The use of glass waste cullet in the concrete production as an important factor in the circular economy

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Abstract. The paper focuses on the use of glass waste as a substitute for aggregates (0/4, 4/8 and 8/16 mm) in the production of concrete in order to reduce the negative impact of existing waste on the environment. For the study, 5 mixtures were designed with gradual replacement of individual natural aggregate fractions in the concrete mixture by glass cullet. Real density, total water absorption and compressive strength were monitored on cubes with an edge of 100 mm for a period of 14 days to 3 years. The achieved compressive strength of samples with glass as a filler at the level of 50 MPa gives a good precondition for the real use of such concrete in practice. In addition, when combined it with lower real density and total water absorption.

1. Introduction
The best solution for the environment is to prevent the actual generation of waste. Every product we consume will sooner or later become waste that needs to be disposed of. The best possible solutions are prevention and reuse, followed by recycling (including composting) and further recovery for energy production (incineration). The worst solution is landfilling. Although this is the simplest and cheapest solution, it is the most harmful for the environment and human health [1-4].

Between 2005 and 2018, EU per capita municipal waste production fell. Nevertheless, we can observe different trends in different Member States: waste production has increased in Denmark, Germany, Greece, Malta and the Czech Republic, for example, while it has decreased in Bulgaria, Spain, Hungary, Romania and the Netherlands. In absolute terms per capita, most waste is generated in Denmark, Malta, Cyprus and Germany. At least in Hungary, the Czech Republic, Poland and Romania. Richer countries tend to produce more waste on average per capita, but tourism in Cyprus and Malta, for example, also contributes to higher numbers. According to Eurostat, waste production in Slovakia has increased by more than 140 kg (414 kg per capita) in 2018 since 2005 (273 kg per capita) [5-8].

Europe is at the forefront of the global transition to a low-carbon and circular economy (Figure 1), which aims to maintain the value of products, materials and resources for as long as possible by returning them to the production cycle at the end of their use while minimizing waste. This process begins at the very beginning of the product life cycle: intelligent product design and manufacturing processes can help save resources, avoid inefficient waste management and create new business opportunities [9-11].
Construction is an industry that contributes significantly to waste generation in the EU (37%). However, it is also a sector where the generated waste can be recovered. It is not only construction waste, but also waste from other spheres and, of course, municipal waste [12-14]. Glass recycling is a process in which not only primary raw materials are saved, but also heat consumption, energy consumption and the total amount of CO2 emissions released into the air are reduced. In order for glass recycling to proceed without problems, it is very important that the glass sorting itself is of very high quality. The problem with glass waste recycling is that, materials what is similar to ordinary glass, but it has other properties - porcelain, safety laminated glass, car glass, ceramics or glass from classic TV screens [15-18]. In Slovakia, an average of 5% of glass is found in mixed waste. This represents 13.39 kilograms per capita per year. Approximately 72 779 tons of glass end up in landfills every year, which is more than 50 to 57 000 tons of Slovak glass, which are recycled annually in recycling plant Vetropack Nemšová [19].

The paper is devoted to the study of the use of glass waste (three fractions - 0/4, 4/8, 8/16 mm) as a filler in the production of concrete. The main reasons for this experiment include: 1. the ever-increasing consumption of natural aggregates and the associated extraction and devastation of the environment, 2. the more complex recycling of glass depending on the purity of the waste.

2. Material and Methods
The following inputs were used to study the possibility of using waste glass as a filler: Portland cement, natural aggregate and colour glass cullet.
Portland cement was used as a binder, with the following specification: CEM I 42.5 N, specific weight 3100 kg/m³.
Natural aggregate was used as filler in three fractions: 0/4, 4/8, 8/16 mm. Glass cullet of the same fraction were used as a full-fledged replacement for natural aggregates. Cullet were obtained by crushing damaged glass bottles and subsequent sieve analysis. Since the bottles were of different colours, the same can be said for shards.
Drinking water was used in the preparation of the samples and no additives were used.
The test specimens were prepared according to the following recipe per 1m³: cement - 350 kg, aggregate 0/4 mm - 955 kg, aggregate 4/8 mm - 210 kg, aggregate 8/16 mm - 710 kg, water - 198 l.
As shown in Table 1, five test mixtures, called "NGx", were designed to realize the experiment. The NG0 mixture is comparative, containing only natural aggregates, cement and water. On the other hand, NG4 does not contain natural aggregates, but only glass waste in all three fractions. The remaining mixtures, NG1, NG2, NG3, differ from each other only in that only one fraction of the natural aggregate is replaced by glass waste.

### Table 1. Formatting sections, subsections and subsubsections.

| Sample | Natural aggregate | Cement | Glass |
|--------|-------------------|--------|-------|
|        | 0/4 | 4/8 | 8/16 | 0/4 | 4/8 | 8/16 |
| NG0    | ●   | ●   | ●   | ●   | -   | -   |
| NG1    | ●   | ●   | -   | ●   | -   | ●   |
| NG2    | ●   | -   | ●   | ●   | -   | -   |
| NG3    | -   | ●   | ●   | ●   | -   | -   |
| NG4    | -   | -   | -   | ●   | ●   | ●   |

Experimental samples were prepared in the laboratory of the Faculty of Civil engineering, TUKE in a laboratory mixer. First, the dry ingredients (filler and binder) were placed in the mixer, and after mixing, water was added. Following a thorough homogenization of the concrete mixture, the prepared molds, cubes with an edge of 100 mm, were filled with the mixture. Molds filled with concrete were always vibrated. After 48 h, samples from the molds were removed and placed in a water bath. Real density, total water absorption and compressive strength were monitored on the prepared samples in the period 14 days to 3 years.

### 3. Results and Discussion

The real density of the samples was monitored over a period of 14 days to three years and ranged from 2240 kg/m$^3$ to 2370 kg/m$^3$ (Figure 2). As the amount of glass fragments in the mixture increased, the real density of the samples decreased proportionally. This is of course caused by the lower bulk density of glass compared to natural aggregates by about 7%. We considered this result before the experiment itself.

![Figure 2. Real density of tested samples in kg/m³.](image)

Total water absorption of experimental concrete samples shows Figure 3. It is clear from the results that the lowest absorbency (2.1 - 2.3%) in the observed period was achieved by the NG4 sample, prepared without natural aggregates. Again, this is due to the input material, glass, which has almost zero absorbency. The absorbency of the other samples ranged from 2.4 to 3.2%, again depending on
the amount of glass in the mixture. At almost every time monitored, the comparative sample achieved the highest absorbency.

With respect to real density and total water absorption, the trend was obvious that the more glass the sample contained, the more favourable values of the observed property we obtained. With compressive strength, this trend changes rapidly. As shown in Figure 4, the NG4 sample (only glass as a filler) achieved the lowest strength throughout the observed period.

The comparative sample always had the highest strength. However, if we look at the achieved strengths of the other samples, they were at the level of 85% of the comparative sample after 28 days and 80% of the comparative sample after 3 years. The very shape and especially the edges of the glass cullet carry with them the least favourable presumption of incorporation of such particles into the concrete mixture (Figure 5).
Figure 5. View of the cube sample after the compressive strength test.

4. Conclusion
The idea of using waste glass as a filling for concrete arose from the need for wider use of waste glass other than just recycling. The experiments themselves were not taken into account Alkali-silica reaction (ASR) of glass, although on the other hand, in a 3-year follow-up, this negative would certainly have manifested itself somehow. The achieved properties, especially the achieved compressive strength (50 MPa) of samples containing glass cullet, can be considered as a very good and concrete with such parameters it certainly could be applied in construction practice.

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