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Potential of substituting waste glass in aerated light weight concrete

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Abstract

This paper investigates the potential of substituting the waste glass in making aerated light weight concrete. The physical, chemical and activity index properties of the ground waste glass are first investigated. Subsequently, the waste glass is incorporated in the aerated light weight concrete formulation as cement substitution at different ratios. The density and initial compressive strength of aerated light weight concrete result are then compared. Based on the initial experiment results, the ground waste glass can be potentially substituted up to 20% as pozzolanic material in making aerated light weight concrete.

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Keywords: Waste glass; Aerated light weight concrete; Pozzolanic material; Cement replacement; Sand replacement.

1. Introduction

According to 2014 Singapore National Environment Agency (NEA) annual statistic report, 79,500 tons of waste glass was generated in Singapore and only 20% of the amount was recycled [1]. The remaining quantity of waste glass was either disposed at landfills or recycled back to low cost glass product at the neighboring countries [2]. The deposition of waste glass to landfills is definitely not a sustainable environmental solution to Singapore. Although, the waste glass can be recycled back to new glass products; however, the process of sorting, crushing and re-melting which require high energy is not favourable in long run. Furthermore, these recycling process may also instigate air pollution if there is any mishandling.

Aerated light weight concrete or also known as cellular concrete is a light weight building material that has been aerated to reduce its density before to the setting of Portland cement in the formulation. The LWC offers not only low density, they also possess superior insulation and acoustic performance, fire resistant properties as well as

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relatively high strength coupled with dimensional stability. The LWC can be used to make partitions, prefabricated unit, floating platform and many other applications in building and construction that require low load application. The quick and easy installation of LWC also can significantly reduce the intensive labour and overall load of buildings.

Therefore, the main objective of this study is to investigate the potential of substituting the increasing waste glass number as in the production of aerated light weight concrete (LWC). Furthermore, converting the waste glass into raw materials in building material open up an attractive option in the building and construction industry. The benefits not only reduce the reliance on natural resources, lower the disposal cost and landfill volume but also help to reduce the carbon dioxide emission to our environment [3]. Utilizing industrial by-products such as bottom ash, pulverize fly ash and steel slag as fine aggregate for cement substitute has been common in the building and construction industry [4]. However, there are still very limited studies focusing on the use of waste glass as the replacement raw material in making LWC.

This paper therefore present the preliminary investigation of using finely ground waste glass in making LWC in terms of physical (dry bulk density) and mechanical (compressive strength) as a partial replacement of cement or sand. The LWC sample are water cure by conventional method and the properties are investigated and compared. This research hopes to improve the building and construction industry by increasing the usage of waste glass while sustaining good LWC performance and enhance the waste glass recycling rate. By substituting waste glass in LWC as partial replacement of cement can pose an advancement towards the development of a sustainable environment, energy efficient concrete-based building and construction industry.

2. Materials and experiment

2.1. Materials

The main materials used to produce the LWC samples were Ordinary Portland Cement (OPC) CEM I 42,5N, water, sand, lime, gypsum, ground granulated blast furnace slag (GGBS) and aluminum powder. The waste glass used in this research was a typical clear soda-lime glass that obtained from post-consumer glass product.

2.2. Waste glass

Two types of post-consumer waste glass (colored and non-colored clear type) were used on this study. The post-consumer waste glass was crushed into cullet size and followed by grinding process to fine particles using a Fritsch Planetary Mill PULVERISETTE 5. The glass particles were then sieved into desired particle size range. The ranges of glass particle size used in the experiment were:

- Waste glass having particle size in the range of >90µm
- Waste glass having particle size in the range of 45-75µm

The chemical properties of both color and non-colored clear glass were first compared using X-ray fluorescence (XRF).

2.3. Mixtures

The basic materials used to produce the LWC sample is summarized in Table 1. Milled waste glass, foaming agent (aluminum powder), water, lime, cement, GGBS and gypsum were added at different proportions with varying the ratio. The bulk density of the waste glass and cement are 1051 kg/m^3 and 1522 kg/m^3 respectively. To investigate the potential of replacing the waste glass in making LWC, a specific proportion of waste glass is incorporated in LWC formulation as cement.

Table 1 summarizes the LWC formulations prepared in this paper. The finely grounded waste glass was mixed and casted into 100x100x100mm steel mould based on the formulation in Table 1. Six LWC mould samples were prepared for each formulations. The LWC samples were demolded after 24 hours, the excess expanded portion of the sample were trimmed and oven dried for 24 hours at $80^{0}C \pm 5^{0}C$, until the constant weight was obtained before the water-curing for 7 and 28 days at room temperature.

To study the influence of the finely grounded waste glass to the properties of LWC, the waste glass was incorporated as cement substitute in sample C at 10% and 20% by weight percentage. The control samples contained the same set of raw material except without any glass replacement.

Table 1: LWC formulations with different loadings of waste glass as partial replacement of cement or sand

Formulations	OPC (g)	Glass (g)	GGBS (g)	Gypsum (g)	CaO (g)	Water (g)	Al powder (wt% of binder)
Control C	100	0	500	5	30	450	0.08
C10	90	10	500	5	30	450	0.08
C20	80	20	500	5	30	450	0.08

2.4. Experiment

2.4.1. Waste glass characterization

The chemical composition of both finely grounded colored and non-colored glass were analyzed using an X-ray Fluorescence (XRF) ARL 8400 based on BS EN 196-2:2013 [5].

2.4.2. *Activity indexes of waste glass and cement mortars*

During the initial stage, the activity index of waste glass was investigated accordance to BS EN 196-1:2005 [6]. The mixed waste glass was crushed into cullet, milled and sieved into particle size range (a) >90 µm and (b) 45-75 µm. These waste glasses were then incorporated 10% and 30%, as cement replacement in making standard mortar bars. The mortar bars were water-cured for 7 and 28 days at room temperature. The evaluation of the activity indexes of test mortar bars would give an estimated of optimum waste glass percentage and particle size can be used in the LWC formulations.

2.4.3. *Dry bulk density and compressive strength*

The LWC formulations with various proportion of waste glass incorporated as substitution for cement are summarized in Table 1. Six cubes (100 x 100x 100 mm) were casted. Prior to compression test, the dry bulk densities of the LWC samples were measured in accordance to ASTM C567 [7]. The LWC samples were tested in accordance to BS EN 12390-3:2000 [8] for the compressive strength at 7 and 28 days curing age.

3. Results and discussion

3.1. Waste glass characterization

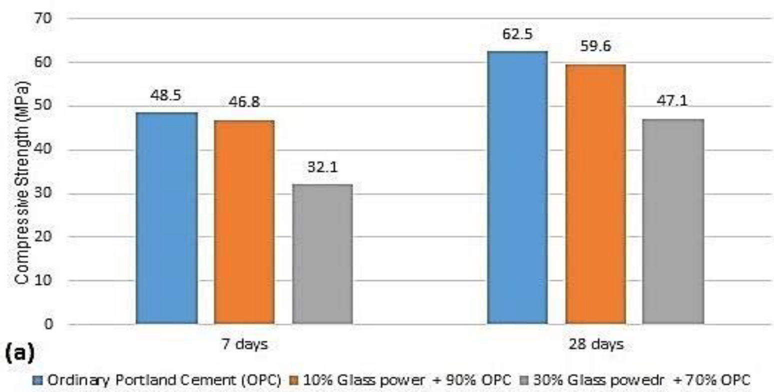
The chemical composition of both the colored and non-colored clear waste glass is shown in Table 2. From Table 2, the major composition of both the colored and non-colored clear glass are mainly SiO_2. Although some traces of elements such as TiO_2 and Cr_2O_3 are present in the colored waste glass, while BaO, Pb, ZnO are found present in non-colored clear waste glass. But the percentage is fairly minor as compared to SiO_2, Na_2O, CaO and Al_2O_3.

Table 2: Chemical compositions of clear and mixed waste glass used in this research

Element	Colored	Clear
SiO_2	66-67%	66-68%
Na_2O	14-16%	14-16%
CaO	14-16%	14-16%
Al_2O_3	1-2%	1-2%
K_2O	<1%	<0.5
Fe_2O_3	<0.5	<0.1
TiO_2	<0.5%	0.0
Cr_2O_3	<0.1%	0.0
SO_3	<0.1%	<0.5
SrO	<0.1%	<0.5
MnO	<0.1%	0.0
BaO	0.0	<1
Pb	0.0	<0.1
ZnO	0.0	<0.5

3.2. Activity indexes of waste glass and cement mortars

To investigate the potential use of the waste glass in replacing the cement in making aerated light weight concrete (LWC), the activity index of powdered waste glass is investigated. In this studies, both the colored and non-colored waste glass was mixed as one sample since no significant difference in chemical composition is found based on the previous studies. The activity index results of the sample are indicated in Fig. 1.



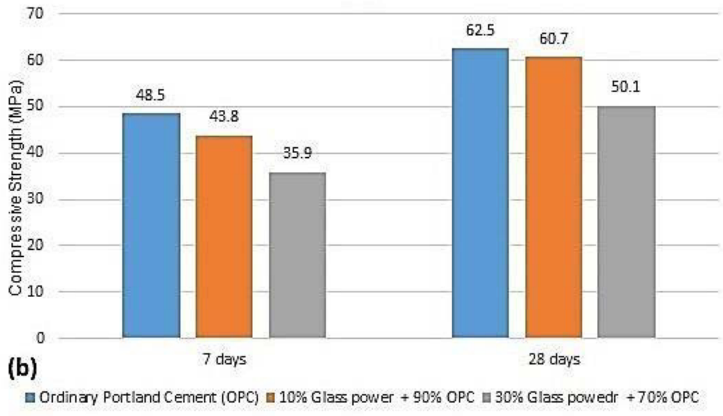


Fig. 1: Activity indexes of mortar bar with (a) >90 µm, (b) < 75 µm

First, it is evident that the incorporation of waste glass as cement replacement is possible at the percentage of not more than 10%. It is obvious that the early activity index (7 days) of mortar bar with 10% waste glass substitution shown insignificant difference with the control mortar bar which uses only the OPC cement. The compressive strength for mortar bars with waste glass of particle size >90 µm and <75 µm is 46.8 MPa and 43.8 MPa respectively as compared to the standard cement mortars of 48.5 MPa. Subsequently, the attained 28 days activity index rise almost close to standard cement 59.6 MPa and 60.7 MPa as compared to the standard cement mortars of 62.5 MPa.

On the other hand, both the 7 and 28 days activity index of the sample decrease obviously when the waste glass content is increased to 30% replacement as compared with the 10% replacement in cement content. The early activity index (7 days) of the mortar bars with 30% loading of waste glass particle size of >90 µm and < 75 µm is 32.1 MPa and 35.9 MPa respectively as compared to that of the standard cement mortar (48.5 MPa). While the early activity index (28 days) of the mortar bars with 30% loading of waste glass particle size of >90 µm and < 75 µm is 47.1 MPa and 50.1 MPa respectively as compared to that of the standard cement mortar (48.5 MPa). The reduction of the activity index is almost by 25 - 32%.

In addition, it is observed that the mortar bar with waste glass particle <75 µm performs better than mortar bar with waste glass particle >90 µm in both 10% and 30% substitution samples. Such observations could possibly relate to the amorphous content in waste glass increases with decreased glass particle size. Based on such result, the waste glass with particle size range of <75 µm seem to provide better pozzolanic properties [9].

3.3. Dry bulk density and compressive strength

The density of the LWC samples at different loading proportion are measured and summarized in Table 3. In this studies, the glass particle is milled and sieve to <75 µm to cast the sample. The density is calculated based on the LWC samples dry bulk weight after oven dried. As can be observed, the density of the LWC samples decrease when the waste glass is used to substitute the cement portion in the formulation. The bulk density of the waste glass and cement used in this studied are measured and compared. The density of waste glass and cement are found to be 1051 kg/m^3 and 1522 kg/m^3 respectively. Hence, it is expected that the replacement of the waste glass in the cement can reduce the overall density of the LWC.

Table 3: Effect of glass content on the dry bulk density of LWC samples

Formulation	Dry bulk density (kg/m^3)
Control C	738
C1	719
C2	620

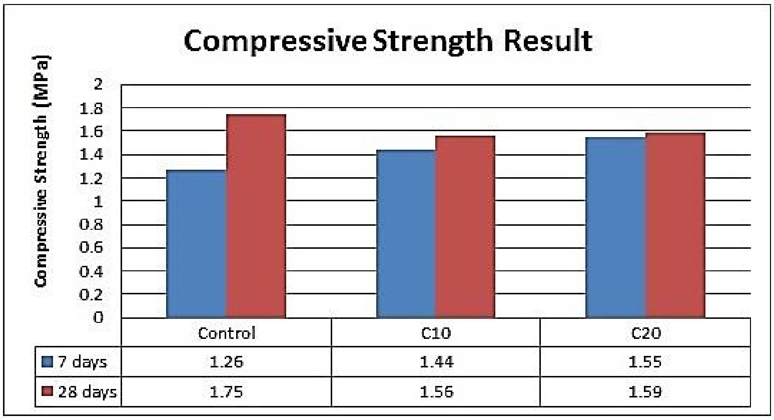


Fig. 2: Compressive strength result

Generally, compressive strength of aerated light weight concrete has a lower mechanical properties in comparison with ordinary concrete. For the sake of early investigation, this study focus on the potential use of waste glass to replace the cement content in LWC. Hence the LWC is cured in room temperature condition instead of autoclaving. The compressive strength of the LWC samples is represented at Fig. 2.

The result clearly indicated that the early compressive strength of the LWC increased with waste glass loading. The compressive strength of the C10 and C20 LWC sample are 1.44 MPa and 1.55 MPa as compared to that of the control sample 1.26 MPa. This observation could be contributed by the high amorphous structure of the finely grounded waste glass offers excellent pozzolanic properties and hence provides early strength development within the LWC.

Conversely, it is notice that the compressive strength of C10 & C20 LWC samples is slow down at the age of 28 days. The compressive strength of C10 and C20 LWC samples are 1.56 MPa and 1.59 MPa respectively as compared to control sample 1.75 MPa. One of the possibility reasons is that the addition of waste glass in LWC formulation decreases the Dicalcium Silicate (C_2S) formation within the LWC which usually formed at a slower rate. Therefore, the reduced of cement content in C10 and C20 retard the overall strength at 28 days. This further indicates that the replacement of waste glass as cement need to be controlled and optimized so that to prevent the weakening of the LWC.

4. Conclusion

This study aim to investigate the potential of recycle the waste glass in light weight concrete. The activity index, density and the preliminary compressive strength of the LWC were studied and compared. In this investigation, the LWC was prepared and cured at room temperature. The activity index, density and preliminary compressive strength were then analyzed and compared. Based on the work, the following conclusions can be drawn:

- The ground waste glass can be used to replace cement in LWC.
- The fineness of the waste glass used has a strong influence on the activity index of cement.

- The bulk density of LWC were decreased as the ground waste glass was incorporated into the LWC samples. Such observation is mainly due to the overall bulk density of ground waste glass is less dense that cement material.
- The use of ground waste glass as cement substitute is possible at maximum of 10% and the compressive strength gain is mainly control by the pozzolanic characteristics in the waste glass

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