

The Feasibility of Using Milled Glass Wastes in Concrete to Resist Freezing-Thawing Action

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Abstract—The using of waste materials in the construction industry can reduce the dependence on the natural aggregates which are going at the end to deplete. The glass waste is generated in a huge amount which can make one of its disposals in concrete industry effective not only as a green solution but also as an advantage to enhance the performance of mechanical properties and durability of concrete. This article reports the performance of concrete specimens containing different percentages of milled glass waste as a partial replacement of cement (Powder), when they are subject to cycles of freezing and thawing. The tests were conducted on 75-mm cubes and 75 x 75 x 300-mm prisms. Compressive strength based on laboratory testing and non-destructive ultrasonic pulse velocity test were performed during the action of freezing-thawing cycles (F/T). The results revealed that the incorporation of glass waste in concrete mixtures is not only feasible but also showed generally better strength and durability performance than control concrete mixture. It may be said that the recycling of waste glass in concrete mixes is not only a disposal way, but also it can be an exploitation in concrete industry.

Keywords—Durability, glass waste, freeze-thaw cycles, non-destructive test.

I. INTRODUCTION

GLASS waste is one among many waste materials used in concrete industry, and due to the fact that glass is an inorganic material made by sintering selected raw materials, it can be neither incinerated nor decomposed. Glass recycling can reduce the complete reliance on natural aggregate resources and decrease the generated environmental waste (green solution).

Glass waste can be used in construction industry as a partial replacement of fine aggregate or/and as a partial replacement of Portland cement (glass powder). Pattengill and Shutt (1973) were the first who used the grounded powdered glass as pozzolanic material to replace the cement partially [1]. Many research works were published on the topic of adding glass waste to the concrete mixtures as an alternative solution to reduce the generated bulk of glass waste, and to establish a ground for understanding and examining the glass waste recycle process [2]-[19]. Expansive reactions between amorphous silica (glass) and alkalis (such as: sodium and potassium found in high concentration-alkali Portland cement) could have deleterious effects if glass is used in concrete structures. Bazant et al [3] found that glass particle sizes of

around 1.5 mm caused excessive expansion whereas particles less than 0.25 mm caused no expansion in laboratory tests on concrete. Carpenter and Cramer [10] also reported that powdered glass was effective in reducing alkali-silica reaction expansion in mortar tests.

Freeze-thaw cycles (F/T) are one of the environmental causes of deterioration effects on concrete. When water freezes to ice in the pores of the concrete, it expands about 9 percent more than volume of water. Since there is no enough space in the porous concrete, freezing can cause pressure in the pores and if that pressure exceeds the tensile strength of the concrete, the cavity will dilate and rupture. The accumulative effects of freeze-thaw action throughout successive winter seasons and disruption of paste and aggregate can cause in the vast majority of cases expansion and cracking, scaling and crumbling of the concrete. Typical example of a deterioration of concrete due to the environmental action of freeze-thaw cycles is shown in Fig. 1.

Kim et al. [2] used waste glass sludge as a partial replacement of cement to improve the durability properties of concrete under condition of (F/T) with the existence of deicing salts. They found that the resistance to (F/T) was improved with and without de-icing salts.



Fig. 1 Typical example of concrete deteriorated from freeze-thaw actions. (Non-air-entrained concrete railing, PCA vol. 19/1 1998)

This study presents a preliminary study to assess the reuse of waste glass as fractional cement replacement in concrete mixes. Different percentages of powdered glass (0%, 5%, 10%, and 15%) were incorporated in the concrete mixes. Two types of mechanical test specimens have been used, namely, compressive strength specimens 75-mm cubes (BS 1881 Part 108) and 75 x 75 x 300-mm prisms. The concrete specimens containing the different glass percentages were exposed to 0, 100, 200 and 230 cycles of freezing and thawing with temperature range of -16°C to $+6^{\circ}\text{C}$. The results indicated that the using of glass waste in concrete was able to improve the mechanical properties and decrease the deterioration of concrete subjected to freezing-thawing action.

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II. MATERIALS

Natural crushed fine and coarse limestone aggregates and ordinary Portland cement (OPC) were used to prepare all concrete mixes. The fineness modulus of fine aggregate was 2.8 and the maximum coarse aggregate size was 12.5 mm. Table I shows the aggregate properties.

TABLE I
THE AGGREGATE PROPERTIES USED IN THE RESEARCH

Aggregate type (limestone)	ASTM test designation	Bulk specific gravity	Apparent specific gravity	Absorption percentage
Coarse	C 127	2.5	2.52	4.5
Fine	C 128	2.47	2.485	7
Mineral filler	C 128	2.515	2.534	

Glass contains about 70 percent of Silicon dioxide (SiO₂) which is considered the most common glass-former. The used waste glass in the research was obtained from bottles and window glass which is referred to Soda-lime glass type. This type accounts for approximately 90 percent of glass produced in the United States of America. The typical chemical composition of Soda-lime glass type is shown in Table II.

TABLE II
CHEMICAL COMPOSITION AND THEIR PERCENTAGES OF SODA-LIME GLASS [20]

SiO ₂	70-73
Al ₂ O ₃	1.7-2.0
Fe ₂ O ₃	0.06-0.24
Cr ₂ O ₃	0.1
CaO	9.1-9.8
MgO	1.1-1.7
BaO	0.14-0.18
Na ₂ O	13.8-14.4
K ₂ O	0.55-0.68

The waste glass used was crushed and milled to obtain fine and powder gradations as shown in Table III. The sizes of crushed glass used as a partial replacement of fine aggregate were between 4.75 mm and 0.075 mm, whereas, the size used as a partial replacement of cement was less than 0.075mm.

III. EXPERIMENTAL WORK AND TEST METHODS

A. Mixture Proportions

To achieve the main objective of this research, a total of four concrete mixtures were prepared to determine the impact of replacement many percentages of milled glass wastes on the performance of mechanical properties and durability of concrete subjected to freezing-thawing cycles. Glass waste was incorporated in concrete mixtures for comparison at different percentages of 5%, 10%, and 15% as a partial replacement of cement.

The control concrete mixture (without waste glass) had a water to cement ratio (w/c) of 0.5, and a proportion (by weight) of 1.75 and 3.25 for fine and coarse aggregates respectively.

A slump test was carried out to determine the workability of fresh concrete for each mixture where superplasticizer was used to achieve the required slump.

TABLE III
SIEVE ANALYSIS GRADATIONS OF THE CRUSHED WASTE GLASS

Sieve size	% passing (mid-point)	% retained	% cumulative retained
3/4" (19.5mm)	100	0	0
1/2" (12.5mm)	95	5	5
3/8" (9.5mm)	88	7	12
# 4 (4.75mm)	51	37	49
# 8 (2.36mm)	31	20	69
0.85 mm	11	20	89
0.425 mm	6	5	94
0.075 mm	2	4	98
pan		2	100

B. Test Methods

1. Compressive Strength

The compressive strength test was performed according to (BS 1881 Part 108). The concrete mixtures having glass waste were prepared according to the previous mentioned glass waste percentages. The all mixtures were cast in molds consisting of 75-mm cubes and prisms of 75 x 75 x 300 mm. Two concrete cubes and two prisms were cast for each concrete mixture and they were cured in standard conditions for 28 days. Thereafter, part of specimens containing the previously mentioned different percentages of glass waste as well as the specimens of control mixture concrete were tested to measure the mechanical strength of concrete mixes. The rest of specimens were subjected to different freezing-thawing cycles and then some of them were tested to measure the mechanical strength.

2. Non-Destructive Test

The non-destructive test including the ultrasonic pulse velocity method was performed using prisms of 75 x 75 x 300 mm subjected to certain numbers (0, 100, 200 and 230) of freezing-thawing cycles (F/T) to measure the compressive strength.

3. Freezing and Thawing Test

The cubes and prisms specimens were subjected to repeated freezing and thawing cycles according to ASTM C666 (standard test method for resistance of concrete to rapid freezing and thawing, procedure A, rapid freezing and thawing in water) in order to simulate the real environmental action of freezing and thawing. All specimens were subjected to F/T cycles after curing in water for 28 days. In this test the temperature of the F/T cycles was lowered from 6 to -16°C and raised from -16 to 6°C in 2.5 hours. The ultrasonic velocity readings were taken at 0, 100, 200, and 230 cycles of freezing and thawing.

IV. RESULTS AND DISCUSSIONS

The laboratory and non-destructive testing of concrete specimens yielded the following results:

A. Resistance of Weight Loss of Concrete Prisms

Fig. 2 shows the weight loss percentage of concrete specimens caused by the concrete surface scaling, which occurred when concrete specimens were subjected to the action of freezing and thawing cycles. In all figures the letter P indicates that the glass waste powder replaces partially the cement. The results showed that the addition of glass waste played a significant role in decreasing the surface scaling, especially when was added as a partial replacement of 10% of cement. This decreasing may be related to the fact that the glass makes the concrete relatively less thermal conductive as well as the creation of hydrated phases C-H-S due to the pozzolanic reaction of glass powder which leads to a reduced risk of expansion due to Alkali-Silica reaction and a reduction in permeability. Those results agree well with [2].

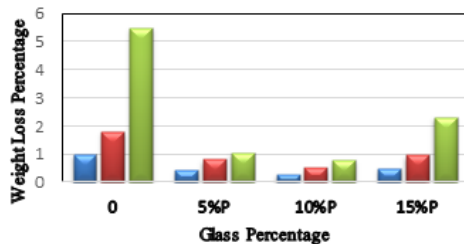


Fig. 2 Weight loss percentage of concrete prisms containing different glass percentages at 100, 200 and 230 F/T cycles

B. Compressive Strength

Fig. 3 shows compressive strength results of cubes based on experimental test results related to the mixtures containing different glass waste percentages when they were subjected to the action of freezing and thawing cycles at zero and 230 cycles.

For the specimens which were not exposed to freezing thawing action (at zero cycle), it can be seen that the compressive strength of the concrete cubes containing glass waste replaced partially the cement increased more comparing to the conventional concrete specimens whereas, the maximum compressive strength was achieved when the powder of glass was partially replaced the cement by 5%.

For the specimens who were exposed to 230 F/T cycles, the mixture containing also the powdered glass of 5% showed the highest compressive strength. These test results indicated that the addition of glass waste as a partial replacement of cement enhances the durability and improves the compressive strength of concrete at zero and 230 F/T cycles.

C. Ultrasonic Velocity Test Results

The damage indices of the concrete mixtures when subjected to freezing and thawing cycles by using the ultrasonic velocity method are shown in Fig. 4. The damage index of the control specimens increased significantly after 200 cycles, while those with 10% of glass waste powder had the least damage index after 200 cycles.

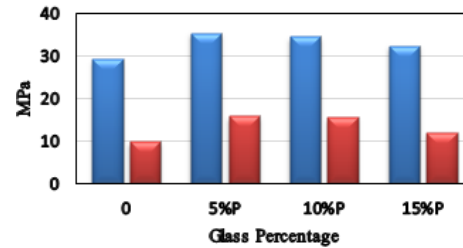


Fig. 3 Compressive strength of concrete cubes containing different glass percentages at zero and 230 F/T cycles based on experimental test results

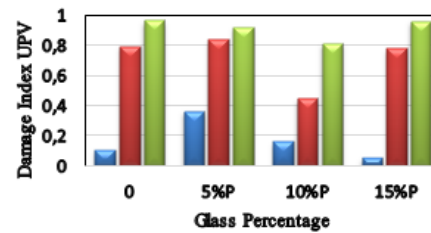


Fig. 4 Damage indices of concrete prisms containing different glass percentages at different F/T cycles using the ultrasonic pulse velocity readings (UPV)

The results showed that the concrete mixture containing 15% of glass waste replaced partially of cement had the least damage index when it was subjected to 230 F/T cycles. Hence, more improved durability and strength could be expected in that concrete mixture. This decreasing in damage index may be related to the fact that the glass makes the concrete relatively less thermal conductive as well as less porous.

The damage index in terms of UPV, $(DI)_{UPV}$, was computed using:

$$DI_{UPV} = 1 - \left(\frac{UPV^{dam}}{UPV^o} \right)^2$$

where, UPV^o is the initial ultrasonic pulse velocity and UPV^{dam} is the ultrasonic pulse velocity of F/T-damaged concrete prisms.

V. CONCLUSIONS

The findings of this research indicate that the using of glass waste in concrete can not only reduce problems encountered with environmental pollution, but also it may enhance the durability and mechanical properties of the concrete subjected to an environmental condition of freezing and thawing cycles. The results of this investigation draw the conclusion that:

1. The incorporation of the glass waste partially in concrete improved the resistance of the surface scaling of concrete subjected to freezing and thawing cycles. The largest resistance of that incorporation was when using glass waste powder as a partial replacement of cement, in particular the incorporation of 10 percent of glass powder.
2. The compressive strengths of concrete were improved with using glass powder. Moreover, the compressive

- strength of specimens with glass powder decreased less after the action of freezing and thawing cycles comparing to the conventional mixture.
3. Consequently, the addition of glass waste partially can be used to improve the early strength of concrete as well as to enhance the durability properties of concrete under the environmental action of freezing and thawing cycles.
 4. The results of this research encourage the disposal the glass waste by the mean of recycling it as a partial aggregate or cement replacement as well as its environmental benefits by decreasing the mining of natural resources.

The laboratory and non-destructive tests results in durability and compressive strength seem to indicate that the adding of milled glass wastes to concrete mixtures subjected to F/T cycles enhance the concrete mixture strength over the conventional limestone mixture. This is may be due to the fact that the glass has pozzolanic characteristics; especially the powder glass, as well as it is not water absorbing and more brittle than limestone.

In general, it is clear that the adding of powdered glass to the concrete mixtures is not only a green solution, but also tends to enhance the mechanical properties durability of concrete mixtures.

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REFERENCES

- [1] M. Pattengil and T. Shutt, "Use of ground glass as pozzolan," Proc., Int. Symp. On Utilization of Waste Glass in Secondary Products, ASCE, Albuquerque, N.M 1973.
- [2] J. Kim et al "Durability properties of a concrete with waste glass sludge exposed to freeze-and-thaw condition and de-icing salt" Construction and building materials, vol. 66, 2014, pages 398-402.
- [3] Z. Bazant and C. Mayer" Fracture mechanics of concrete structures," Proceedings of fracture mechanics: part 3, pages 1687-1693, 1998.
- [4] N. Saikia and J. de Brito "Mechanical properties and abrasion behavior of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate," Construction and building materials, vol. 52, February 2014, pages 236-244.
- [5] R. Madandoust and R. Ghavidel "Mechanical properties of concrete containing waste glass powder and rice husk ash," Biosystems Engineering, vol. 116, issue 2, October 2013, pages 113-119.
- [6] B. Tuan et al "Development of lightweight aggregate from sewage sludge and waste glass powder for concrete," Construction and building materials, vol. 47, October 2013, pages 334-339.
- [7] A. Saribiyik et al "The effects of waste glass powder usage on polymer concrete properties," Construction and building materials, vol. 47, October 2013, pages 840-844.
- [8] T. Ling et al "Management and recycling of waste glass in concrete products: current situations in Hong Kong, Resources, conservation and recycling, vol. 70, January 2013, pages 25-31.
- [9] I. Metwally "Investigations on the performance of concrete made with blended finely milled waste glass," Advances in structural engineering, vol. 10, no. 1, 2007
- [10] A. Carpenter and S. Cramer "Mitigation of ASR in pavement patch concrete that incorporates highly reactive fine aggregate," Transportation research record 1668, no. 99-1087, pages 60-67. 1999.
- [11] R. Nasser and P. Soroushian strength and durability of recycled aggregate concrete containing milled glass as partial replacement for cement Construction and building materials, vol. 29, April 2012, pages 368-377.
- [12] Z. Ismail and E. AL-Hashmi "Recycling of waste glass as a partial replacement for fine aggregate in concrete" Waste management, vol. 29, issue 2, February 2009, pages 655-659.
- [13] L. Federico and S. Chidiac Waste glass as a supplementary cementitious material in concrete" cement and concrete composites, vol. 31, September 2009, pages 606-610.
- [14] C. Shi and K Zheng "A review on the use of waste glasses in the production of cement and concrete" Resources, conservation and recycling, vol. 52, issue 2, December 2007, pages 234-247.
- [15] I. Topcu and M. Canbaz "Properties of concrete containing waste glass" Cement and concrete research, vol. 34, issue 2, February 2004, pages 267-274.
- [16] Y. Jani, W. Hogland "Waste glass in the production of cement and concrete- A review" Journal of Environmental Chemical engineering, vol. 2, issue 3, September 2014, pages 1767-1775.
- [17] F. Paiva Cota et al "Mechanical properties and ASR evaluation of concrete tiles with waste glass aggregate" Sustainable Cities and Society, vol. 16, August 2015, pages 49-56.
- [18] R. Onna et al "Development of ultra-lightweight fibre reinforced concrete applying waste glass" Journal of Cleaner Production, July 2015.
- [19] M. Saribiyik et al "The effects of waste glass powder usage on polymer concrete properties" Construction and Building Materials, vol. 47, October 2013, pages 840-844.
- [20] S. Prithvi "Waste materials in hot mix asphalt- an overview" National Center for Asphalt.