Concrete with glass for aesthetic application

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Summary

Huge amounts of glass are produced each year for a variety of purposes. Recycling of this glass after its first use is one of the modern strategies for managing the flow of raw materials and waste materials. The use of glass in concrete has been proposed many times in the past, but most of these initiatives have never led to successful applications. People were reluctant to use the concrete with glass because of the risk of alkali-silica reactions. However, the increasing amount of glass and the increasing environmental awareness, as well as the potential of making new types of aesthetic concretes, are the main reasons for renewed interest in glass-modified concretes.

In a joint project of the faculties of Architecture and Civil Engineering and Geosciences of the Delft University of Technology the use of recycled glass in concrete was investigated. The main goal of the study was to develop glass-modified concretes and concrete elements for aesthetic purposes. In this contribution the main results of this study will be presented and discussed.

Keywords: New type of concrete, composite building material, recycle glass, reinforcement, reflection, transparency, aesthetic application, glass-modified concretes.

1. Introduction

From early days the traditional mix of cement, water, sand and gravel or crushed rock has been used to construct the building material concrete in the Netherlands. The gravel or crushed rock are the aggregates which carries most of the compressive load. One of the problems that have arisen in modern times is the large-scale use of concrete, which is threatening to use all sources of gravel in the coming decades. Nowadays the decreasing supply of gravel in the Netherlands is mainly compensated by an increasing import of gravel from Germany. The consequences for the engineer are not big, but importing it from abroad does not solve the problem of the decreasing supply of gravel. Alternative aggregate materials are thus desirable to reduce the consumption of gravel. One candidate for this is glass. Meanwhile significant research has been done on the potentialities of glass as aggregate in concrete. In these studies emphasis was on the possibilities to use glass in a decorative or structural way [1,2,3], on solutions for waste glass problems [4] or on the tedious and intriguing problems of the alkali-silica reaction, which causes a big concern about the long-term stability [5]. Against the background of existing studies and reluctance to use glass in concrete, it was felt that a fresh approach might result in new ideas and applications. Additionally the possibility of using glass fragments as aggregate and long continuous large pieces of glass rods as reinforcement was felt to offer possibilities to simultaneously increase the architectural appeal and mechanical properties.

There are a few advantages of using recycle glass. First of all, recycle glass is available in large quantities. Also, a big variety of colours, forms and sizes are available on the market. The use of recycle glass creates new possibilities, the depletion of gravel and sand decreases, a waste problem decreases by using a waste material in a useful way and recycle glass gives concrete an additional value.

2. Material

A new type of concrete using glass fragments as aggregate and long continuous large pieces of glass as reinforcement has been developed. The glass reinforcement increases the strength and the Young's modulus of the composite material. Due to the higher elastic energy content at failure, fracture is more rapid than with normal concrete, i.e. more brittle.

This new type of concrete is a composite material made of recycle glass and a mixture of cement, different kind of natural stones, colour pigments and water. The glass fragments give the material a special and surprising effect. Much more depth is developed in comparison with the use of gravel or natural stone. It is also possible to accomplish reflection in the material and to create transparency by using glass fragments. Ornamental concrete with a varying character and an unique radiation will be created by experimenting, or 'playing' with blank, green, blue and brawn (float)glass or big recycle pieces of glass and colour pigments (Fig. 1 and 2).

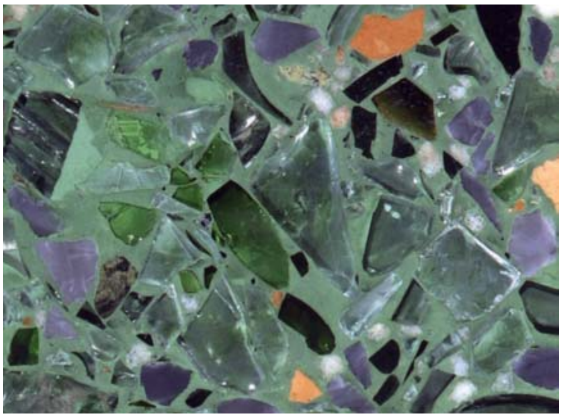

Fig. 1&2: Different kinds of glass-modified concretes.

2.1 Research

In a joint project of the faculties of Architecture and Civil Engineering and Geosciences of the Delft University of Technology the use of recycled glass in concrete was investigated. A regular concrete, grade B25 (characteristic cube compressive strength 25 MPa) was compared with a number of mixtures using different types of glass aggregate. These types are:

A Large shards from bottle and thin flat glass

B Small shards from bottle and thin flat glass

C Large rough pieces of glass recovered from glass ovens

D_1 Concrete with large pieces of 8-millimeter thick glass plate fragments

D_2 Concrete with large pieces of 19-millimeter thick glass plate fragments

E Concrete with large shards from bottle and thin flat glass and long continuous pieces of 19-millimeter thick glass over most of the length of the specimen

The glass for the experiments was washed and sieved to achieve a reasonable particle size distribution. Concrete mixtures were made using these glass factions using 64% by weight of glass aggregate. All concrete specimens were demoulded after one day of hardening at 20°C and left to harden for 28 days under water at 20°C.

For these mixtures, all containing 64% recycled glass of different fineness, mechanical and physical properties were determined, viz.: compressive strength, tensile strength, mass density, young's modulus, flexural strength, freeze-thaw resistance, transparency, bond between glass and cement matrix.

2.2 Material properties

The compressive strength, tensile strength and the density of glass-modified concretes are compared with the properties of ordinary concrete. As regards the Young's modulus, the flexural strength, the freeze-thaw resistance and the transparency the glass concrete performed better than the normal reference concrete made with gravel as aggregate. The size and distribution of the pieces of recycle glass have a positive influence on the material properties and the strength. Therefore it is possible to create a benefit by placing large strips of glass in the right position. One of the benefits is the reduction of steel bars, which are used to make structural concrete.

Table 1: The properties of concrete versus glass-modified concretes.

Properties	**Concrete**	**Glass-modified Concretes**	
Compressive strength	35	25-45	MPa
Tensile strength	4	3.6	MPa
Mass density	2400	2320	kg/m^3
Young's modulus	40	41	GPa
Flexural strength	4	3.6-16.2	MPa
Freeze-thaw resistance	3000	940	g
Transparency	0	0-88	lux

2.2.1. Compressive strength

Concrete mixtures were made from compositions A, B, C, D_1, which were cast into standard 150-millimeter cubic moulds. Figures 3, 4, 5 and 6 show polished cube specimens of the different types.

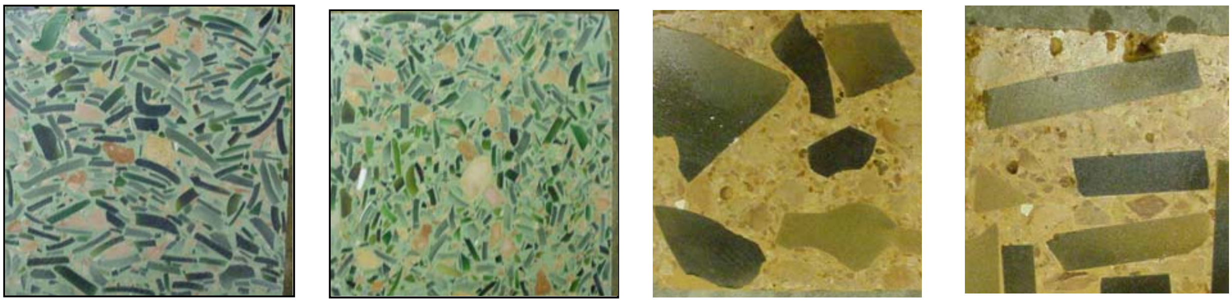

Fig. 3, 4, 5, 6: Cube specimens of compositions A, B, C and D.

Specimens were tested after 1 and 4 weeks to determine the development of the compressive strength, σ_c. The results are given in table 2.

The results suggest that the rough pieces of glass in mixture C induce failure by the increased stress concentrations. The large flat pieces in mixture D seem to increase the early compressive strength but have little effect on the 28-day strength.

Table 2: Compressive strength of mixtures tested.

Mixture	σ_c **1 week**	σ_c **4 weeks**	
A	23	37	MPa
B	26	40	MPa
C	25	31	MPa
D	30	40	MPa
Concrete, B25	15	25	MPa

2.2.2. Flexural strength

To investigate the flexural behaviour of the concrete with glass aggregate rectangular specimens of dimension 1000x100x40 millimetre were made. These were tested in 3-point bending tests. Four compositions were tested as well as solid glass rods to provide a reference. The results given are the average of a minimum of 6 tests. The flexural strength, $\sigma_{c,f}$, of the compositions is given in table 3.

Table 3: Flexural strength of compositions.

Mixture	$\sigma_{c,f}$	
A	3.5	MPa
D_1	5.2	MPa
D_2	4.5	MPa
E	18.3	MPa
Glass	74.0	MPa

The failure behaviour of the materials differs significantly. In displacement controlled tests the mixtures A, D_1 and D_2 cracked slowly after reaching the maximum load while the load dropped. Mixture E and glass fail in a totally brittle mode.

2.2.3. Freeze-thaw resistance

To investigate the freeze-thaw resistance of the concrete glass aggregate standard 150-millimeter cubic moulds were cast. Specimens were tested after 1 week of varying temperature according to “RILEM Recommendation for Test Method for the freeze-thaw resistance of concrete”. The results are given in table 4.

Table 4: Freeze-thaw resistance of compositions.

Mixture	**Weight reduction**	
A	0.9	kg
D	0.9	kg
Concrete, B25	3	kg

The results suggest that glass-modified concretes have a better freeze-thaw resistance than normal concrete. By doing research in the open air and in different weather situations for several years the freeze-thaw resistance and the durability of glass-modified concrete will give a more realistic view.

2.2.4. Bond between glass and cement matrix

One question that arose during the investigation is the effect of the different surface quality of glass and gravel. Glass is much smoother than gravel and non-porous. Gravel has a rougher and slightly porous surface. The cement can thus adhere better to gravel than to glass. Especially as the glass is also used as reinforcement adequate adhesion is essential. To determine if this was a problem some glass rods were sandblasted to give a rougher finish. Specimens were made of rectangular pieces of normal and sandblasted glass embedded in concrete. The glass is then pushed out of the concrete in a universal testing machine and the required shear stress, $\sigma_{c,b}$, calculated. In addition composition D bending specimens were made with normal and sandblasted glass rods. The results of both experiments are given in table 5.

Table 5: Effect of glass surface treatment.

Surface conditions	τ_p	$\sigma_{c,b}$	
Normal	0.98	16.2	MPa
Sandblasted	2.95	16.6	MPa

3. Product development and full-scale prototype

As an example of the use of decorative glass strips in concrete elements, panels were designed for a dome-shape roof. The span of the dome was 8 meter. The panels were made of a concrete with a green colour pigment and glass strips through which some light could be transmitted. Six full-scale panels were made. After hardening, the panels were polished and installed in a frame that represented a part of the load-bearing structure of the dome.

Another example is a self-supporting façade element for a school building in Arnhem, The Netherlands. This element is one of the experimental elements, which is assembled in three special parts of the façade of this new building. This pilot participates in a running research to the durability of glass-modified concrete exposed to different weather situations.

Fig. 7&8: The assembly of a small part of the dome with six panels with decorative glass strips in it.

Fig.9: A self-supporting façade element in a school building in Arnhem, The Netherlands.

4. Discussion and challenges

The focus of attention in this study was on the potentialities of glass as an alternative for aggregate in concrete. Apart from saving scarce raw materials and to contribute to solving a waste problem, the glass was used for its architectonic potential. The challenge was to find applications where we could benefit from the specific properties of glass, its transparency and colour. In this study, more in particular with the development of the glass-reinforced panels in the pilot project, the decorative properties of glass concrete could be demonstrated in a convincing way. The use of this kind of panels in a real structure is considered as a next and promising step to further use of architectonic glass concrete.

5. Conclusions

In this preliminary study on the use of (large pieces of) glass in concrete, challenging and promising applications could be shown. For a small number of glass concrete mixtures the mechanical properties were determined. In line with previous studies it was confirmed that from the mechanical point of view glass concrete could be considered as a realistic alternative for traditional concretes in the strength class under consideration. Question ahead concern the long-term behaviour of glass-modified concretes. This concerns the risk of shrinkage-induced cracks caused by rigid inclusion of glass, creep effects and the most-feared alkali-silica reaction. As long as glass concrete will be used in a dry environment the risk of alkali-silica reaction is not expected to be a serious problem. To which extent shrinkage-induced cracking caused by cast-in rigid pieces of glass will cause a problem also strongly depends on the environment in which the composite will be used and whether or not the elements have to fulfil a load-bearing function. For architectonic applications, however, particularly for indoor applications, glass-modified concretes are considered a promising alternative.

6. Acknowledgements

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