Faculty of Engineering

STUDY ON SILICA BASED WASTE MATERIAL AS PARTIAL CEMENT REPLACEMENT IN MORTAR

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STUDY ON SILICA BASED WASTE MATERIAL AS PARTIAL CEMENT REPLACEMENT IN MORTAR

AIZAT BIN GANI

Master of Engineering

(Civil Engineering)

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To my beloved family, my respected supervisor, and my trustworthy friends.

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ABSTRACT

The accumulation non-biodegradable waste glass in the overpopulated landfills of developed and developing countries is becoming a serious environmental issue. Numerous researches have been conducted in the past to study the application of waste glass as an alternative material in concrete production. The chemical properties such as high silica content making it an attractive material to be used as partial cement replacement. This research investigates the potential of powdered green waste glass (PGWG) as partial cement replacement in mortar with the research aim of assessing its pozzolanicity in relation to the fineness of the PGWG (>75μm, <75μm ->38μm, and <38μm) and percentage of cement replacement by weight (10%, 20%, 30%, and 40%). Mortar cubes were prepared with water to cement ratio of 0.45, and cement to sand ratio of 0.6. The mortar cubes are cured in room temperature of± 32^{O}C with 90% relative humidity and prepared for compressive strength test. Modified cement paste with the same PGWG size and cement replacement percentage were prepared for FTIR analysis. Mortars and cement paste with 10% cement replacement and PGWG size of <38μm recorded the highest compressive strength test result and display the highest degree of pozzolanic activity from the FTIR analysis respectively.

ABSTRAK

Masalah penimbunan bahan buangan yang bersifat tidak terbiodegradasi seperti kaca di tapak pelupusan sampah menjadi isu alam sekitar bagi negara-negara maju dan membangun. Bagi mengatasi isu berkenaan, pelbagai kajian telah dilaksanakan bagi mengkali pengunaan kaca buangan sebagai bahan alternatif dalam bidang pembinaan. Sifat kimia kaca yang mengadungi kandungan silika yang tinggi menjadikan ia sebagai bahan yang berpotensi untuk diguna sebagai bahan separa-gantian bagi simen. Kajian ini menyiasat potensi serbuk kaca sisa hijau (SKSH) untuk digunakan sebagai bahan separa-gantain bagi simen dalam mortar dengan tumpuan penyelidikan nilai pozzolanicity yang berhubung kait bengan kehalusan SKSH (>75μm, <75μm - >38μm dan <38μm) dan peratusan gantian simen mengikut berat (10%, 20%, 30%, dan 40%). Kiub mortar disedaikan dengan nisbah air kepada simen sebanyak 0.45 dan nisbah simen kepada pasir sebanyak 0.6. Kuib mortar diletakan pada suhu bilik± 32^{O}C dan 90% kelembapan relatif bagi menguji kekuatan mampatan. Pes simen yang diubahsuai mengunakan saiz SKSH yang sama dan peratusan penggantian simen juga disediakan bagi menlaksanakan analisis FTIR. Sampel mortar dan pes simen yang diubahsuai mengunakan 10% pengganti simen dan saiz SKSH <38μm telah merekodkan kekuatan mampatan tertinggi dan memaparkan tahap pozzolanic yang paling aktif daripada analisis FTIR.

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CHAPTER 1

INTRODUCTION

1.1 Background

In the 21st century, post-consumer product such as metal, plastic and glass are considered as non-biodegradable solid wastes. Non-biodegradable solid waste disposal has become an environmental issue faced by most developed and developing countries. Most of non-biodegradable solid wastes end up in landfills and very small amount are recycled. For a developing country like Malaysia, this scenario is becoming a major environmental challenge. It was estimated that Malaysia has generated around 5.5 million tons of solid waste in 2001 and only 5% of the solid wastes were recycled. The other 95% were disposed in Malaysia's overpopulated landfills (Samsudin and Mat Don; 2013). These types of materials are not suitable to be disposed in landfills as they are not environmentally safe. Unlike metal and plastic, solid waste glass is not a popular recycle material in Malaysia due to the lower recycle value when compared to plastic, paper and metals wastes. Tedious process and the cost of separating coloured waste glass also plays a part in making it an unpopular recycle material. Thus, to reduce the amount of waste glass in landfill other means of reusing them need to be looked into. Many studies on wastes glass application in the construction industry have been conducted in the past few decades as there are a great potential using them in large amount in this industry (Poutos; 2007)

In developed countries such as the United States, United Kingdom and other European countries, waste glass has already been widely used as an alternative material for all sorts of applications Rindl (1998) reported that waste glass are used as an alternative material in asphalt paving, insulations, building application such as glass tiles and wall decorations, highway constructions, reflective beads, and concrete production. The promising physical properties and chemical properties of glass for concrete production have been attracting researchers to study the characteristic of concrete with waste glass. The physical property of glass such as glass hardness and high absorption resistance makes it an attractive material to be used as a coarse aggregate for concrete. It was also found that crushed glass possesses very similar properties of sand being a hard, granular material with similar particle density (Dhir, et. al.; 2001). It was also discovered that glass used as aggregates are highly resistance abrasion compared to quartz sand and other fine aggregate material. Most of the earlier studies conducted on waste glass in concrete was using waste glass cullet as coarse aggregate replacement.

Even though the physical properties of glass shows great potential for using it as coarse aggregate, the chemical properties of glass which is rich in silica composition becomes a threat when it reacts to the alkaline solution produced during the cement hydration process. This Alkali Silica Reaction (ASR) causes a major durability problem as the concrete deteriorates due to the ASR. ASR causes concrete expansion, cracking and deters the aggregate-cement bond. The poor understanding of ASR in the earlier studies of using waste glass as aggregate causes them to be unsuccessful (Meyer; 2001). After extensive studies and research on ASR in concrete were conducted, it is found that ASR can be reduced and mitigated by using pozzolanic material together with cement to produce concrete (Xu, et.al.; 1995).

Glass chemical properties are rich in Silica (SiO_2), Sodium (Na_2O), and Calcium (CaO). With the high percentage of silica (SiO_2) in glass, it has a potential to be a pozzolanic material. In fact, studies showed that when glass is grinded to less than 40µm it reacts in a pozzolanic manner making them a potential cement replacement material as such fly ash and silica (Khmiri, et. al.; 2012). This research studies the potential of powdered waste glass as partial cement replacement by studying the powdered waste glass pozzolanicity characteristic.

1.2 Problem Statement

The amount of solid waste glass in landfills is increasing yearly. As solid waste glass is a non-biodegradable material, it is not environmentally safe to be disposed to landfill. The increasing amount of waste glass in land fill is a concern as they occupy the landfill for a very long time and will cause environmental issues and health issues. Therefore studies have been conducted to study the potential of the waste glass to be used as construction industries to reduce the amount of waste glass in landfills.

Research on the microstructure of pozzolanic reaction of waste glass as cement replacement have been conducted in numerous countries for the past two decades. Mixed colour waste glass with the size ranging from 1.2mm to as small as 10μm used for these researches. Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDX) test are mostly used in the research to study the microstructure. Only a handful of research conducted Fourier Transform Infrared (FTIR) and Thermo-gravimetric analysis (TGA) test on the samples.

Based on the limited research done on a specific glass colour as cement replacement, this research focuses on the utilisation of specific waste glass colour as cement replacement. FTIR analysis will be conducted to study the pozzolanicity of a specific waste glass colour.

1.3 Aim and Objectives

The aims of this research is to assess the pozzolanicity of powdered green waste glass as partial cement replacement and its effect on concrete mechanical properties. To achieve these aims, the following objectives need to be completed.

- To determine the compressive strength of cement mortar with green waste glass as cement replacement.
- To study the product of pozzolanic reaction of powdered green waste glass as partial cement replacement by Fourier Transform Infrared (FTIR) analysis to identify the surface functional groups of pozzolanic reaction product to determine the pozzolanicity.

1.4 Research Hypothesis

Based on the previous researches conducted, it is known that the size and the percentages is a huge factor in determining the strength and the pozzolanicity level. The hypotheses of this research based on the literature review are:

- The modified samples will show a significant difference of pozzolanicity between glass size of $<38\mu m$ and $<75\mu m$
- There will be a significant drop of pozzolanicity when percentage of cement replacement is more than 20% due to dilution effect

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, previous researches and studies related to the use of waste glass in concrete production are reviewed and analysed. This chapter will cover mainly on the previous research conducted to understand the cement hydration process, the properties of glass as a concrete material, the ASR when using waste glass in concrete, the pozzolanic reaction of waste glass in concrete, and the micro-structure of concrete made with waste glass.

2.2 Cement Hydration

Cement hydration is the hydration process of cement when reacts with water to produce an artificial rock known as concrete. There are numerous reactions that occur during this hydration stage, which often occurs simultaneously. The reactions will cause the mixed materials particles (sand, gavels, and cement paste) to bond and harden. The main compound that cement possess in an anhydrous state are tricalcium silicate (C_3S) also known as alite, dicalcium silicate (βC_2S) also known as belite, aluminate (C_3A), ferrite phase (C_4AF), clinker sulphate (includes sodium, potassium, and calcium) and gypsum (Winter; 2012).

The reaction during hydration will generate heat. Therefore by monitoring the heat rate generated, the rate of minerals reactions can be determined. A typical reaction rate over time of Portland cement hydration is as illustrated in Figure 2.1.

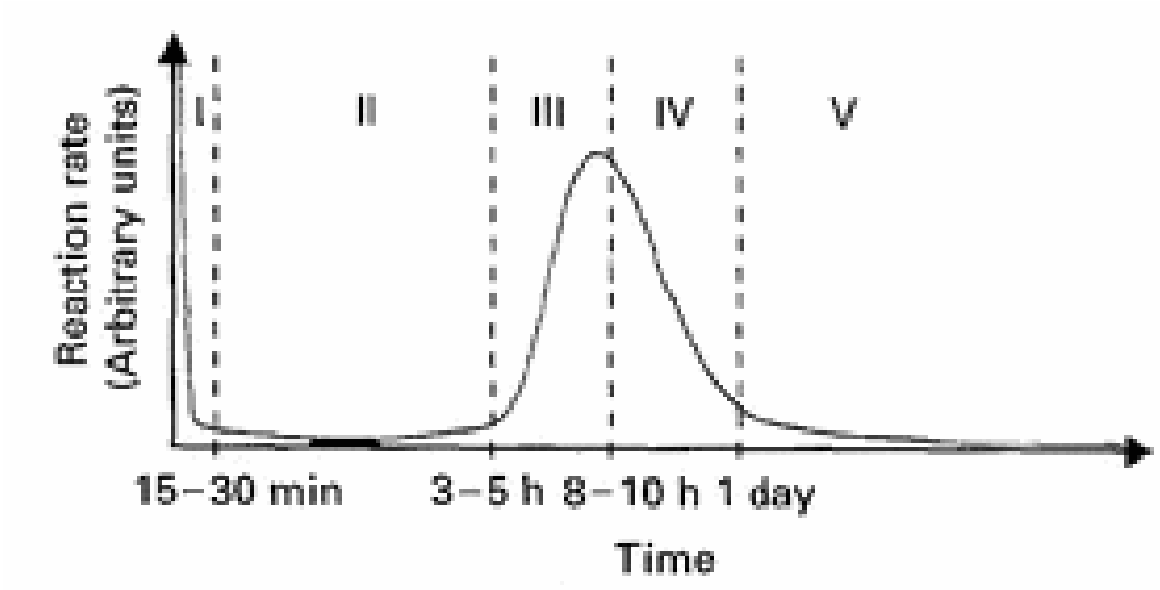

Figure 2.1: Reaction rate of minerals over time during cement hydration process of Portland cement. (Mitchell, et.al.; 1996)

Figure 2.1 shows the mineral reactions during cement hydration can be indicated into five stages. Stage I is the pre-induction period, where the initial heat is generated. Soon after water is added to the cement mixture, clinker sulphate and gypsum dissolve and produce an alkaline, sulphate-rich solution. In stage I, aluminate (C_3A) reacts with water which will form an aluminate-rich gel. Figure 2.1 indicates that reaction rate at stage I is the highest. This is because among the mineral components in cement, aluminate (C_3A) is the most reactive mineral (Winter; 2012). Although the reaction rate is at its highest during this stage, the reaction does not last long. After a few minutes of high reaction rate in stage I, a low reaction rate follows in stage II. Stage

II is the dormant period, also known as induction period. During this stage, the process of hardening progresses along the dormant period.

At the end of dormant period, another reaction of minerals starts in stage III. Here, alite and belite starts to react. This reaction will form calcium silicate hydrate (C-S-H) and calcium hydroxide (CH). Stage III is the main period of hydration because of the formation of calcium silicate hydrate (C-S-H). According to Mitchell, et.al, (1996), calcium silicate hydrate (C-S-H) will dictate the properties of cement end product as calcium silicate hydrate (C-S-H) contributes to the strengthening of the cement end product. The hydration in stage III continues in stage IV where the reaction rate starts to decrease.

Stage V is considered as the diffusion period where the reaction rate starts to slow down. Usually the strength gain of a product using Portland cement will continue for a month where the product will achieve its full strength. Winter, (2012) found that the rate of reaction is slower when partly replacing cement with other pozzolanic material such as fly ash and silica fume. When compared to harden Portland cement, the duration for cement mixed with pozzolanic material to gain full strength needs more than a month. According to Winter, (2012), it may need several months or even a year to gain full strength. The duration depends on the properties of the material used to partly replace cement.

2.3 The Properties of Glass

2.3.1 Introduction

The process of properties identification of a material to be used in a research study is very important. Identification of the material properties provides a better understanding of the research result. Since this research will be using waste glass as cement replacement, it is important to identify the properties of glass before going further into the research.

2.3.2 Physical Properties of Glass

Studies have identified that the physical properties of glass such as low water absorption making it one of most durable material known and its hardness gives a good abrasion resistance which could benefit the various types of concrete products (Meyer; 2001). This is supported by Park, et.al. (2004) study on the physical properties of glass findings is tabulated in Table 2.1.

Table 2.1: Physical properties of waste glass (Park, et.al.; 2004)

Type	Test				
	FM	Specific Gravity	Water Absorption (%)	Absolute Volume (%)	Unit Weight (kg/m3)
Amber	3.49	2.52	0.4	61.03	1559
Emerald green	3.48	2.5	0.41	61.78	1543
Flint	3.48	2.5	0.43	62.6	1551

Table 2.1 provides the data collected for three different colour glasses which shows that they have similar physical properties. From the data in Table 2.2, it is indicated that glass is suitable to be used as fine aggregate in concrete production as it possess a similar or even better

than physical properties of typical fine aggregate such as sand. Park, et.al. (2004) compared glass physical properties to typical fine aggregate properties such as sand as shown in Table 2.2.

Table 2.2: Physical properties of typical fine aggregate and coarse aggregate (Park, et.al 2004)

Type	FM	Specific Gravity	Absolute Volume (%)	Unit Weight (kg/m3)
Fine	2.68	2.65	1.4	1650
Coarse	7.08	2.7	1.32	1480

2.3.3 Chemical Properties of Glass

Although the physical properties shows great potential for glass to be used as fine glass aggregate, the chemical properties of glass needs to be put into consideration before coming to a conclusion. Park, et.al (2004) studied the chemical composition of waste glass in South Korea by using Scanning Electron Microscopy with Energy-dispersive X-ray spectroscopy (SEM/EDX) and found that they are rich in Silica (SiO_2), Sodium (Na_2O), and Calcium (CaO). The result of the SEM test conducted is tabulate in Table 2.3.

Table 2.3: Chemical composition of waste glass in South Korea (Park, et.al.; 2004)

Type	Test		
	Emerald green glass (%)	Amber glass (%)	Flint glass (%)
SiO_2	71.3	72.1	73.04
Al_2SO_3	2.18	1.74	1.81
Na_2O+K_2O	13.07	14.11	13.94
CaO+MgO	12.18	11.52	10.75
SO_3	0.53	0.13	0.22
Fe_2O_3	0.596	0.31	0.04
Cr_2O_3	0.44	0.01	-
Grain Shape	Angular	Angular	Angular

The same SEM/EDX test on waste glass in Portugal was conducted by Braganc¸ (2007) gives a slight different percentage of chemical composition as shown in Table 2.4 when compared to the result obtained by Park, et.al. (2004)

Table 2.4: Chemical composition of waste glass in Portugal (Braganc¸ 2007)

	Flint glass (%)	Amber glass (%)	Green glass (%)
Na_2O	9.94	10.37	10.54
MgO	0.75	0.81	1.18
Al_2O_3	2.57	3.09	2.54
SiO_2	74.07	73.27	72.25
Cl_2O	-	-	-
K_2O	1.14	1.1	1.15
CaO	11.53	11.36	12.35
TiO_2	-	-	-
Fe_2O_3	-	-	-
SO_3	-	-	-

This shows that waste glass from a different area has different chemical properties. This is because the process of glass production at a country could be different to another. Thus, it is very important to conduct SEM/EDX test before going further into other studies.

The high Silica (SiO_2) content in glass could either be an advantage or disadvantage to concrete production. This is because the cement hydration process produces an alkaline solution which could react to the high silica (SiO_2) composition in glass. When alkaline reacts with silica (SiO_2), it would form a gel which will cause concrete to expand and could cause cracking. The high silica (SiO_2) content could also benefit concrete production by reacting in a pozzolanic manner. This is when the silica (SiO_2) reacts with calcium hydroxide (CH) product of cement hydration which will form calcium silicate hydrate (C-S-H) (Xu, et.al.; 1995). This will benefit concrete production as the formation of silicate hydrate (C-S-H) will contribute to the strengthening of concrete. The understanding of glass chemical composition reaction with other concrete material is very important when using glass as an alternative material.

2.4 Alkali-Silica Reaction (ASR) in Concrete with Glass Aggregate

2.4.1 Introduction

Alkali-Silica Reaction (ASR) is a reaction of alkaline and reactive silica phase. This reaction has been causing problem to most concrete structures all around the world for decades. ASR was first discovered in the early 1930s by Thomas Stanton in California USA. ASR in concrete structure was also found in Canada in 1957 and in 1960s it was also discovered in the European countries. It was found that concrete structures such as dams, bridges, pavements and buildings were experiencing expansion and cracking due to ASR. Thomas Stanton continued his study on the cracks and expansion of the concrete structures and found that it was caused by the reaction of alkaline in cement and the siliceous aggregate such as opalinechert and strained quartz **(**Federal Highway Administration US; 2013**).** Since the discovery of ASR to concrete structure many research and studies were conducted to get a better understanding of the harmful reaction. After decades of research and studies, there is a better understanding of ASR in concrete. The complexity of ASR is still under research and study to get a full understanding of the reaction and the means of mitigation.

As mentioned previously, glass chemical composition contains a significantly high percentage of silica which makes it a potential candidate to experience ASR when used as concrete aggregate. This is confirmed by the results obtained by most researchers studying the effect of glass application in concrete (Meyer; 2001).