Effect of Using Windscreen Glass Waste Powder (WGWP) As Cement Replacement on the Mechanical Properties of Mortar

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Abstract. Sustainability issues have obtained major attentions around the globe. In this regard, there are challenges which the cement and glass industries are facing due to the high greenhouse gases emissions, the intensive use of energy and the reduction of natural resources on earth. However, the chemical compositions and the pozzolanic properties of waste glass are very encouraging for its use in cement and concrete industries and to provide an environment-friendly solution. For sustainability, it is high time to look into the possibility of replacing cement with windscreen waste glass. A study was conducted on the effects of various proportions of windscreen glass waste powder (WGWP) on the compressive strength of mortar. The mortar was prepared by incorporating several compositions of WGWP (0%, 5%, 10%, 15% and 20% by weight of cement), while three cement to sand (C:S) ratios of 1:2.5, 1:3.0 and 1:3.5 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 was carried out at 7 and 28 days. Results have shown that WGWP has good pozzolanic properties. In term of compressive strength, it was observed that employing C:S ratio of 1:3.0 is better than 1:2.5 and 1:3.5 of C:S ratio.

1. Introduction

Waste glass is a major environmental issue across the country [1]. This non-biodegradable material occupies most of the landfill causing serious environmental pollution. Lack of space for new landfills is considered a major problem faced by the world's denser population. The best solution to overcome the environmental impact of this waste glass is to recycle and reuse it. By recycling this waste, it retains the natural resources of the earth, reduces landfills and saves energy and money [2]. Large quantity requirements, low quality requirements and extensive construction sites make the construction industry one of the most attractive ways to address the environmental impact of waste glass.

The glass industry uses enormous natural resources as raw materials. It is estimated that 1 kg of sheet glass uses 1.73 kg of raw material and 0.15 m³ of water [3]. Besides that, it was found that the production per ton of glass containers consumed 1.2 tonnes of expensive raw material [4].
Practically, the crushed waste glass can be recycled glass known as cullets are widely used in the production of glass containers and glass wool.[5]. Hence, using cullet as a raw material in glass production requires only 40% of the energy used to make glass from sand [6]. In theory, without losing any of its chemical and physical properties, glass can be recycled completely and infinitely [7-9].

The construction industry, especially the cement and concrete industries can provide very important and useful solutions to the environmental impact of glass waste due to the chemical composition and physical properties of glass comparable to sand and cement.[10-12]. The production of cement and concrete The use of glass waste instead of cement and concrete can conserve the earth's natural resources, saving energy and money, reducing CO2 emissions and other greenhouse gases.

The cement industry is the second largest producer of CO2. This process produces about 50% of the chemical process, 40% of the fuel burned and 5% of the global CO2 emissions.[13]. One of the most effective ways to minimize the CO2 emissions is to reduce clinker in cement. [14]. This can be done by using a mixture of wastes and clinkers to produce cement. It is reported that using 5% of the waste mixture can reduce CO2 emissions[15], and study shows that as higher as 20% of waste can be mixed [14]. Using waste in the production of cement and concrete can save the earth's natural resources, save energy and decrease cement’s production costs.

The objective of this paper to analyse the effect on windscreen glass waste powder (WGWP) is to discover its potential as cement replacement material. The chemical, physical and compressive strength of mortar with different proportions of WGWP cement to sand (C:S) ratios were studied.

2. Methodology

To determine the specific surface area the test of fineness using the nitrogen absorption method and Brunauer, Emmatt and Teller (BET) equipment was investigated. Gas Pycnometry-Micromeritics 1340 to test the density. In determining the element content of WGWP, the energy dispersing x-ray spectroscopy (EDAX) and x-ray diffraction (XRD) were conducted.

The windscreen glass was acquired from workshop in Terengganu, Malaysia. The Organo Cycler machine at Mariwealth Engineering & Consultancy Sdn. Bhd, Selangor was used for the process of removing polymers from windscreen glass. The windscreen glass waste powder (WGWP) was made by used the Los Angeles machine to grind with 10,000 revolutions. The flow of the process of producing WGWP was shown in Figure 1. Other materials used in the mortar mixture were Ordinary Portland Cement (OPC) and fine aggregate of 5 mm maximum size.

![Figure 1: Preparation of windscreen glass waste powder](image-url)
The study was conducted by providing 45 sample mortar cube with dimensions 50mm x 50mm x 50mm. Using the ratio of cement to sand (1: 2.5, 1: 3.0 and 1: 3.5, five (5) proportions were made up of various percentages of WGWP (0%, 5%, 10%, 15% and 20%) by weight of cement. The water to cement (w/c) ratio was fixed at 0.5. The samples of cube mortar were water cured until the day of the compressive testing at 7 and 28 days. For mix compositions of 1:2.5, 1:3.0 and 1:3.5, the cement contents were 2.27kg, 2.07kg and 1.89kg respectively. The sand contents were 6.39kg, 6.93kg and 7.37kg respectively. In accordance with ASTM C: 109 compressive strength was carried out. [16]. Three (3) replicates were used for each batch.

3. Results and Discussion

The surface of a material is the dividing line between a solid and its surroundings, liquid, gas or another solid. An important factor in solid behavior is surface area. Surface area may affect adsorption capacity of air and water and the processing of most powders and porous materials. Whenever solid matter becomes smaller particles, new surfaces are created thereby increasing the surface area. The result of BET surface area and total area for both OPC and WGWP is shown in Table 1.

Table 1: BET surface area and total area of OPC and WGWP

| Parameter                        | OPC  | WGWP |
|----------------------------------|------|------|
| BET surface area (m²/g)          | 1.0242 | 0.6462 |
| Total area in pores (m²/g)       | 0.1250 | 0.2100 |
| Density (g/cm³)                  | 2.9885 | 2.5318 |

The result shows that WGWP has smaller surface area than OPC. Practically, particle size and surface area are closely related to their inversely proportions. The particle size becomes smaller as the surface area increases. The specific surface area increases if the particles have pores. In this study, WGWP has higher total area than OPC. In determining the workability, water absorption and durability of concrete, surface area plays an important role.

Table 2: Chemical compositions of raw materials

| Composition            | OPC  | WGWP |
|------------------------|------|------|
| Silicon dioxide, SiO₂  | 16.03 | 76.11 |
| Calcium oxide, CaO     | 69.06 | 5.01 |
| Aluminum oxide, Al₂O₃ | 4.14  | 3.45 |
| Ferric oxide, Fe₂O₃    | 5.09  | 0.38 |
| Sodium oxide, Na₂O     | 0.02  | 10.10 |
| Magnesium oxide, MgO   | 0.67  | 4.00 |
| Sulphur oxide, SO₃     | -    | 0.05 |
| Potassium oxide, K₂O   | 1.3   | 0.33 |
| Loss on Ignition, LOI  | -    | -    |
From Table 2, the calcium oxide (CaO) content in the OPC was 69.06%, while the silicon dioxide (SiO$_2$) WGWP was 76.11%. The chemical compositions of raw materials were determined using energy dispersing x-ray spectroscopy (EDAX). The result is in agreement with ASTM C618-02[17] which requires a sum of SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$ higher than 70% for good pozzolan. The total for the investigated sample of WGWP is 79.94%. The studied windscreen glass waste glass presents a satisfactory chemical composition. It is classified as Class N natural pozzolan and therefore it is likely to become good pozzolan.

The chemical compositions, however, should not be used as the only criteria for the prediction of the pozzolanic activity. The amorphous state is also required. It has been confirmed for WGWP by XRD as shown in Figure 2. Indeed, no peaks attributed to any crystallized compound can be identified except a broad diffraction halo which is attributed to the glassy phase. The results XRD of WGWP shown in Figure 2 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 $\theta = 20^\circ$.

![Figure 2: Amorphous or glassy](image)

Figure 3 and Figure 4 are presented the results of the compressive strength for the various mixes at 7 and 28 days water curing. Three (3) samples were used to show the average value of WGWP mortar strength with different percentage. It can be observed that at 7 days, the compressive strength at (C:S) ratio of 1:2.5 gradually decreases with the replacement of WGWP with the highest compressive strength at 5% WGWP replacement. It shows that the control at age 7 days was 31.31 N/mm$^2$. For 5%, 10%, 15% and 20% replacement of WGWP were 32.54 N/mm$^2$, 23.47 N/mm$^2$, 25.53 N/mm$^2$ and 22.16 N/mm$^2$ respectively. It shows that the replacement of cement with 5% WGWP improved compressive strength of mortar at both (C:S) ratio of 1:2.5 ad 1:3.0. However further increases in replacement resulted in reduced strength. This is also true for 1:3.0 and 1:3.5. The reduction in compressive strength is caused by a reduction in the quantity of cement content available for the hydration process.
Figure 3 and 4 also show that the prolonged curing of mortar resulted in increased strength. At 28 days curing, the compressive strength of mortar at (C:S) ratio of 1:3.0 and the control sample (0% WGWP) were 39.59 N/mm$^2$ and 34.91 N/mm$^2$ respectively. It can be concluded that replacement of 5% cement with WGWP reveals the higher compressive strength at 28 days than other levels of WGWP replacement indicating that the use of WGWP enhances pozzolanic activity. It can be concluded that the optimum mix was 5% WGWP replacement and (C:S) ratio of 1:3.0.

4. Conclusions

Based on surface area findings, it can be inferred that OPC is finer than WGWP and its density is higher than WGWP. The surface area is increased as the particle size become small. Therefore, a small particle will react much more quickly than a large particle. The XRD pattern indicates that WGWP is amorphous material which is attributed to the glassy phase. The chemical analysis shows that WGWP can be classified as Class N natural pozzolan. Replacement of 5% cement with WGWP reveals the higher compressive strength at 7 and 28 days than other amount of replacement. The ratio of 1:3.0 was chosen as the optimum ratio which gave an improved compressive strength as compared to that of C:S ratio of 1:2.5 and 1:3.5.
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