement of cementitious materials to improve the toughness and energy absorption capability of matrix (Sun et al., 2001). The combination of silica fume and polypropylene fiber is able to produce mortar with better mechanical performance.

1.2 Problem Statement

- Cement production results in the release of a significant greenhouse gaseous emission globally has increased in recent years that brings to the environmental issues.
- Utilization of supplementary cementitious materials (SCMs) such as silica fume taking toward sustainability to reduce cement consumption and produce more sustainable mortar and concrete.
- The fineness of silica fume are good indicators for assessing the potential for plastic shrinkage cracking under hot weather condition.
- Therefore, different percentage of polypropylene fiber have been used in this research as an effective way to improve the toughness and energy absorption of the mortar containing silica fume.

1.3 Objectives

The purpose of doing this research is to evaluate the effects of polypropylene fibers on the performance of mortar containing silica fume. The specific objectives of this research are:

1) To determine the effect of polypropylene fiber content on plastic shrinkage cracking characteristics of mortar containing silica fume.
2) To evaluate the strength development of mortar containing silica fume and polypropylene fiber.
3) To investigate the effect of polypropylene fiber on porosity and permeability of mortar containing silica fume.

1.4 Scope of Work

The main purpose of the research is to evaluate the effect polypropylene fibers on the performance of mortar containing silica fume on plastic shrinkage cracking characteristics, strength development as well as porosity and permeability. In order to achieve these objectives, four mortar mixes have been prepared. One is the control mix which is containing 10% of SF as a replacement by mass of OPC with another three mixes added different volume fractions of fiber, 0.1, 0.3 and 0.5% by weight of mortar.

Samples were tested after 7, 14 and 28 days of curing period. In the case of strength, mortar cubes (size 50 x 50 x 50 mm) were used to determine the compressive strength of the mortar. For flexural test, beams (size 70 x 70 x 300 mm) have been used. Mortar cores of diameter 50 mm with 40 mm thickness were used for the determination of porosity and gas permeability of mortar. For plastic shrinkage cracking test, the mortar samples have been moulded in a specially fabricated ring mould that is placed into a control temperature room.

1.5 Layout of Dissertation

The dissertation consists of five chapters. In this chapter, the introduction of the general background, problem statement, objectives and scope of work are provided. Next, chapter 2 discusses and reviews the relevant literatures related to the use of silica fume and polypropylene fiber in mortar and concrete. Chapter 3 explains the whole of research methodology undertaken in the research work in order to achieve the stipulated objectives. Chapter 4 presents and discusses the results obtained from the laboratory works. Chapter 5 provides the conclusions of the study and suggests possible recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Selection of Materials

The selection of materials for silica fume mortar by adding polypropylene fiber is important to reduce the shrinkage cracking and to improve the impact resistance of mortar. The materials that have been used for this study are Ordinary Portland Cement (OPC), polypropylene fiber, silica fume, sand, water and superplasticizer.

2.1.1 Ordinary Portland Cement

Cement is the important construction material throughout the world. It has adhesive and cohesive properties enabling it to form good bond with other materials (Anniamma and Lovely, 2013). Cements manufactured by different companies vary slightly in their chemical compositions and the materials used which directly reflects on the physical properties. The cement to be used in a particular concrete or mortar will be selected on the basis of the particular properties required. A typical chemical composition of Ordinary Portland Cement (type 1) is provided in Table 2.1.

Table 2.1: Chemical Composition of Cement (Ramli and Chee Ban, 2010)

Oxides	Composition (%)
SiO_2	21.28
Al_2O_3	5.60
Fe_2O_3	3.36
CaO	64.64
MgO	2.06
SO_3	2.14
Na_2O	0.05
Loss of ignition	0.64

2.1.2 Silica Fume

Global consumption of silica fume exceeds 1 million tonnes per annum. It is generally a dark grey to black or off-white in colour and can be supplied as a densified powder or slurry depending on the application and the available handling facilities. With the use of silica fume, strength over 200 N/mm² can be designed for applications such as fibre cement, refractory mortars and castables and in the use of specialized ultra high strength precast sections (King, 2012). Silica fume is a material that has been usually used as repair material. This is due to the addition of silica fume that improved bond strength of shotcrete to substrate surfaces, and improved the cohesion (Wolsiefer and Morgan, 1993).

Silica fume, also referred to as microsilica or condensed silica fume, is a by-product material that is used as a pozzolan. A pozzolan is a siliceous material which in fine powder form reacts with calcium hydroxide and moisture to form a cementitious material. This by-product is a result from the reduction of high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume is sold in in powder form but commonly available in liquid. Silica fume is used in amount between 5% and 10% by weight of the total cementitious material. Because of its low bleeding characteristics, concrete or mortar containing silica fume may exhibit an increase in plastic shrinkage cracking (Kosmatka et al., 2011).

Silica fume is normally used with a superplasticizer (SP) as to maximize the full strength enhancing potential of silica fume in concrete or mortar. The dosage of SP will depend on the amount of silica fume and the type of admixture used. This is due to the higher water demand of mortar containing silica fume with an increasing the amount of silica fume (King, 2012).

Fresh mortar or concrete containing silica fume is more cohesive and less prone to segregation than concrete without silica fume. Silica fume addition has been used to assist in pumping concrete long distances, especially vertically. Concrete was pumped in a single operation to a height of 601 metres at the Burj Khalifa project in Dubai, the world's tallest building (King, 2012).

Silica fume has effectively a similar heat of hydration to Ordinary Portland Cement (CEM I). A reduction in the early age temperature rise can reduce the risk of early-age thermal cracking. Indicative values for the chemical and physical properties of silica fume compared with other supplementary cementitious materials are given in Table 2.2.

Table 2.2: Chemical composition and physical properties of silica fume with fly ash and GGBS (King, 2012)

	Fly ash	GGBS	Silica fume
Fineness (m^2/kg)	450	350 to 550	15, 000 to 35,000
Bulk density (kg/m^3)	1300	1200	1350-1510
Specific gravity	2.2	2.9	2.2
Main element			
SiO_2, %	38 to 50	30 to 40	> 85
Al_2O_3, %	20 to 40	5 to 20	< 2
Fe_2O_3, %	6 to 16	< 2	< 1
CaO, %	1.8 to 10	35 to 40	< 1
MgO, %	1.0 to 3.5	5 to 18	< 1
Na_2O, %	0.8 to 1.8	< 1	< 1
K_2O, %	2.3 to 4.5	< 1	< 1
Cl, %	< 0.01	< 0.1	< 0.3
Loss on ignition, %	3 to 20	< 3	< 4
SO_4, %	0.42 to 3.0	< 1	< 1

2.1.3 Polypropylene Fiber

Polypropylene fibers, produced by the fibrillation of polypropylene films, have been used in Portland cement concrete since the late 1960s (Bentur et al., 2007). PP fibers have been used for the reinforcement of cementitious materials to improve the toughness and energy absorption capability of the matrix. They are found to be extremely effective in reducing free plastic shrinkage cracking, in retarding first crack appearance and in controlling cracking development. In most cases, volume fractions of fibers for this application ranged from 0.1% to 0.5% (Alwahab and Soroushian, 1987).

The type of polypropylene fiber that is used in this research is macro polypropylene fiber. This fiber is a kind of high strength fiber which is usually applied in construction engineering to control the concrete toughness. It can replace traditional steel fabric and steel fiber, therefore reduce the construction cost. The macro PP fiber is manufactured from modified polypropylene polymer as the main raw material, through special process technology and production. The characteristics of this fiber are rough surface, the wave shape, high tensile strength, modulus of elasticity, as well as strong acid and alkali resistance. The fibers are usually manufactured in bundles or collated together and come in lengths of 1/2, 3/4, 1-1/2, or 2 inches (Milind, 2015).

The effect of polypropylene fibers depends on the type, length, and volume fraction of fiber, the mixture design and the nature of the concrete materials used (Toutanji, 1999). The general results are that permeability, abrasion and impact resistance are all significantly improved by the addition of polypropylene fibers (Balaguru and Shah, 1992). The large and the strong fibers control large cracks. The small and soft fibers control crack initiation and propagation of small cracks (Ravi and Karvekar, 2014).

2.2 Properties of mortar containing silica fume and polypropylene fiber

The properties of mortar containing silica fume and polypropylene fiber based on the available literature are reviewed in the following section.

2.2.1 Workability

The addition of polypropylenes fiber and silica fume showed adverse effect on workability of concrete. Concrete containing polypropylene fiber shows rapid decrease rate (45-36%) in workability in comparison to concrete having no content of polypropylene fiber. As the dosage of silica fume increased, showed lesser reduction in rate of decrease in workability compared to referenced concrete. It is observed from slump test results that there is continuous decrease in workability of concrete with increase in polypropylene fiber content (Rakesh et al., 2013).

Then, by adding of silica fume will normally densify the mixture by filling voids in the cement matrix. This will produce a stiffer mixture and a corresponding increase in the slump. The addition of fibers and silica fume exhibited detrimental effects on the workability of fresh expansive-cement concrete (Toutanji, 1999).

ACI Committe 226 stated that the SF particle is ultra-fine, it becomes a filler to fit into the spaces between the cement grains, while the sand fills the space between the particles of coarse aggregates and the cement grain fills the spaces between the sand grains. This can increase the internal cohesion of fresh concrete. Generally, it was observed that workability of mortar mixes with no super plasticizer content increases with increasing water/cement ratio. The observation is consistent with the fact that the water content of the mix is the main factor affecting workability of concrete whereby increase in water content will result in higher workability of mix (Neville, 1995).