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NEW DIRECTION FOR WASTE UTILIZATION IN CIVIL ENGINEERING PRODUCTION

NOWE KIERUNKI UTYLIZACJI ODPADÓW W BUDOWNICTWIE

Abstract

This paper is focused on waste disposal through utilization in civil engineering production. Coal fly ash, steelmaking slag and fragments of bottle glass were mixed into concrete, and its compressive strength was tested. The experiment was carried out in three parts. In part 1 of our experiment we made concrete samples with partial replacement of cement with Slovakian mechanochemical activated coal fly ash. The result showed that the investigated activated method for coal fly ash and coal fly ash cement mixtures has a positive influence on compressive strength development of the tested samples. Part 2 deals with steelmaking slag for use as a natural aggregate replacement in the concrete mixture. The results showed that slag used as a coarse aggregate in concrete has no negative effects on the properties of hardened concrete. Part 3 of our study is aimed at utilization of fragments of bottle glass in civil engineering. The results showed that selected fractions of bottle glass waste can be successfully used as an aggregate in concrete production and have positive effects with respect to fair-faced concrete surfaces requirements.

Keywords: coal fly ash, steelmaking slag, fragment of bottle glass, concrete, utilization

Streszczenie

W artykule zawarto badania dotyczące wykorzystania odpadów wytworzonych w różnych dziedzinach gospodarki, w budownictwie lądowym. Popioły lotne, żużel z hutnictwa stali oraz stłuczkę szklaną dodawano do betonu i badano ich wpływ na wytrzymałość na ściskanie. Badania prowadzono w trzech częściach. W części 1 eksperymentu sporządzono próbki betonu z różnym udziałem popiołów lotnych pochodzących ze Słowacji, aktywowanych mechanochemicznie. Badania wykazały, że zastosowanie mechanochemicznie aktywowanych popiołów lotnych ma pozytywny wpływ na wytrzymałość testowanych próbek. W części 2 naturalne materiały wiążące zastąpiono częściowo żużlem wielkopieczowym. Wyniki wskazują, że żużel nie wykazuje negatywnego wpływu na właściwości betonu. Część 3 badań została poświęcona utylizacji stłuczki szklanej. Wyniki badań wskazują, że wybrane frakcje stłuczki szklanej mogą być z powodzeniem wykorzystywane w produkcji betonu.

Słowa kluczowe: popiół lotny, żużel wielkopieczowy, stłuczka szklana, beton, utylizacja

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1. Introduction

Rapidly increasing quantities of waste generated in European countries are a major concern for Europe's environment. It is estimated that Europe produces annually over 250 million tonnes of municipal waste and more than 850 million tonnes of industrial waste. The present disposal and processing capacity is probably not sufficient to deal with the expected growth. The existing facilities are often not adequate to ensure acceptable environmental standards. The sites of new facilities usually encounter considerable opposition from local people concerned with the potential risks for their local communities [1].

European countries today recognise the fact that reducing pollution loads requires an integrated pollution control strategy. A hierarchy of preferred options for waste management was adopted by the OECD countries in 1976 [1].

“The waste hierarchy generally lays down a priority order of what constitutes the best overall environmental option in waste legislation and policy, while departing from such hierarchy may be necessary for specific waste streams when justified for reasons of, *inter alia*, technical feasibility, economic viability and environmental protection” [2].

Reducing waste at source not only minimises the impact of waste treatment and disposal, but also enhances the efficient use of raw materials. However, despite the increasing emphasis on waste prevention, waste amounts have increased. Landfill and incineration, instead of recycling, are still the predominant practices in waste management, although differences exist between countries. Waste often still escapes control or avoids strict regulations through transfrontier movement across European countries and from Europe to developing countries [1].

Much research has been done and is still necessary to be done on this topic worldwide, and also in Slovakia. The study [3] concentrates on those waste materials, specifically glass waste, plastics and building construction waste, to be used as substitutes for conventional materials, mainly aggregates, in ordinary Portland cement concrete mixes. The use of plastic materials and glass in a number of civil engineering applications has been investigated in a large number of research studies. These have been conducted to examine the possibility of using plastics and glass powder in various civil engineering projects in the construction field [4]. Experiments show many uses of waste glass, which include road construction aggregate, asphalt paving, concrete aggregate, and many other applications [5].

Coal fly ashes are mainly utilised in the building material industry, in civil engineering, in road construction, for construction work in underground coal mining, for recultivation and restoration purposes in open cast mines. The majority of coal fly ashes are produced to meet certain requirements of standards or other specifications with respect to utilisation in certain areas. Due to different boundary conditions regarding climate, taxes and legislation, the utilization rate of coal fly ashes is different across European countries and worldwide [6]. Based on our previous works [7], mechanically and chemically activated coal fly ashes added to cement mixtures significantly influence the development of the compressive strength of the composite.

Steelmaking slag, a by-product of steel making, is produced during the separation of molten steel from impurities in steel-making furnaces. The slag appears as a molten liquid and is a complex solution of silicates and oxides that solidifies upon cooling. Virtually all steel is now made in integrated steel plants using a version of the basic oxygen process, or in

special steel plants (mini-mills) using the electric arc furnace process. The slag obtained in steel factories has been mainly used for building materials such as a raw material for cement, roadbed material and fertiliser [8]. Experiments show [9] that steelmaking slag can be used as a natural aggregate replacement in the road concrete production.

2. Materials and Methods

In our study, in order to prepare concrete mixtures we used the following as raw materials: Portland cement (CEM I 42.5), Slovakian brown coal fly ash, steelmaking slag, bottle glass fragments and natural aggregate.

Coal fly ash (CFA, density: 2.277 g/cm^3) originated from electrostatic separators from classical incineration of brown coal fly ash in the Slovakian power plant Novaky (ENO A). The following minerals present in coal fly ash as major components are quartz, mullite, hematite, albite and magnetite. Based on the chemical analysis, the used coal fly ash is high silica ash with the molar ratio of $\text{SiO}_2 / \text{Al}_2\text{O}_3 = 3.18$. The presence of crystalline phases was detected by the X-ray diffraction (XRD) analysis on the diffractometer DRON 2.0 with goniometer GUR-5 (Technabsexport, Russia). The content of CaO, SO_3 and the loss of ignition of coal fly ash was evaluated according to the European standard [10].

Steelmaking slag used in our investigation was obtained from steel production in U.S. Steel Košice, Slovakia. Two different fractions (4–8 and 8–16 mm) were used as a natural aggregate replacement in concrete mixtures.

The **glass waste** used in this study was obtained from mixed coloured glass bottles. Bottle glass was manually crushed in the laboratory and then sieved. Fractions 0–4 mm, 4–8 mm and 8–16 mm were used as a natural aggregate replacement in concrete mixtures.

Three different fractions of **natural aggregate** (0–4 mm, 4–8 mm and 8–16 mm) from VSH a.s. company (Turňa nad Bodvou, Slovakia) were used to prepare concrete samples. The natural aggregate was evaluated according to the Slovakian standard [11].

To improve Slovakian coal fly ashes properties, we used mechanochemical activation in accordance with the European standard [10]. The aim of our experiments was the cement partial replacement in concrete by activated coal fly ash products. In order to achieve the required coal fly ash fineness according to the standard ($\Delta R-45 > 60 \%$) [10], the mechanochemical activation of CFA was carried out by dry milling (without and with the application of solid NaOH) and wet milling (5 M of aqueous NaOH solution) in the laboratory vibratory mill (0.25 and 0.5 h). By optimization of milling conditions the products with different fineness (mean particle diameter from 23.6 to $41.4 \mu\text{m}$) were prepared, where the particle size analysis was carried out on the laser granulometer Helos/LA with the dry dispersion unit Rodos 11 SR (Sympatec GmbH, Germany).

Coal fly ash/cement mixtures with 25 wt.% cement replacement were prepared with milled (samples M1–M6) coal fly ash at solid/liquid ratio of 0.5. Comparative cement mixtures were prepared by mixing only cement with water (sample marked “Xc”). Compression strength measurements were carried out on the coal fly ash/cement samples of $40 \times 40 \times 160 \text{ mm}$ in size after 28 and 90 days of hardening according to the standard [10].

Four different mixtures (called S1–S4) at solid/liquid ratio of 0.55, including a plastifying admixture, were proposed for research of the selected natural aggregate (fractions 4–8 and

8–16 mm) replacement with steelmaking slag in concrete. Cubes of a 150 mm edge were made from all of these mixtures. They were tested for compression strength after 28 and 90 days.

To study the possibilities of coloured bottle glass fragments utilization as a selected natural aggregate replacement in concrete, eight different mixtures (samples G1-G4 and GP1-GP4) at solid/liquid ratio of 0.55 and two comparative mixtures (samples G0 and GP0) were prepared. Samples called “GPx” were prepared with 25 wt.% cement replacement with CFA as a starting agent. Experimental samples were made from all of these mixtures and then they were tested for compression strength after 7 and 28 days of hardening according to [10].

The compressive testing machine for all the studied samples was ELE 2000 (ELE INTERNATIONAL LIMITED, GB).

3. Results and Discussion

Composition of samples based on a partial cement replacement with the coal fly ash milled under various conditions is given in Table 1. Fig. 1 illustrates the compressive strength of samples after 28 and 90 days of hardening based on a partial cement replacement with the coal fly ash milled under various conditions.

Table 1

Composition of samples based on partial cement replacement with mechanochemical activated coal fly ash

Sample		M1	M2	M3	M4	M5	M6	M7	M8	Mc	
Sample composition	Milling	0.25 h	●	●	●	●	–	–	–	–	
		0.5 h	–	–	–	–	●	●	●	●	–
		dry	●	●	●	–	●	●	●	–	–
		wet	–	–	–	●	–	–	–	●	–
		NaOH	–	–	●	●	–	–	●	●	–
	Cement	75	75	75	75	75	75	75	75	100	
	Coal fly ash I	25	25	25	25	25	25	25	25	–	
	H ₂ O	●	–	●	●	●	–	●	●	●	
	5M NaOH	–	●	–	–	–	–	●	–	–	

As it can be seen in Fig. 1, from all the samples only two samples (M1 and M5) based on 25 wt. % cement replacement with mechanochemically activated coal fly ash reached the highest compressive strength after 28 and 90 days of hardening. Sample M1 was based on 0.25 h dry milled coal fly ash (25.5 and 30.4 MPa) and sample M5 contained 0.5 h dry milled coal fly ash (27.6 and 28.7 MPa), both milled without any addition. The compressive strength of a comparative sample was 32.1 after 28 days of hardening and 33.6 MPa after 90 days of hardening. Based on our previous results published in [12], high compressive strength is connected with coal fly ash fineness enhancement, and above all with the activity of the newly created surface area of particles at milling. Components formatted on the surface of coal fly ash particles are hydrated faster, which contributes to the improvement

of the physicochemical consolidation process at hardening of coal fly ash/cement mixtures, formation of a dense composite structure, and increase in compressive strength of the composite after hardening [13].

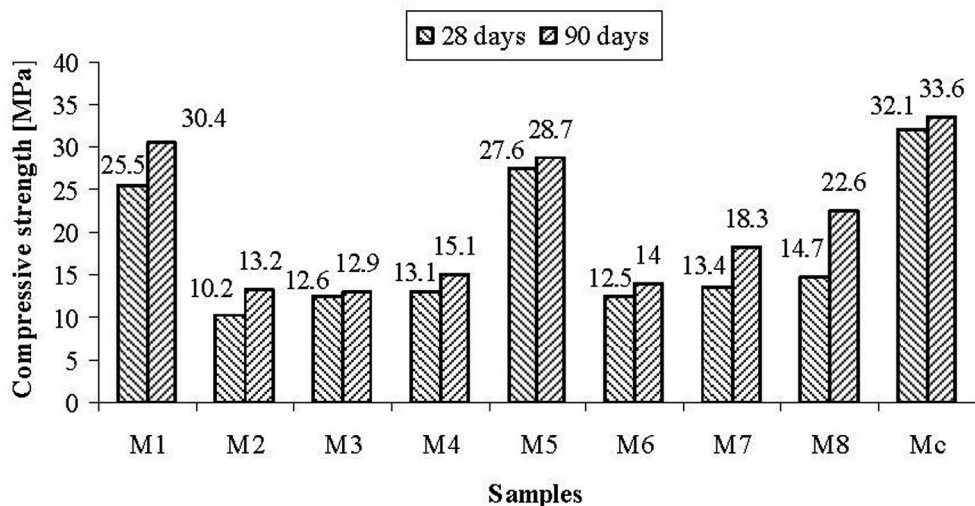


Fig. 1. The compressive strength of samples after 28 and 90 days of hardening based on partial cement replacement with coal fly ash milled under various conditions

Rys. 1. Wytrzymałość na ściskanie próbek z dodatkiem popiołów lotnych o różnym uziarnieniu po 28 i 90 dniach wiązania

Table 2 illustrates the composition of concrete samples with a natural aggregate replacement with Slovakian steelmaking slag.

Table 2

Composition of concrete samples with natural aggregate replacement by Slovakian steelmaking slag

Sample	Mixture composition						
	Cement [kg]	Water [kg]	Aggregate fr. 0–4 mm [kg]	Aggregate fr. 4–8 mm [kg]	Aggregate fr. 8–16 mm [kg]	steelmaking slag fr. 4–8 mm [kg]	steelmaking slag fr. 8–16 mm [kg]
S1	•	•	•	•	-	-	•
S2	•	•	•	-	•	•	-
S3	•	•	•	-	-	•	•
S4	•	•	•	•	•	-	-

Figure 2 shows compressive strength after 28 and 90 days of sample hardening. From the analysis of the obtained results follows that concrete samples with a natural aggregate replacement with two different fractions of slag (S1 and S2) lead to higher compressive strength after 28 and 90 days of hardening in comparison to the sample prepared only with the natural aggregate (S4). The considerable increase in compressive strength was reached in sample S1 after 28 days and in sample S2 after 90 days. The compressive strength in sample S1 was 4.8% higher in comparison with sample S4 (only natural aggregate), and similarly sample S2 was 3.9% higher. The complete natural aggregate replacement with two fractions of slag together (sample S3) leads to decreased cubes strength in comparison with sample S4 (after 28 days – 10.7% and after 90 days – 0.85%).

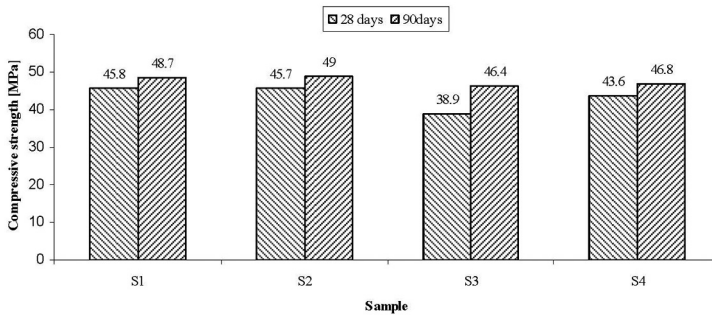


Fig. 2. Cubes compressive strength (R_c) of concrete samples with steelmaking slag after 28 and 90 days of hardening

Rys. 2. Wytrzymałość kostkowa na ściskanie (R_c) próbek betonu z dodatkiem żużla wielkopieczowego po 28 i 90 dniach wiązania

Table 3 illustrates the composition of samples based on a selected natural aggregate replacement with mixed coloured bottle glass fragments.

Table 3

Composition of samples based on natural aggregate replacement with coloured bottle glass fragments

Sample		G0	G1	G2	G3	G4	GP0	GP1	GP2	GP3	GP4	
Sample composition	Cement	•	•	•	•	•	•	•	•	•	•	
	CFA	–	–	–	–	–	•	•	•	•	•	
	natural aggregate	0–4	•	•	•	–	–	•	•	•	–	–
		4–8	•	•	–	•	–	•	•	–	•	–
		8–16	•	–	•	•	–	•	–	•	•	–
	H ₂ O	•	•	•	•	•	•	•	•	•	•	
	glass fragment	0–4	–	–	–	•	•	–	–	–	•	•
		4–8	–	–	•	–	•	–	–	•	–	•
		8–16	–	•	–	–	•	–	•	–	–	•

Compressive strength after 7 and 28 days of hardening of the samples based on a partial natural aggregate replacement by three fractions of mixed coloured bottle glass fragments is shown in Fig. 3. From the analysis of the obtained results follows that concrete samples with a natural aggregate replacement by three different fractions of bottle glass fragments do not lead to higher compressive strength after 7 and 28 days of hardening in comparison to the sample prepared only with the natural aggregate (G0). From all the investigated samples prepared in this experiment, sample G2 (35.5 MPa) reached the highest compressive strength corresponding with concrete strength class C 25/30. A partial cement replacement with coal fly ash as a starting agent in samples GP0-GP4 leads to low compressive strength after 7 and 28 days of hardening, and these samples reached only 70% value of samples G0-G4 in comparison with the samples without coal fly ash.

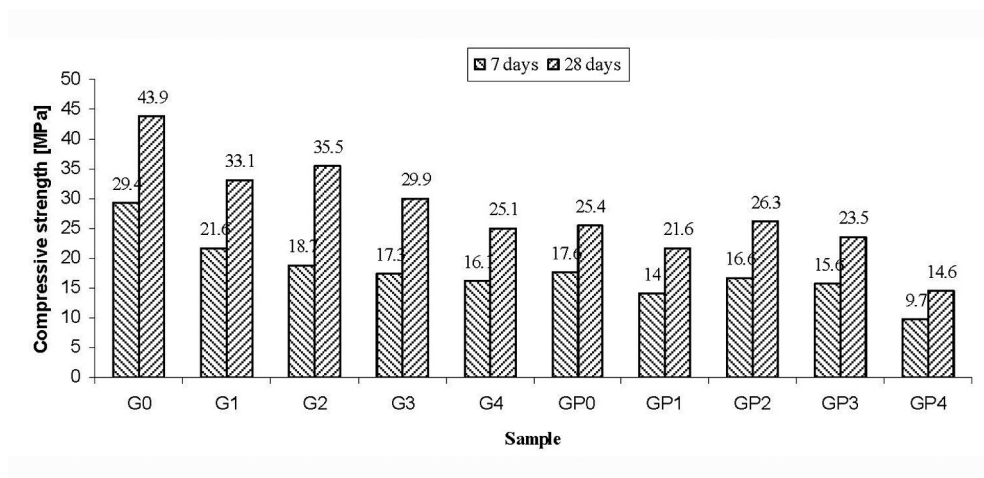


Fig. 3. Compressive strength of samples based on partial natural aggregate replacement with mixed coloured bottle glass fragments after 7 and 28 days of hardening

Rys. 3. Wytrzymałość na ściskanie próbek z dodatkiem szkła butelkowego po 7 i 28 dniach wiązania

4. Conclusions

The first part of this paper is focused on Portland cement replacement with mechanochemically activated coal fly ash. Two samples M1 and M5 reached the highest values of compressive strength after 28 and 90 days of hardening. Sample M1 was based on 0.25h dry milled coal fly ash (25.5 and 30.4 MPa) and sample M5 contained 0.5h dry milled coal fly ash (27.6 and 28.7 MPa); both were milled without any addition. The selected treatment method of coal fly ash, i.e. mechanochemical activation, has a positive influence on compressive strength development of the tested samples.

The second part of this paper is aimed at a natural aggregate replacement with the selected fractions of steelmaking slag in a concrete mixture. Experiments show that steelmaking slag can be successfully used as a natural aggregate replacement in the road concrete production and has no negative effects on the properties of the hardened concrete. However, such a use of slag in concrete can be recommended only after the necessary investigation of durability and corrosion properties of steelmaking slag concrete has been carried out.

The final part of this paper focused on a natural aggregate replacement with three different fractions of bottle glass fragments in the concrete mixture production. The obtained results show that the sample prepared with a bottle glass fraction of 4-8 mm (G2) reached 81% compressive strength value of a comparative sample (G0). A partial cement replacement with coal fly ash as a starting agent in samples GP0-GP4 leads to low compressive strength after 7 and 28 days of hardening. The use of bottle glass fragments in concrete has no negative effects on the strength characteristics of the hardened concrete and has positive effects with respect to fair-faced concrete surfaces requirements.

According to our previous experiments, industrial waste such as coal fly ash, steelmaking slag and bottle glass fragments, can be potentially used in civil engineering, for example in the road concrete production, but first it is necessary to investigate the durability and corrosion properties of these wastes in concrete.

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References

- [1] European Environment Agency, *Waste production and Management* (<http://www.eea.europa.eu/publications/92-826-5409-5/page036new.html>).
- [2] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.
- [3] Batayneh M., Marie I., Asi I., *Use of selected waste materials in concrete mixes*, [in:] *Waste management*, Elsevier, vol. 27, 2007, 1870-1876.
- [4] Chanbane B., Sholar G.A., Musselman J.A. Page G.C., *Ten-year performance evaluation of asphalt-rubber surface mixes*, [in:] *Transportation Research Record No. 1681*, Washington D.C., 1999, 10-18.
- [5] Bazant Z.P., Zi G., Meyer Ch., *Fracture mechanics of ASR in concrete with waste glass particles of different sizes*, [in:] *Journal of Engineering Mechanics*, vol. 126/3, 2000, 226-232.
- [6] Querol X., Moreno N., Umana J.C., Alastuey A., Hernandez E., *Synthesis of zeolites from coal fly ash: an overview*, [in:] *International Journal of Coal Geology*, vol. 50, 2002, 413-423.
- [7] Junák J., Številová N., Sičáková A., *The temperature influence on final compressive strength of coal fly ash cement free samples*, [in:] *Czasopismo Techniczne*, vol. 105, 2008, 151-156.

- [8] Skuza Z., Kolmasiak C., Prusak R., *Possibilities for the utilization of metallurgical slag in the conditions of the Polish economy*, METABK, 48, 2009, 125-128.
- [9] Václavík V., Lembák M., *Industrial wastes as an effective material for the building dams*, Górnictwo i Geoinżynieria, Zeszyt 3/2, 29, 2005, 111-120.
- [10] EN 450-1:2005, Fly ash for concrete. Definition, specifications and conformity criteria.
- [11] STN EN 12620, Aggregates for concrete.
- [12] Junák J., Številová N., *Alkaline modified coal fly ash as an addition to concrete*, [in:] Chemické listy, vol. 102, 2008, 882-883.
- [13] Junák J., Številová N., *Effective utilization of the industrial wastes in concrete production, design, technology, refurbishment and management of buildings*, 37th IAHS World Congress on Housing, Santander (Spain) 2010.