

Concrete based on full natural aggregate replacement by glass household waste

J Junak and N Junakova

Institute of Environmental Engineering, Faculty of Civil Engineering, Technical University of Kosice, Vysokoskolska 4, Kosice 04200, Slovakia

Abstract. The amount of municipal waste produced is increasing every year. Waste preventing is the best way, but it is not always possible. There is a need to look for new ways of municipal waste management, such as material recovery of waste in the construction industry. This paper shows the possibilities of using glass waste in the production of concrete. Three fractions of glass bottle cullet - 0/4, 4/8 and 8/16mm, as a full-scale replacement of natural aggregates were used. The results of the compressive strengths of more than 50 MPa and the bending compressive strength at more than 4.4 MPa, show considerable potential in this direction of use. In addition, at half of the prepared samples, cement was replaced by fly ash from biomass combustion. The negative effect of alkali-silica reaction of glass did not appear in our experiment.

1. Introduction

In the Slovak Republic, 10.5 mil. tonnes of wastes were created in 2015. Compared to 2014, the year-on-year increase in total waste generation in 2015 is almost 16%. In the production of waste according to the classification of economic activities, the largest producer of waste is industrial production, which accounts for about 38% of the total waste production, followed by the section of construction with about 24% share [1].

With regard to municipal waste (MW) production, in Slovakia about 1.8 million tonnes of municipal wastes were generated in Slovakia in 2015, or 348 kg per capita. Compared to 2014, this represents an increase of 17 kg per capita, but in a Europe-wide comparison, Slovakia is still among the countries with the lowest MW output. Negative is the fact that the dominant activity in the management of MW was landfilling. The share of landfilled municipal waste in total MW management was 69%, which represents a year-on-year increase of 3%. Municipal waste recycling, calculated according to Decision 2011/753/EU, reached only 20.11% in 2015. Reducing landfilling rates is a prerequisite for more efficient use of material resources in our country [2].

The main objective of Slovakia's waste management by 2020 is to minimize the negative effects of the generation and management of waste on human health and the environment. In order to achieve the stated objectives, a stronger enforcement and compliance with the binding waste management hierarchy will be avoided, with the aim of increasing waste recycling, in particular for municipal waste and construction and demolition waste, in line with the requirements of the Waste Framework Directive [3-4].

It is the Construction industry that appears to be an appropriate sector that can increase the share of the use of waste - both industrial and municipal waste. Many studies in Europe and in the world have shown that filler and binder in concrete can be successfully replaced by different materials: hemp



hurds and cellulosic fibers [5-8], slag [9-12], fly ash [13-19], recycled brick and concrete aggregate [20-22], polyurethane foam [23], crushed glass [24-26], but by bottom sediment also [27-29].

Glass waste is produced in many forms, including packaging of container glass (bottles, jars), flat glass (windows, windscreens), bulb glass (light globes), cathode ray tube glass (TV screens and monitors), all of which have a limited life in the form they are produced and need to be reused/recycled. Current collection methods for glass products are quite limited, therefore, only a small fraction of the solid waste can be recycled directly to the primary market - the bottling and container industry [30-32].

The term fly ash was first used in the electrical power industry in 1930, the first comprehensive data on its use in concrete in North America were reported in 1937 [33]. Coal fly ash is generated by fluid combustion of black or brown coal in thermal power plant. The coal fly ash produced in thermal power plants and heat plants is waste and therefore needs to be disposed or store. This is, however, quite costly and also involves a considerable ecological burden. The coal fly ash, with its finest increases the fine particle content of the concrete, which contributes favourably to the improvement of the processability of fresh concrete. However, due to the need for content of tap water, it is necessary to use a plasticizer in the manufacture of such concrete. The coal fly ash has a beneficial effect on the course of hydration heat in concrete and prevents cracks from excessive shrinkage. A higher percentage of coal fly ash in concrete partially reduces the rate of growth and final strength of concrete, nevertheless this type of concrete is suitable for many design solutions, even for special applications [34-37].

This paper is devoted to the study of the possibility of using glass waste as a full replacement of natural aggregate for concrete production. The following properties were observed: real density, compressive strength and flexural strength. On prepared beams with dimension 100x100x400 mm, compressive strength and flexural strength were after 14, 28, 90, 180, 365, 730 and 1095 days tested.

2. Material and methods

The materials used in our experiment were: Portland cement, fly ash, glass bottles cullet and natural aggregate.

In our study were used two different types of binders. The main binder was Portland cement CEM I 42.5 N with specific weight 3100 kg/m³ [38]. As a substitute for cement, the fly ash from a biomass burning power plant (Kosice, Slovakia) with an average particle size of 12.038 μm and molar ratio of SiO₂/Al₂O₃ = 3.88 was used. The chemical analysis of the fly ash is as follows: MgO (6.33%), Al₂O₃ (1.37%), SiO₂ (5.32%), P₂O₅ (3.09%), SO₃ (7.26%), K₂O (12.26%), CaO (47.33%).

Two different types of fillers were used in the preparation of concrete composites. Natural aggregate - three fractions (0/4 mm, 4/8 mm and 8/16 mm) from company RRH Slovakia were used like basic filler [39]. Further, three fraction of glass bottles cullet (GBC), 0/4 mm, 4/8 mm and 8/16 mm were used as natural aggregate full replacement in concrete mixtures. GBC was obtained from mixed coloured glass bottles, which were manually crushed in the laboratory and then sieved.

To prepare concrete mixtures drinking water was used [40].

Table 1 shows basic composition of concrete to 1m³.

Table 1. Reference concrete mix proportion per cubic meter.

Composition	1 m ³
Cement (kg)	350
Aggregates 0/4 mm (kg)	955
Aggregates 4/8 mm (kg)	210
Aggregates 8/16 mm (kg)	710
Water (l)	198

For research the possibilities of crushed colour glass bottles cullet (GBC) utilization as a natural aggregate full replacement in concrete, ten different mixtures (samples G0 - G4 and GF0 - GF4) at w/c

ratio of 0.6 were prepared. Two of these mixtures was comparative (samples G0 and GF0). Samples GF0 - GF4 were prepared with 25 wt.% cement replacement by fly ash without any treatment. Table 2 shows composition of samples based on a natural aggregate replacement by mixed coloured glass bottle culets.

Table 2. Composition of samples based on natural aggregate replacement by crushed coloured glass bottles.

Sample	Cement	Fly ash	Natural aggregate			H ₂ O	GBC		
			0/4	4/8	8/16		0/4	4/8	8/16
G0	●	-	●	●	●	●	-	-	-
G1	●	-	●	●	-	●	-	-	●
G2	●	-	●	-	●	●	-	●	-
G3	●	-	-	●	●	●	●	-	-
G4	●	-	-	-	-	●	●	●	●
GF0	●	●	●	●	●	●	-	-	-
GF1	●	●	●	●	-	●	-	-	●
GF2	●	●	●	-	●	●	-	●	-
GF3	●	●	-	●	●	●	●	-	-
GF4	●	●	-	-	-	●	●	●	●

Experimental mixtures were processed in the laboratory mixer with a horizontal rotary drum with a capacity of 150 l. Compounding process was chosen as follows: to a mixing drum are tipped aggregate in the order of fractions 8/16 mm, 4/8 mm, 0/4 mm. After a careful mixing of the all components concrete mixture were placed into cleaned metal forms. Thus prepared forms were then over 15s compacted on a vibrating table. After filling, prism forms were labelled and placed on a flat surface next 48 hours. After 48 hours, the prism were removed from the forms and then placed in a water bath. In order to realize the experiment program was made prism with dimensions of 100x100x400 mm. All of these concrete mixtures were tested in compression and flexural strength with strength machine ELE 2000 after 7, 28, 90, 180 and 360 days of curing according to the standard [41].

3. Results and discussion

Figure 1 shows the results of real density. The real density has been monitored during period three years.

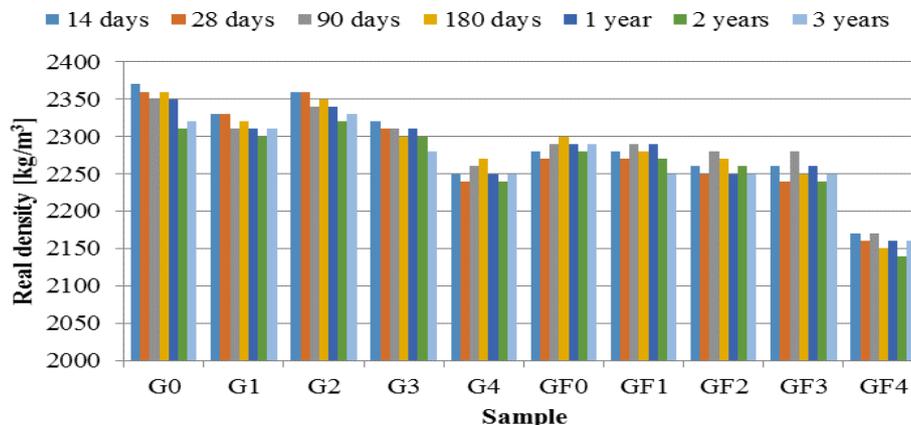


Figure 1. Real density of samples prepared with crushed coloured glass bottles.

The development of density value all samples is not unambiguous. The highest real density was obtained by the comparison sample (G0). On the contrary, the lowest density sample contained the

glass in all three fractions and, in addition, was prepared with 25% cement replacement by fly ash. Values of real density ranged between $2370 \text{ kg}\cdot\text{m}^{-3}$ (sample G0) and $2140 \text{ kg}\cdot\text{m}^{-3}$ (GF4).

The results of compressive strength are shown in figure 2. Similar to real density, the highest compressive strengths after 3 years (except for the comparison sample) reached sample G2. The achieved strength of 51.3 MPa is at the level of concrete strength class C 40/50 according [41]. The lowest compressive strengths reached sample GF4 (29.8 MPa after 3 years; C 20/25), which contained no single fraction of natural aggregate and the standard binder CEM I 42.5 N was replaced with fly ash (25%). The substitution of natural stone with glass bottle cullet meant a decrease in the strength by more than 8 MPa in the G2 sample (13% decrease) and by 17 MPa in the G4 sample (28% decrease), compared to the comparison sample. Sample G2 contained glass waste in place of natural aggregate fraction 4/8 mm. Composites containing fly ash and glass waste reached values of compressive strength lower on average 18%, in comparison with samples prepared with glass waste, only.

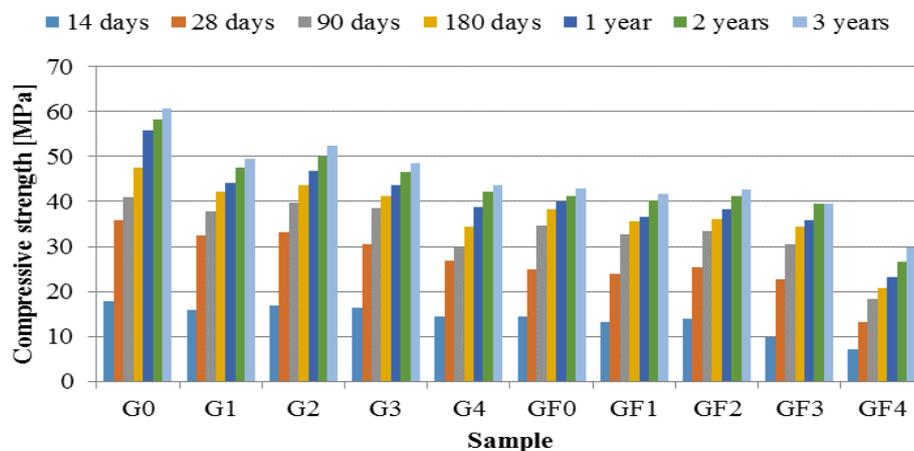


Figure 2. The running of the compression strengths of the experimental samples.

Flexure strength of experimental samples (figure 3) were tested on samples after compressive strength test. The obtained values of strength ranged between 5.6 MPa and 2.4 MPa.

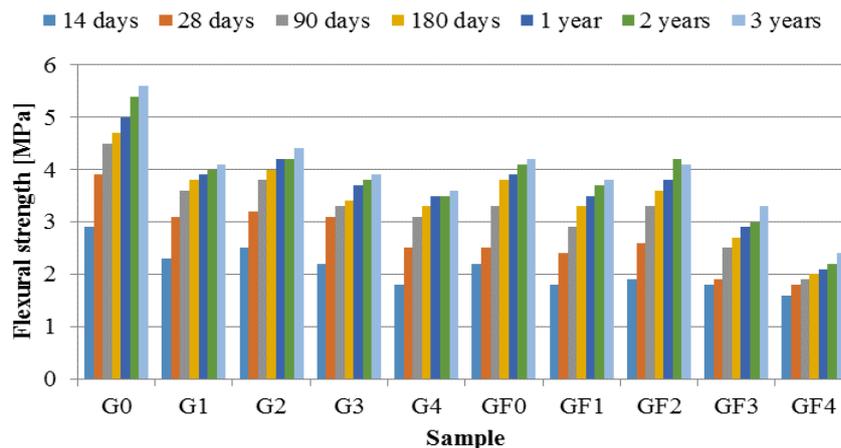


Figure 3. Flexural strength of samples based on glass waste as a filler.

If the comparative sample is not taken into account, the highest values of flexural strengths (4.4 MPa) have been achieved by samples containing glass waste fraction 4/8 mm - this applies equally to the sample containing the fly ash as a binder. The decrease of flexural strength of fly ash concrete samples is significantly lower than the compressive strength, is at the level of 10%.

The increase of the each strengths (compressive and flexural) was more noticeable at the beginning of the period under review (28 days), and then the strengths was increased slowly. Such development of concrete strengths is no exception, especially when we used "N" cement as a binder and the samples were standardly treated (water bath, 20°C) [42].

4. Conclusion

The aim of the paper was to show a new dimension of the reuse of household waste - glass bottle cullet. The results of real density, compressive and flexural strength indicate great potential for use in construction industry. Replacement of natural aggregate by glass waste was partially reduced: real density (5%), compressive strength (13%) and flexure strength (10%). However, generated waste will be used to save the natural raw materials and free place on landfill site. Moreover, if fly ash as a binder in the samples is used, greenhouse gases production will be significantly reduced. In the end, reached properties of the prepared samples, in particular the compressive strength of nearly 50 MPa predict this concrete for versatile use.

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