The use of waste glass in concrete production as a partial replacement of cement

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Abstract. The reuse and recycling of waste are considered the only way to reduce their generation. However, the application of waste in the construction industry is still at the research stage, providing an opportunity for the implementation of new technologies and the resolution of environmental aspects in this direction. This enables the creation of new eco-friendly building materials. The article discusses research in the field of using solid household waste in construction. It also explores the impact of particle size and the percentage of cement replacement with waste glass on the properties of the cementitious solution. The relevance of scientific research in this article lies in the possibility of using waste glass in concrete to improve the durability and sustainability of building structures. The use of glass waste as a pozzolanic material or as a partial replacement of cement can contribute to reducing CO_2 emissions into the atmosphere, which is an important step in reducing the impact of construction on the environment. The results of this work can contribute to the development of a more sustainable and environmentally friendly construction industry.

Keywords: mortar, microstructure, compressive strength, cement, concrete, pozzolanic reactivity, waste glass powder, cement replacement.

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INTRODUCTION

Concrete is one of the most widely used building materials in the world. However, the production of Portland cement, an important component of concrete, leads to significant CO_2 emissions, a greenhouse gas; approximately one ton of CO_2 and other greenhouse gases are emitted per ton of Portland cement clinker produced. The level of carbon dioxide in the atmosphere has increased by almost 30% over the last 200 years [1].

Environmental issues play an important role in the sustainable development of the cement and concrete industry. There is a need to replace some of the cement with pozzolanic materials to reduce cement consumption and, consequently, reduce environmental pollution [2].

Waste recycling helps to conserve limited landfill space and reduce waste disposal costs. The energy required for reusing recycled materials is lower than for primary materials. The use of secondary materials in the construction industry is the most attractive option due to the significant increase in construction activity [3].

Some industrial wastes, such as fly ash, ceramic wastes, marble powder, blast furnace slag, etc., have already found their application in concrete. Recent studies have shown that glass waste can be effectively used in concrete as a pozzolanic component. Research in the concrete industry has demonstrated the feasibility of using glass waste powder as a partial replacement for cement. Today, there is much research being conducted on replacing Portland cement using various secondary materials, such as fly ash (FA), ceramic powder, ground granulated blast furnace slag (GGBS), and marble powder, among others. Like FA and GGBS, glass waste powder (GP) can also be used as a binder component with partial cement replacement, participating in the hydration reaction and acting as a filler [4-8].

Glass powder exhibits pozzolanic properties since it contains SiO_2, and therefore, it can replace cement in concrete and contribute to increased strength gain [9]. Studies have shown that particles smaller than 75 µm can exhibit pozzolanic activity, thereby improving the microstructure of the mortar and the physical-mechanical properties of concrete in the long term [10-11]. Amorphous silica in glass dissolves in the alkaline environment of the cement mortar. Afterward, it can react with calcium hydroxide (CH) to form secondary hydrated calcium silicate (C-S-H), a process known as pozzolanic reaction, which can be expressed as $CH + S + H \rightarrow C\text{-}S\text{-}H$. The pozzolanic activity of glass particles increases due to a larger surface area available for reaction [12-13]. According to previous studies by the authors, the expansion of alkali-silica reaction (ASR) in the solution containing glass particles as fine aggregate will be insignificant if the glass particles are smaller than 0,3 mm [13-15].

The use of glass waste in Portland cement and concrete has attracted enormous interest worldwide due to increasing waste disposal costs and environmental issues. Glass used for containers, jars, and bottles is soda-lime glass, which consists of 80% recycled glass [12].

The impact of glass powder on the physical-mechanical properties and microstructure was analyzed by preparing cement mortar with the addition of 5%, 10%, 15%, and 20% glass powder as a partial replacement by weight of cement. The control mortar was named CM0 (without glass powder), and the experimental mortar were named CM5, CM10, CM15, and CM20, where the number indicates the replacement of cement with glass powder.

All samples were prepared for testing according to the European standard EN 196-1 in the form of prisms measuring 40 × 40 × 160 mm. The prism samples of the mortar were kept in water at a temperature of 20 ± 1°C until testing.

The determination of compressive strength was carried out according to EN 196-1 on the 28th, 90th, and 180th day of curing. The compressive strength test results were calculated as the arithmetic mean of six individual results from a set of prism samples. If one of the six results differs from the average by more than ±10%, it is rejected, and the average is calculated from the remaining five results.

Microstructural analyses were conducted using a scanning electron microscope.

Materials. Mortar samples were prepared with ordinary Portland cement CEM I 42,5 R, which complies with the requirements of European Standard EN 197-1. The Blaine fineness of cement is about 4130 cm^2/g. The mineral compositions of cement are given in Table 1. The mineralogical composition was determined using the Rietveld method.

Table 1. Mineralogical composition (XRD analysis, X-ray diffractometer AERIS Cement, Malvern Panalytical), %

Names of materials	C_3S Alite	C_2S Belite	C_4AF Ferite	C_3A Aluminate	C_3A ortho	FreeLime-CaO	Portlantide	Periclase MgO	Arcanite-K_2SO_4	Aphthitalite-$K_3Na(SO_4)_2$	Calciolangbeinite $K_2Ca_2(SO_4)_3$	Gypsum-$CaSO_4{*}_2H_2O$	Hemihydrate $CaSO_4{*}0.5H_2O$	Anhydrite $CaSO_4$	Calcite-$CaCO_3$	Quartz-SiO_2	Others
CEM I 42,5 R	59,35	11,93	8,74	2,50	2,86	0,12	2,51	0,89	0,00	0,28	0,00	2,85	1,29	0,03	2,15	0,13	4,37

Standard quartz sand and de-ionized water were used for all experimental mortar.

The glass powder is melted made of soda glass break. Impurities are only to approx. 0.1 thread % permissible. The Blaine fineness of glass powder is about 3100 cm^2/g. The chemical compositions of glass powder are given in Table 2.

Table 2. Chemical composition of glass powder, %

Name of material	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	Others
Glass powder	68,73	1,05	0,08	2,81	9,13	17,05	1,15

The scanning electron microscope images of powder glass are shown in Figure 1.

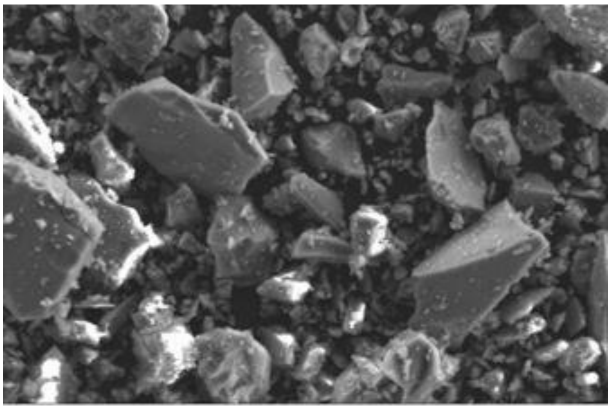

Figure 1 Scanning electron microscope images of glass powder

Tests. The results of compressive strength testing of mortar samples at different age stages, considering the addition of glass powder, are shown in Figure 2. It can be observed that after 28 days of curing, the compressive strength decreases with increasing content of glass powder. The most noticeable decrease in compressive strength was observed in mortar CM20 with 20% replacement of cement with glass powder. However, this situation changes at the 90 and 180-day age stages, where partial replacement of cement with glass powder does not lead to a decrease in compressive strength. In fact, there is even a slight increase observed for samples CM5 and CM10 after 90 and 180 days of curing, respectively.

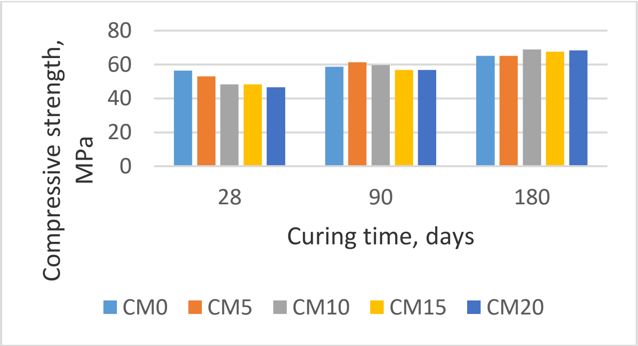

Figure 1.1. Compressive strength of mortars with glass powder addition

In the early stages of curing, the glass powder acts only as an inert material, leading to a decrease in compressive strength. The increase in compressive strength at later curing stages in the solution with added glass powder may be due to the pozzolanic reactivity of the glass powder. The pozzolanic reaction between the reactive silica oxide in the glass powder and calcium hydroxide results in the formation of C-S-H phases, leading to the densification of the microstructure of the cement matrix and, consequently, an increase in compressive strength. The densification of the microstructure can be observed in Figure 2.

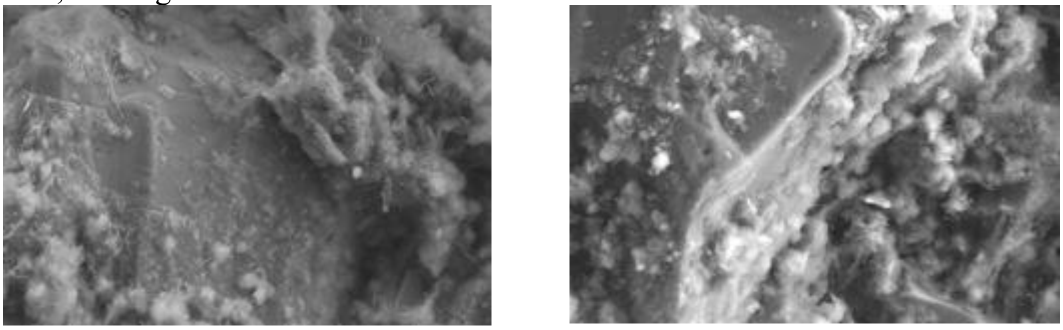

Figure.2. SEM images show the crystallization of C-S-H phases on the glass powder surface after 2 h (left) and after 12 h (right) of hydration

The influence of glass powder addition on cement hydration was investigated through the analysis of the microstructure of the cement matrix at early hydration stages. It was also noted that the C-S-H phase crystallizes on the particles of glass powder (Figure 2). The very fine particles of glass powder act as nucleation centers, providing additional surface area where C-S-H nuclei can deposit. Thus, a slight acceleration of hydration was observed. The interfacial region visible on the surface of the glass grain is dense and similar to the matrix far from the surface. Crystals of calcium hydroxide or increased local porosity in the contact zone were not observed. Heteronucleated small crystals of hydrated calcium silicates are visible on the surface of the glass.

Differences in pore size distribution can be observed with other active mineral additives. We can argue that the use of glass powder in the solution leads to the modification of pore size. According to previous studies [16,17], the number of capillary pores decreases, while the total porosity increases. This is due to the small particle sizes of the glass.

CONCLUSIONS

According to studies, glass powder exhibits slight pozzolanic reactivity, and an increase in the specific surface area of the glass powder leads to an increase in pozzolanic reactivity.

Adding glass powder has a negative effect on strength in the early stages of curing, which is due to insufficient pozzolanic activity during this period. At a later age, an increase in compressive strength of the solution with added glass powder is observed. This is mainly attributed to the pozzolanic activity of the glass powder, which manifests in the later period.

There was no negative impact on the microstructure of the outer surface. The glass grain acts as centers for heteronucleation of C-S-H crystals.

Ground wastes from production in the form of glass can be used as a partial replacement for cement. In this case, a slight increase in compressive strength of test samples is observed, and there is no deterioration in porosity. For more effective use of this waste, it should be ground to a finer size, to a specific surface area (the Blaine fineness) not less than that of cement. This will increase the pozzolanic activity of the glass

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Використання відходів скла у виробництві бетону як часткова заміна цементу

Оксана БЕРДНИК, Сергій ВИГОВСЬКИЙ

Анотація. Повторне використання та переробка відходів вважаються єдиним способом скоротити їх утворення. Проте застосування відходів у будівельній галузі все ще знаходиться на стадії досліджень, що дає можливість для впровадження нових технологій та вирішення екологічних аспектів у цьому напрямку. Це дозволяє створювати нові екологічно чисті будівельні матеріали. У статті розглядаються дослідження в галузі використання твердих побутових відходів у будівництві. Він також досліджує вплив розміру частинок і відсоток заміни цементу відходами скла на властивості цементного розчину. Актуальність наукового дослідження в даній статті полягає в можливості використання відходів скла в бетоні для підвищення довговічності та стійкості будівельних конструкцій. Використання відходів скла як пуцоланового матеріалу або як часткової заміни цементу може сприяти зменшенню викидів CO2 в атмосферу, що є важливим кроком у зменшенні впливу будівництва на навколишнє середовище. Результати цієї роботи можуть сприяти розвитку більш стійкої та екологічно чистої будівельної галузі.

Ключові слова: розчин, мікроструктура, міцність на стиск, цемент, бетон, пуцоланова реакційна здатність, порошок відходів скла, заміна цементу.