Characteristic of Cement Mortar Containing Windscreen Glass Waste Powder

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Abstract
Cement is produce and manufactured on a large scale from the silicate industry and used mostly in building homes, industrial buildings and other structures. Cements are produce from raw naturally occurring materials and the production involved both mining and manufacturing components, and it is a major source of greenhouse gas emission. For sustainability, and to reduce the greenhouse gas emission cause by cement production, therefore it is highly time to look into the other possibility of replacing this cementitious material. This paper was conducted to effects of various proportions of Windscreen Glass Waste Powder (WGWP) on the compressive strength in mortar. The mortar was prepared by incorporating several compositions of WGWP (5%, 10%, 15% and 20% by weight of cement) and cement to sand (C:S) ratio of 1:3.0 were employed. Fixed water to cement (w/c) ratio of 0.5 was used for this study. The samples were water cured and the assessment of the strength performance of mortar cubes were carried out at 7, 28, 60, 90 and 120 days. Studies conducted have shown that WGWP has the good pozzolanic properties. In term of compressive strength, it was observed that the compressive strength increases with an increase in percentage of WGWP from 5% until 20% of replacement. The corresponding Strength Activity Index (SAI) with 20% WGWP were 85%, 78%, 80%, 81% and 85% at 7, 28, 60, 90 and 120 curing days respectively.

Keywords: cement replacement, windscreen glass waste powder, pozzolanic, compressive strength, mortar

1.0 Introduction

Cement is the most important material for all kinds of constructions. In Malaysia, the demand of cement has increased with increasing in the development of the country and so is the problem associated with it. Cement production poses problems in many areas with respect to its availability, cost and environmental impact such as emission of airborne pollution due to dust, gases, noise and vibration when operating the machine and during the blasting process in quarries. Cement industry is the second largest industry producing CO_2 whereby it produces about 50% from its chemical process, 40% from burning fuel and 5% from global man-made CO_2 emission (Environmental Impact Assessment (EIA)), 2006. According to Raju and Kumar (2014) the release of green house gas like carbon dioxide can lead and contributes to 65% of global warming and about 7% of green house gas release to the atmosphere is produced from cement production industry.

Accidents among vehicles such as cars, lorry, buses and motorcycles are the common incidents happened in Malaysia. The accident rates in Malaysia are currently increased every year especially during festive seasons. It is reported in the Malaysian Institute of Road Safety Research (MIROS) that the statistics of accidents about road crashes in Malaysia are increasing gradually from year 1997 to year 2014. When the accidents happen, commonly the windscreen glass of the vehicles will break and scattered on the road and these glass will be considered as a waste. Therefore, this windscreen glass waste will be disposed in the landfill sites.

Recycling of waste helps saving the landfill space and save waste disposal cost (Omoniyi *et al,* 2014). Glass recycling can save millions tons of glass from being landfill and it has been common since the 1970. Glass is product that can be found in different forms such as bottle, jars, windows and windshields, bulbs and others (Omoniyi *et al,* 2014). Glass is made of sand (silicon dioxide) and soda ash (sodium carbonate). Glass does not deteriorate or weaken when reprocessed due to its structure by which hundred percent of the waste can be reclaimed. When glass waste is grind similar to those of natural sand particle, it will have same properties of an aggregates material. Waste glass powders are made from the waste glass material that cannot be reused due to the high cost of manufacturing (Vasudevan and Pillay, 2013).

Shi *et al.* (2005) reported that the use of recycled material in construction is the most suitable options due to large quantity consumptions of the materials. Currently, the waste glass powder has been used in construction industry as part of construction materials include a partial replacement for aggregates in asphalt concrete, as fine aggregates in unbond base course and as aggregates in cement concrete (Shi *et al,* 2005). Since the main material composition of glass is silica that also contain in cement production, therefore, the waste glass powder will be used as a replacement of cement in mortar.

The objective of this study on windscreen glass waste powder (WGWP) is to determine its suitability as cement replacement material. The physical, chemical and compressive strength of mortar with cement to sand (C:S) ratio of 1:3.0 were investigated.

2.0 Material and methods

The test of fineness using the nitrogen absorption method and Brunauer, Emmatt and Teller (BET) equipment was conducted to determine the specific surface area. The density was identified using Gas Pycnometry- Micromeritics 1340. The particle size distribution was determined using Mastersizer 2000 Laser Particle Size Analyzer. Scanning Electron Microscope (SEM) model JM6100 was used to study the particle morphology of the sample. The Energy Dispersing X-ray

Spectroscopy (EDAX) and X-ray Diffraction (XRD) analyzer were used in order to determine the content element of WGWP.

The automotive windscreen glass waste was obtained from nearby workshops in Terengganu, Malaysia. The process involved the removing of the gluing polymer from the glass using Organo Cycler machine at Mariwealth Engineering & Consultancy Sdn. Bhd, Selangor. The Los Angeles Machine was used to grind windscreen glass up to 10,000 revolutions to produce the automotive windscreen glass waste powder (WGWP). Figures 1 shows the flow of the preparation process of WGWP. Other materials used in the mortar mixture were Ordinary Portland cement (OPC) and fine aggregate of 5 mm maximum size.

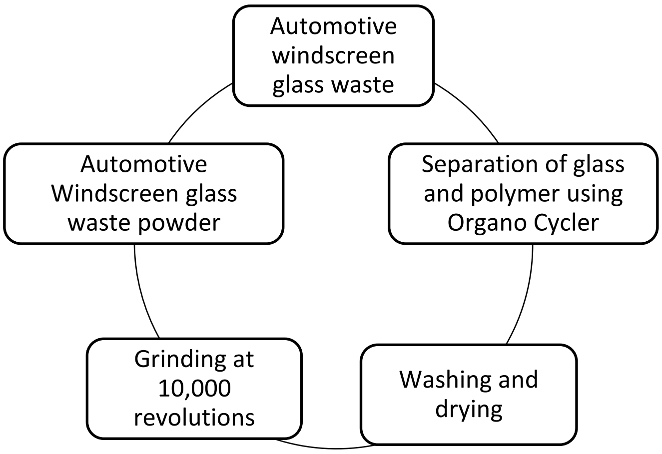


Figure 1: Preparation of automotive windscreen glass waste powder (WGWP)

This study was carried out by preparing 100 numbers of mortar cube specimens with dimensions of 50mm x 50mm x 50mm. Five mix proportions were adopted comprising various percentages of WGWP (0%, 5%, 10%, 15% and 20%) by weight of cement, whilst employing three batches of cement to sand (C:S) ratio of 1:3.0. The water to cement (w/c) ratio was fixed at 0.5. The mortar cube specimens were water cured until the day of the compressive testing at 7, 28. 60, 90 and 120 days.
The compressive strength was conducted in accordance to ASTM C:109 (American Society for Testing And Materials, 2013) at the Concrete Laboratory of Civil Engineering Faculty, UiTM Shah Alam. The strength was assessed using cube specimens of dimensions 50mm x 50mm x 50mm taken at 7, 28, 60, 90 and 120 days. Four replicates were used for each batch. The strength activity index calculation based on ASTM C 618- 12a was adopted (American Society for Testing And Materials ASTM –C618 -12a, 2012).

3.0 Results and discussion

Table 1 shows the result of BET surface area and total area in pores for both OPC and WGWP. It shows that WGWP has smaller surface area as compared to that of OPC. Practically, surface area is closely related to the particle size where they are inversely proportional. The specific surface area increases as the particle size becomes small. In this research, WGWP also has higher total area in pores compared to OPC. Therefore the density of WGWP is lower than OPC. Surface area plays an important role in determining the workability, water absorption and the durability of concrete. The surface of a material is the dividing line between a solid and its surroundings, liquid, gas or another solid. The surface area is an important factor in the behavior of a solid. Surface area affects, cement hydrates, adsorption capacity of air and water purifiers, and the processing of most powders and porous materials. Whenever solid matter becomes smaller particles new surfaces are created thereby increasing the surface area.

Table 1: Surface area and total area in pores of OPC and WGWP

Parameter/Material	OPC	WGWP
BET Surface Area (m^2/g)	1.0242	0.6462
Total area in pores (m^2/g)	0.1250	0.2100
Density (g/cm^3)	2.9885	2.5318

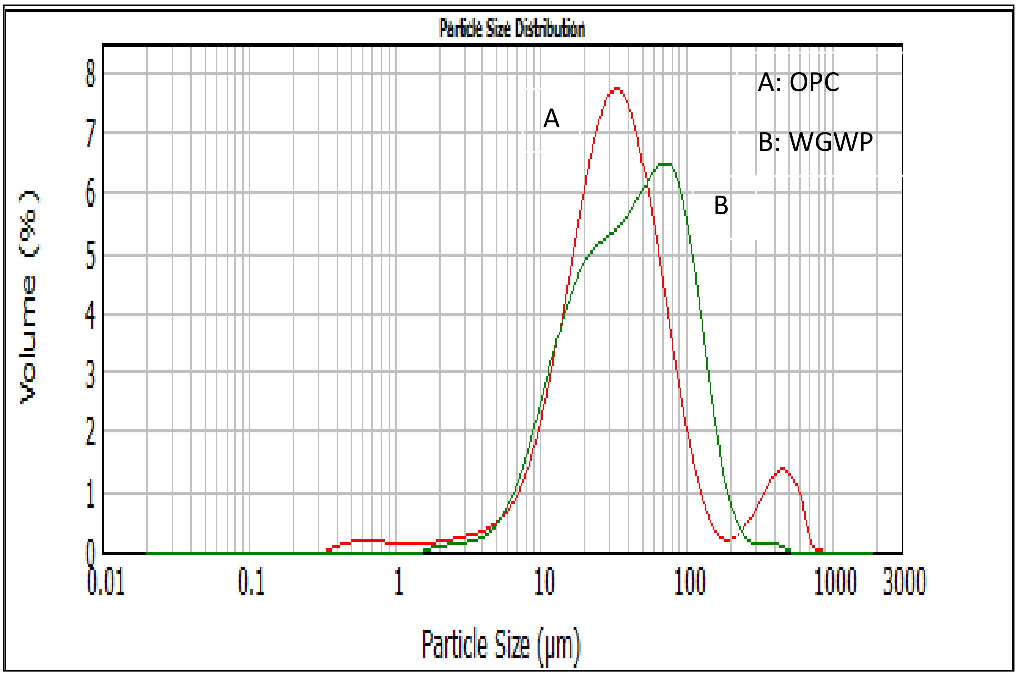
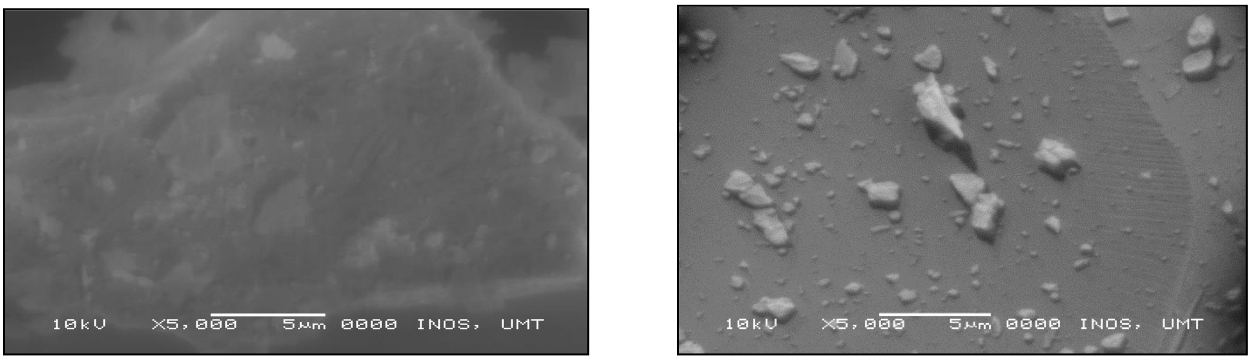


Figure 2: Particles size distributions of OPC and WGWP

Figures 2 shows the particle size distribution of OPC and WGWP. Although the WGWP has a similar mean particle size with the cement. The WGWP was expected to serve as a filler and also a supplementary cementitious material with pozzolanic activity (Nassar & Soroushian., 2012; Kim *et al.*, 2015). Figures 3 (a) and (b), showed the particle morphology of OPC and WGWP which was obtained by using scanning electron microscopy (SEM). Most particles of WGWP had angular and crushed shapes.



(a) OPC particles– 5,000 x magnifications (b) WGWP particles– 5,000 x magnification

Figure 3: SEM of OPC and WGWP particles

From Table 2, the calcium oxide (CaO) content for OPC was about 69.06%, while the silicon dioxide (SiO_2) of WGWP was about 76.11%. The chemical compositions of raw materials determined using Energy Dispersing X-ray Spectroscopy (EDAX). Therefore, this finding is in agreement with ASTM C618-02 (American Society for Testing And Materials ASTM –C618 -12a, 2012), which requires a sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ higher than 70% for good pozzolan. The total for the investigated sample of WGWP is 79.94%. The studied glass sample presents satisfactory chemical composition. It classified the Class N natural pozzolan and therefore, it is likely to produce a good pozzolan.

Table 2: Chemical compositions of raw materials

Material	**Chemical compositions (%)**						
	SiO_2	**CaO**	**Al_2O_3**	**Fe_2O_3**	**Na_2O**	**MgO**	**K_2O**
OPC	16.03	69.06	4.14	5.09	0.02	0.67	1.3
WGWP	76.11	5.01	3.45	0.38	10.10	4.00	0.33

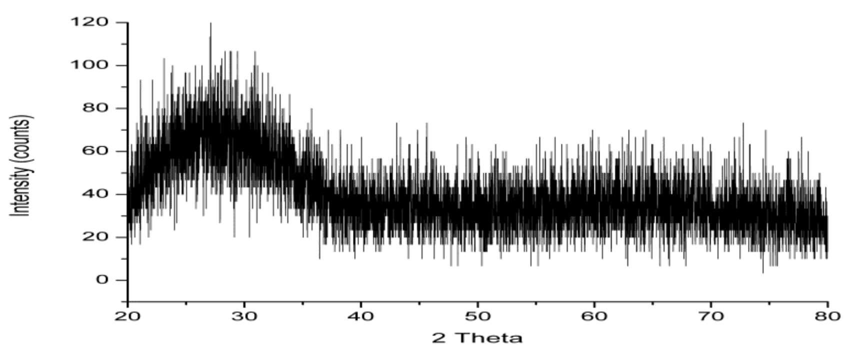


Figure 4: X-ray diffraction of WGWP

However, in order to predict the pozzolanic activity, the chemical compositions should not be used as the only criterion. It is because the amorphous state is also required and it has been confirmed for WGWP using XRD analyzer as shown in Figure 4. Indeed, no peaks attributed to any crystallized compound can be identified except a broad diffraction halo, which is attributed to the glassy phase. The XRD of WGWP shown in Figure 4 indicates that the structure of silica present in WGWP used in the present study is of amorphous material with a diffused peak of 120 counts at about θ = 20°.

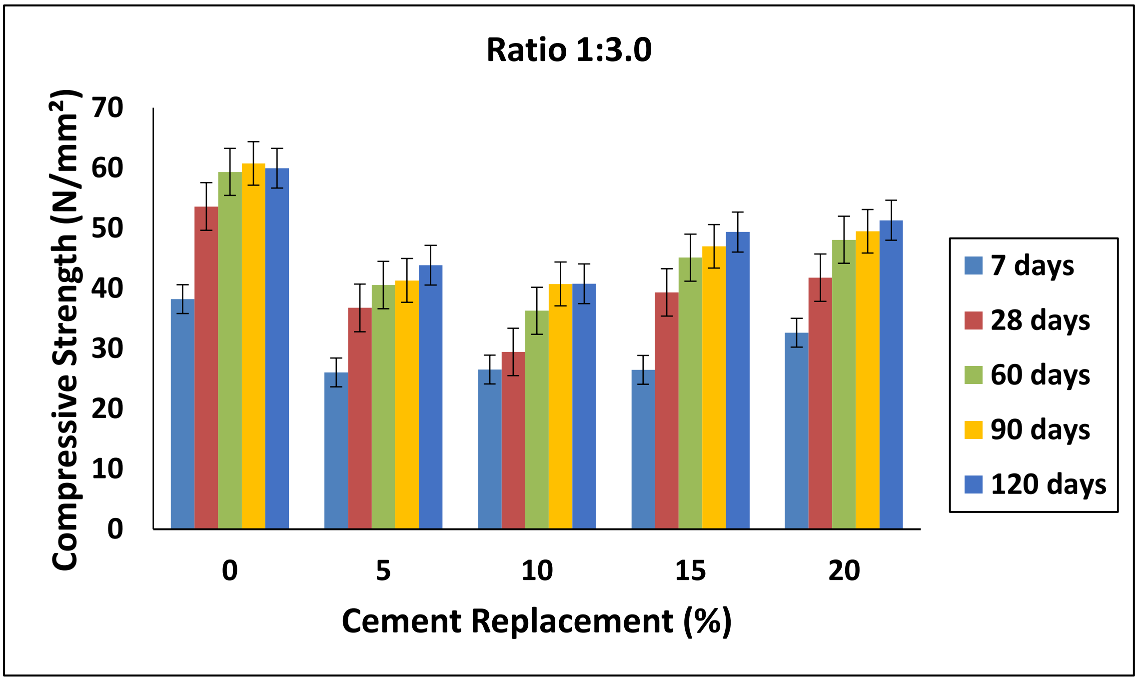


Figure 5: Variation of Compressive Strength Development in Mortar Cube

Variation of compressive strength development of mortar cube containing varying contents of glass powder is as shown in Figure 5. From the Figure 5, the mortar contain 5%, 10% and 15% of glass powder is slightly different from average stress at 7 days where the 10% of WGWP has the higher strength at 7 days of curing but exhibited the lower strength at 28 days of curing. For the 5%, 10% and 15% glass powder mixture shows an increment in average stress at 60 days compare to 28 days value but 10% of glass powder still showed the lower value about 36.28 N/mm^2. The average stress for 10% of WGWP taken at 120 days is almost the same with the result at 90 days age of curing with stress value of 40.77 N/mm^2.

From this study, the compressive strength of the mortar cube increases from 5% of glass powder content to the 20% of glass powder content in the mortar mixture. The 20% of glass powder contained in the mortar mixture has the maximum compressive strength compare with other glass powder content. The increased in compressive strength of mortar cube with glass powder is due to the pozzolanic reactivity. The glass powder has an active pozzolanic particle due to high silica content. Pozzolanic reaction happens in the cement paste when the glass powder mixed with calcium hydroxide to form a second form of calcium silicate hydrate (CSH). According to Kushartomo *et al,* (2015), the silica content is possibly similar to calcium hydroxide in the mix design with a percentage of 20% of WGWP, so that the pozzolanic reaction occurs is at the maximum. Thus, this reaction can improve the properties of mortar including the strength of mortar.

Other than that, based on Figure 5, the compressive strength of mortar cubes for 20% percentage replacement of glass powder increase as the curing age also increased. This may be due to the finely glass powder reacts with calcium hydroxide to form highly stable of complex composition involving calcium, silica and water as suggested by (Omoniyi *et al,* 2014). The production of heat hydration and development of strength is also slow when the pozzolanic reaction is slow (Omoniyi *et al,* 2014). This indicates that the increase of compressive strength in mortar cause by the faster pozzolanic reaction.

Besides, the particle size of the glass used also the key factor that influencing the development of compressive strength. As stated in previous study by Federico and Chidiac (2009), the compressive strength is highest for the mortar paste when used very fine glass less than 100μm and in this study the particle size of the glass is 90μm. It is noted that the maximum strength occurred for mortar with 20% glass powder followed by 15% glass powder as partial replacement of cement.

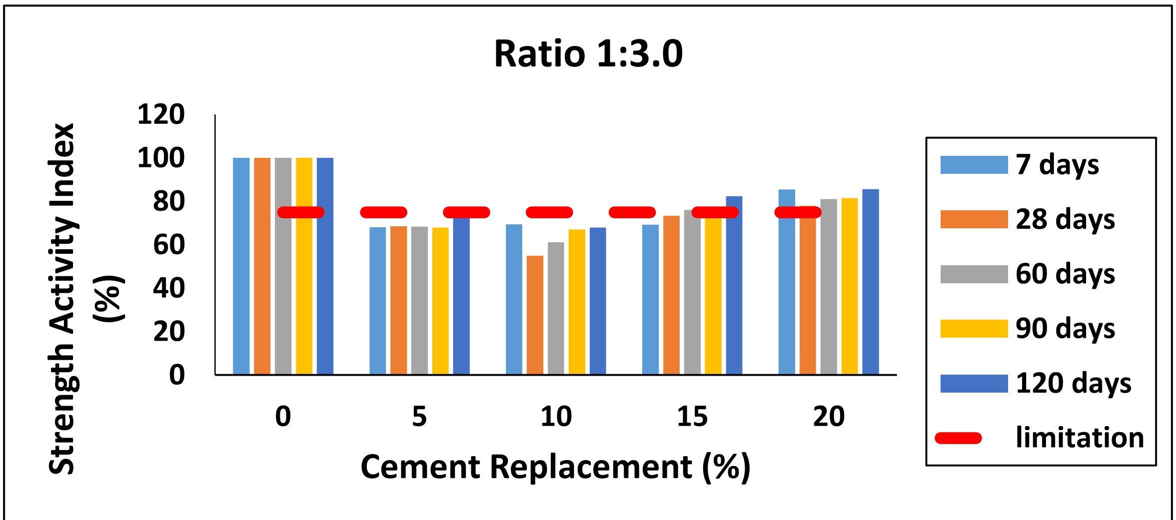


Figure 6: Dashed line indicates the limit of strength activity index at 7,28, 60, 90 and 120 days as prescribed by standard ASTM C 618

Strength activity index as prescribed by ASTM C 618,

Strength Activity Index (SAI) = (A/B) x 100

Where,
A= average compressive strength of blended cement mortar cube
B= average compressive strength of control Mortar cube

The strength activity index for the cement-WGWP mortar is shown in Figure 6 for curing at 7, 28, 60, 90 and 120 days respectively. The minimum requirement for strength activity index as prescribed by ASTM C 618 value is 75%.This gives a measure of how close the values are to the control. From Figures 6, cement to sand (C:S) ratio of 1:3.0 containing 15% cement replacement at 60,90 and 120 days shows mortar achieved the strength activity index of 76%, 75% and 82% respectively.

In figure 6 at 7, 28, 60, 90, and 120 days curing the highest strength activity index with the replacement of WGWP for 20% cement replacement the SAI were 85%, 78%, 80%,81% and 85% respectively. It can be seen that at 28, 60, 90 and 120 days, the SAI of cement-WGWP mortar increased with time. The result was consistant with that of Patel *et al.*, (2012)and Khmiri *et al.*, (2013) that the replacement of glass in cement content have significant effect on the strength development of mortar. It can be conclude that strength activity index achieved (C:S) of ratio 1:3.0 at 20% by mass.

4.0 Conclusions

The surface area of WGWP was coarser than OPC and the density is lower than of OPC. The surface area increased as the particle size become small. Therefore, a small particle will react much quickly than a large particle. The XRD pattern indicates that WGWP is amorphous material which is attributed to the glassy phase and from the chemical analysis shows that WGWP can be classified as Class N natural Pozzolanic. Replacement of 20% cement with WGWP reveals the highest compressive strength at 120 days than any other levels of WGWP replacement. The strength activity index achieved (C: S) of ratio 1:3.0 at 20% by mass.

Acknowledgements

The authors would like to express their appreciation to Universiti Malaysia Terengganu (UMT) and Universiti Teknologi MARA for their assistance, cooperation and supports.

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