**Journal of Civil Engineering, Science and Technology**
*Volume 7, Issue 2, September 2016*

# POZZOLANIC PROPERTIES OF GLASS POWDER IN CEMENT PASTE

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Date received: 10/07/2016 Date accepted: 25/09/2016
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*Abstract* – This paper investigates the formation of Calcium Silicate Hydrate (C-S-H) as a product of pozzolanic reactions in a cement paste with cement partially replaced with crushed recycled glass at the rate of 10% and 20%. Three different particle sizes for crushed glass used in this study were in the range of 150-75µm, 75-38µm and lower than 38µm; and a water to cement ratio of 0.45 was used for all specimens. This study showed that the formation of Calcium Hydroxide $Ca(OH)_2$ is decreased while the formation of C-S-H is increased simultaneously at 90 days for 75-38µm and <38µm glass powder. The use of waste glass as a partial cement replacement improves the cement strength through the formation of C-S-H due to the pozzolanic reaction with $Ca(OH)_2$ improving the strength of the mortar.

***Keywords*:** Pozzolanic Properties, Calcium Silicate Hydrate, Cement Replacement, Waste Glass Powder, Hydration.

## 1.0 INTRODUCTION

GLASS is one of the most fundamental materials that we abundantly use in our day to day life. The amount of waste glass generation also increases with the increase in the use of glass. In theory, glass is a 100% recyclable material; it can be indefinitely recycled without any loss of quality [1]. However, the recycling rate of waste glass is still low compared to other solid wastes due to the cost of cleaning and color sorting, mixing of broken pieces, inconsistency of glass properties, mixing with impurities and increasing shipping cost [2]. Use of waste glass as a partial replacement in construction industry gives a new avenue of using recycled waste glass. Recent work has shown that crushed recycled glass has pozzolanic properties which make it possible to use as a partial cement replacement in concrete and cement mortar [3 - 5].

Waste glass that exhibits either binding properties or pozzolanic properties can be used as a partial cement replacement [6 - 9]. A typical pozzolanic material features three characteristics: it should contain high silica, be X-ray amorphous, and have a large surface area. Glass has sufficient silica content and is amorphous in nature [10]. The glass may satisfy as a pozzolanic material if it is ground to activate pozzolanic behavior. Smaller size of glass will reduce the Alkali Silica Reaction as well [6, 11]. The pozzolanic properties of glass powder can be obtained from its microstructure analysis in terms of hydration. This paper deals with the formation of hydration compounds Calcium Silicate Hydrate (C-S-H) and Calcium Hydroxide (CH), which shows the pozzolanic properties of sample containing three sizes of glass powder (i.e. 150-75µm, 75-38µm and <38µm) through Differential Thermal Analysis (DTA) and Scanning Electron Microscope (SEM). In this experiment, glass powder is partially replaced as cement with 10 to 20 percent by weight.

## 2.0 EXPERIMENTAL PARAMETERS

Experiments were conducted on cement paste prepared by the partial replacement of cement by three sizes waste glass powder. Water-cement ratio was maintained as 0.45 throughout the research. Glass powder was used as partial cement at replacement level of 10% and 20% by weight. 30ml glass containing cement samples were prepared for the age of 28 days and 90 days. A summary of the mix proportion is presented in Table 1.

Table 1 Mixing proportion of cement paste samples with glass powder

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| Samples Name | Control (0%) | 10GP (10%) | 20GP (20%) |
|---|---|---|---|
| Ordinary Portland Cement (g/ml) | 2.17 | 1.95 | 1.74 |
| Powdered waste glass (g/ml) | 0.00 | 0.22 | 0.43 |
| Water (g/ml) | 0.98 | 0.98 | 0.98 |

Glass beaker was used for mixing process of cement paste samples. Portland cement with the intended percentage of glass powder as a replacement was measured accordingly then mixed together until a uniform distribution was achieved. Water was then added to the mix and mixed until a uniform fresh paste of the mixed ingredient was achieved with no visible agglomerates. The cement paste samples were kept until desired day, cut into small pieces and placed into ethanol solution. Samples were then ground into powder form and kept in a plastic packet for testing.

### 2.1 Material Properties

#### 2.1.1 Portland Cement

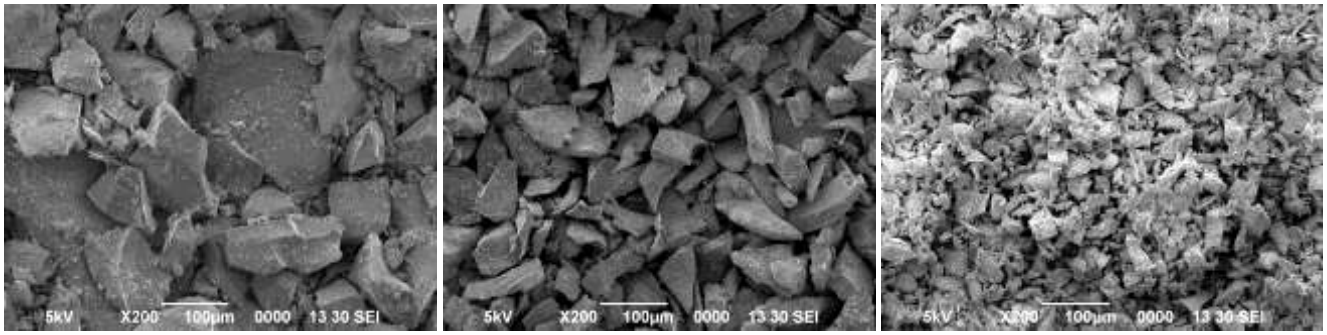
Ordinary Portland Cement (OPC) ASTM Type 1 was used in the research. The cement confirmed the quality requirements specified in the Malaysian Standard MS 522: Part 1: 1989 Specifications for Ordinary Portland Cement.

#### 2.1.2 Glass Powder

Waste Glass used in this current investigation is soda-lime silica glass collected from local recycle center. Glass bottles were cleaned with water thoroughly to remove paper labels from the outer surface of the glass and to remove contaminations. The glass was then ground using the Los Angeles Abrasion Machine. The glass powder was subjected to mechanical sieve analysis to get the specific particle size. In this current investigation, three different sizes were used as shown in Figure1 : (a) Glass Powder A : Glass powder having particles passing a 100 sieve (150 micron) and retained on a #200 sieve (75 micron), (b) Glass Powder B : Glass powder having particles passing a #200 sieve (75 micron) and retained on a #400 sieve (38 micron). (c) Glass Powder C: Glass powder having particles passing a #400 sieve (38 micron). Samples were named $10GP_A$, $10GP_B$, $10GP_C$ for the Glass powder A, B, C respectively at 10% replacement whereas $20GP_A$, $20GP_B$, $20GP_C$ for the corresponding Glass powder A, B and C respectively at 20% replacement.

2.1.3 Water and Ethanol Solution

Potable tap water free from impurities was used for curing, mixing, cleaning and other purpose of cement paste making. Water to cement ratio of 0.45 was maintained throughout the research. In this experiment, ethanol solution with 95% purity was used to stop the hydration at a specific time. Ethanol solution helps to remove the free water from the cement paste to accurately measure the hydration products at specific time. Free water causes continuation of hydration process misleading the amount of hydration products generated at the specific time.




(a) (b) (c)

Figure 1 Particle Size of glass powder (a) Glass Powder A, (b) Glass Powder B and (c) Glass Powder C

2.2 Testing Apparatus

2.2.1 Differential Thermal Analysis

Differential Thermal Analysis (DTA) was carried out on specimens of cement pastes to measure the decomposition of main hydrated product Calcium Silicate Hydrate (C-S-H) and Calcium Hydroxide ($Ca(OH)_2$). Curves of cement paste with various sizes of glass powder and cement paste without glass powder (control) samples were recorded using DTG-60H (C30574900361). The samples were heated from room temperature to 1000 °C with a heating rate of 5 °C/min in a nitrogen atmosphere, while the DTA curve is used to calculate the deformation during heating.

2.2.2 Scanning Electron Microscopy

In this research, SEM analysis was carried out to obtain the morphology of cement pastes with glass powder using Analytical Scanning Electron Microscope (JSM-6390LA) supplied by JEOL Company Limited, Tokyo, Japan. Samples were placed on a double sided adhesive conductive carbon tape to prevent scattering of loose particles. Then the samples were coated with platinum in argon gas atmosphere at a high vacuum of 30MPa in order to make the samples electrically conductive.

3.0 RESULTS AND DISCUSSION

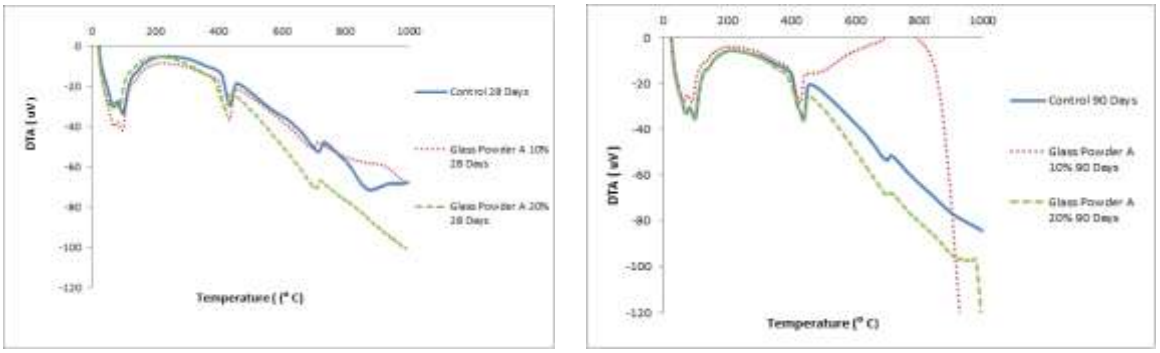
3.1 Differential Thermal Analysis Results

Differential thermal analysis (DTA) were carried out on specimens of control cement pastes with no glass powder, cement paste with glass powder with 10% and 20% replacement. The DTA curves show four different endothermic peaks for all samples of specimen. The first peak was located between 60 °C – 102 °C corresponding to the decomposition of bound water on compounds like ettringite, while the second peak was detected at 102 °C – 160 °C attributed to the deformation of C-S-H. The third endothermic peak was observed in the range 400 °C – 450 °C causes a new loss starting around 360 °C due to the dehydration of $Ca(OH)_2$, while the forth peak referred to the decomposition of calcium carbonate $CaCO_3$ at about 650 °C – 750 °C coming from clinker and the filler [12 - 14].

Lower peak corresponding to C-S-H was found for the control sample at Day 28 compared to other percentage of replacement as shown in Figures 2 (a), 3 (a) and 4 (a). Besides, it causes a significant increase in the deformation of C-S-H especially when 10% replacement is applied rather than 20%

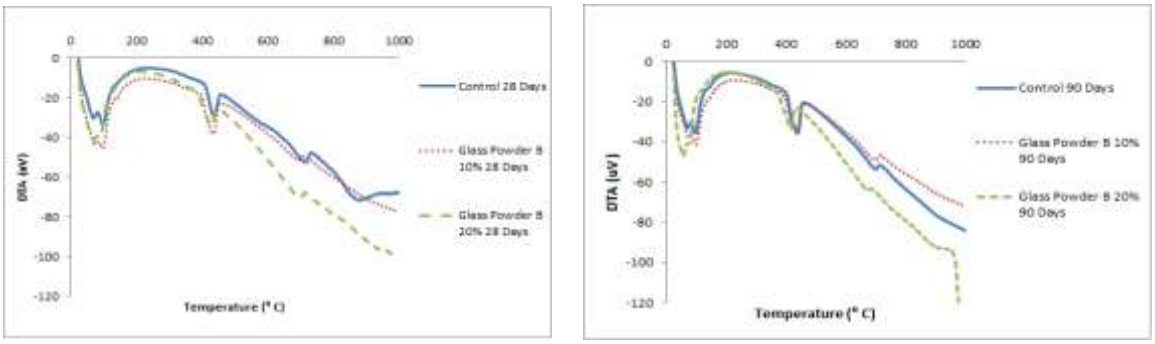
replacement. It is due to the agglomeration of glass powder and takes a long time to form more C-S-H. A similar trend was found for $10GP_A$, $10GP_B$ at 28 days. However, $20GP_C$ shows greater peak than $20GP_A$ and $20GP_B$ because of smaller particle size distribution as shown in Figures 2 (a), 3 (a) and 4 (a).

On the other hand, the third peak which is related to the decomposition of $Ca(OH)_2$ of Glass powder A, B and C appears larger than the same control peak meaning that there is a high amount of free water available that can participate in the hydration reaction. It also shows a slower hydration than normal portland cement. Excess calcium hydroxide participates to produce additional C-S-H forming pozzolanic reaction at later days.



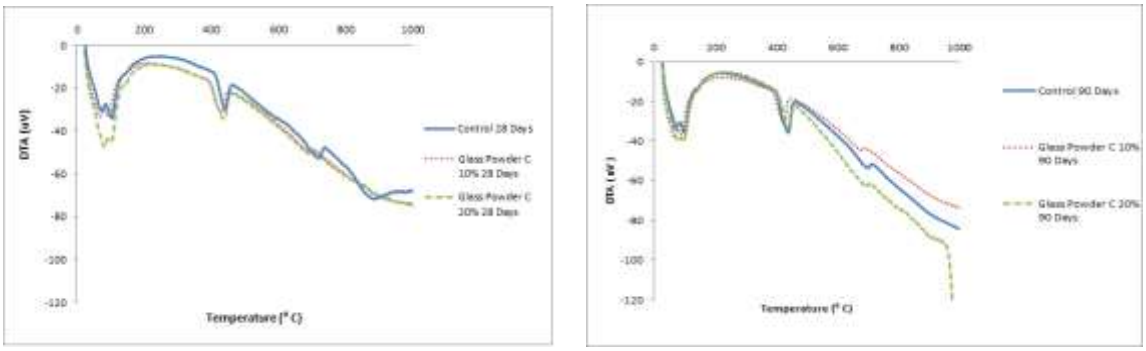

(a) (b)

Figure 2 DTA curve of Control Cement Paste with $10GP_A$ and $20GP_A$ at (a) 28 Days & (b) 90 Days




(a) (b)

Figure 3 DTA curve of Control Cement Paste with $10GP_B$ and $20GP_B$ at (a) 28 Days & (b) 90 Days




(a) (b)

Figure 4 DTA curve of Control Cement Paste with $10GP_C$ and $20GP_C$ at (a) 28 Days & (b) 90 Days

For 90 days result, a slight difference is found when comparing with the replacement levels. The peak due to decomposition of C-S-H was significant at replacement level 20% for all Glass Powder as shown in Figures 2(b), 3(b) & 4(b). The peak referring to decomposition of $Ca(OH)_2$ is increased for $GP_A$, while decreased for $GP_B$ and $GP_C$ . Glass Powder specimen shows lower peak than control specimen for both 10% and 20% replacement which indicates the consumption of CH in the pozzolanic reaction. This agrees with results obtained by Idir et al. [11]. Moreover, Aly et al. [3] also included that the reduction of CH was much greater when nano-sized particles such as colloidal nano-silica was added in mixes together with glass powder. This phenomenon promoted acceleration of pozzolanic reaction and hydration process. The intensity of CH peak decreased up to 90 Days whereas the peak corresponding to C-S-H displayed opposite manner indicating more C-S-H formation by consuming more CH, reported by Heikal et al. [15].

3.2 Scanning Electron Microscopy Results

The major hydrated products of specimen are developed simultaneously on the cement particles. The formation of C-S-H (vide infra) is surrounded by many needle-like structures named ettringite as shown in Figure 5. A gel like structure in a hexagonal shape is also visible in the cement matrix indicating the continuation of hydration [16-17].

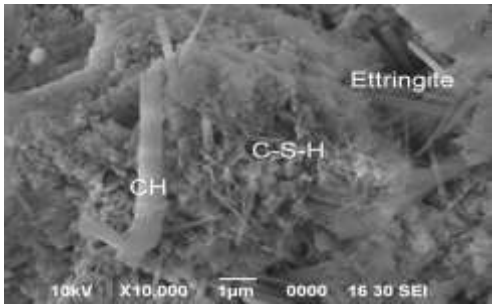
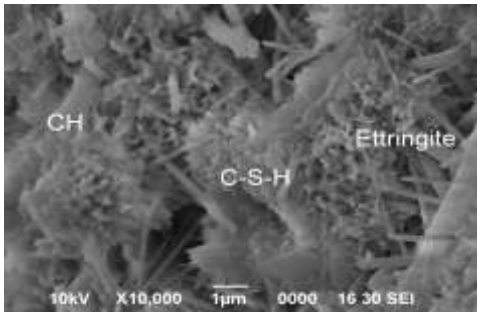
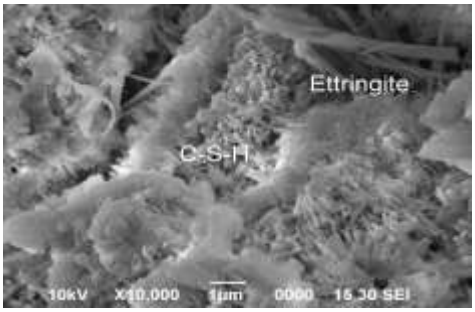



Figure 5 Control sample

The development of C-S-H in the specimen shows dense and compact in nature, while a part of cement is replaced by glass powder in Figure 6-8. The similar phenomenon is also found from the study of Nassar and Soroushian, [4] and Aly et al. [16].

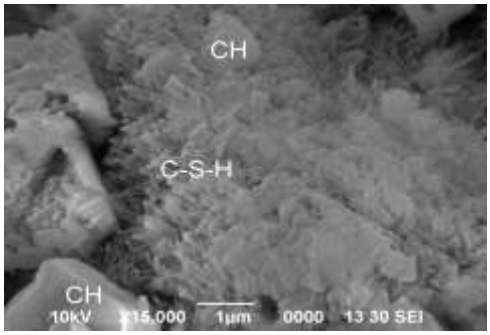



(a) 10%

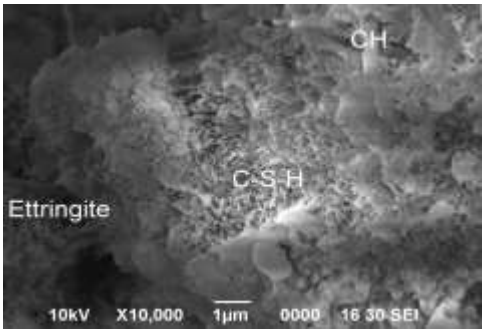



(b) 20%

Figure 6 Cement paste containing Glass Powder A (a) 10%, (b) 20%

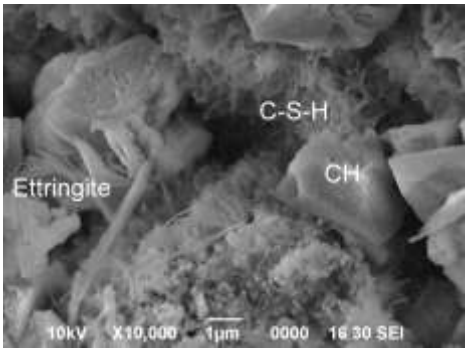


(a) 10%

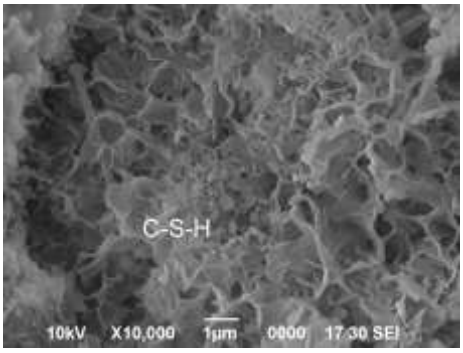


(b) 20%

Figure 7 Cement paste containing Glass Powder B (a) 10%, (b) 20%



(a) 10%



(b) 20%

Figure 8 Cement paste containing Glass Powder C (a) 10%, (b) 20%

A large quantity of C-S-H formation enriches progressive matrix of the reticular network [17]. C-S-H gel fills the pore spaces between the cement structure wherein the pores become small in size. Figure 8 (b) shows that higher replacement level of glass powder causes extensive growth of C-S-H which produces comparatively compact, dense and uniform microstructures.

## 4.0 CONCLUSIONS

All in all, cement paste exhibits the pozzolanic properties when replaced with the glass powder at the replacement level of 10% & 20%. The formation of C-S-H is higher for the $GP_C$ compare to $GP_A$ and $GP_B$. $20GP_C$ shows better pozzolanic properties because of fine particle size distribution. The morphology of sample containing glass powder confirms the formation of C-S-H that developed in the specimen by consuming $Ca(OH)_2$ during hydration and will create the cement system quite dense, homogeneous in nature.

## 5.0 ACKNOWLEDGEMENTS

This study was conducted at Civil Engineering Laboratory, Universiti Malaysia Sarawak, Malaysia and the authors wish to acknowledge Ministry of Education and Universiti Malaysia Sarawak for supporting this work under the ERGS/TK/(02)/1011/2013(08) and FRGS/03(07)/839/2012(79).

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