KORIŠĆENJE KERAMIČKOG I POLJOPRIVREDNOG OTPADA U GRAĐEVINSKOJ PRAKSI U CILJU ZAŠTITE ŽIVOTNE SREDINE

Slobodan Šupić[1], Saša Marinković[2], Mirjana Malešev[3], Ivan Lukić[4], Vladan Pantić[5]

Rezime: Prelazak sa konvencionalnih na građevinske materijale sa niskom emisijom CO_2 je jedan od savremenih ciljeva održivog razvoja za ublažavanje emisije gasova staklene bašte i efekata klimatskih promena. Proizvodnja cementa je odgovorna za 8% globalne emisije CO_2 i potrošnju ogromnih količina prirodnih resursa. Pronalaženje alternativnih materijala, za zamenu dela cementa, predstavlja jedan od izazova u savremenoj građevinskoj praksi. U ovom radu prikupljeni su podaci o dostupnosti lokalnih otpadnih materijala, poreklom iz poljoprivrede i keramičke industrije u Vojvodini i dati rezultati njihove karakterizacije kao potencijalnih cementnih materijala. Rezultati su obećavajući, budući da 5 od 6 ispitanih materijala ispoljava pucolansku aktivnost i visok indeks aktivnosti. Zamena cementa sa lokalno dostupnim otpadnim materijalima doprinela bi očuvanju prirodnih resursa, smanjenju generisanog otpada i smanjenju emisije gasova staklene bašte.

Ključne reči: Gasovi staklene bašte, cement, otpad, poljoprivreda, keramička industrija, karakterizacija

ENVIRONMENTALLY FRIENDLY UTILIZATION OF CERAMIC AND AGRICULTURAL WASTE IN CIVIL ENGINEERING

Abstract: The transition from conventional to low-carbon materials for construction is recognised to be one of the preferable methods to mitigate greenhouse gases emission and the climate change crisis. Cement production is rensposible for 8% of global CO_2 emission and consumption of enormous quantities of natural resources. Finding the alternative, cement replacing materials is one of the challenging issues in contemporary civil engineering practice. This paper includes data on the availability of locally available waste materials, originating from agriculture and ceramic industry in Vojvodina and their characterization as potential supplementary cementitious materials. The results are promising, as 5 out of 6 tested materials displayed positive pozzolanic reaction and obtained high activity index. Substitution of cement with locally available waste materials would contribute to preserving natural resources, lowering generated waste and reducing greenhouse gases emission.

Key words: Greenhouse gases, cement, waste, agriculture, ceramic industry, characterization

1. INTRODUCTION

Massive development in the construction industry has given an unforeseen rise in the demand for concrete, and to accommodate this demand, the world expends billions tonnes of non-renewable materials every year. Increasing population, expanding urbanization, climbing way of life due to technological innovations has demanded a huge amount of natural resources in the construction industry, which has resulted in scarcity of mined materials: sand, limestone, clay, which are the main constituents of ordinary Portland cement (PC) concrete. It has been predicted that the world's population will cross 9 billion milestone by the year 2050 and 11 billion by the end of the century [1], which will result in a considerable increase in the demand for resources, negative reflection on climate change and social concerns. Also, due to the swift population growth and shelter demand, the production of concrete is expected to grow to approximately 18 billion tons a year by 2050 [2].

As a result of the calcination of limestone and the combustion of nonrenewable energy sources, particularly fossil fuels, the manufacturing of PC releases considerable amounts of CO_2 and other greenhouse gases into the environment. As one ton of PC requires 1.5 tons of raw ingredients (clay and limestone) and consumes considerable amount of energy and, one ton of CO_2 is generated into the

[1]Assistant Professor, Faculty of Technical Sciences, University of Novi Sad, e-mail: ssupic@uns.ac.rs
[2]PhD student, Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, e-mail: marinkovic.s@mfkv.kg.ac.rs
[3]Full Professor, Faculty of Technical Sciences, University of Novi Sad, e-mail: miram@uns.ac.rs
[4]Associate Professor, Faculty of Technical Sciences, University of Novi Sad, e-mail: lookic@uns.ac.rs
[5]Teaching Associate, Faculty of Technical Sciences, University of Novi Sad, e-mail: pantic_vladan@uns.ac.rs

environment. Therefore, partial substitution of cement with waste materials, as alternative binders with lesser embodied carbon, enables cleaner concrete production and healthier living environment.

In an endeavor to minimize the use of PC, researchers all over the world are exploring various industrial, agricultural and urban by-products, generally rich in reactive silica (SiO_2) that can be employed as an unconventional cementitious material, and extensive explorations have been reported on effective utilization of fly ash, slag, rice husk ash, silica fume, and metakaolin. A supplementary cementitious material (SCM) must be pozzolanic in essence, established as being siliceous, or a combination of siliceous and aluminous materials, which may not have a cementitious identity, but respond with $Ca(OH)_2$ and water to produce a similar gel product as cement.

When large amounts of SCMs are used, the carbon emissions from the transportation of these raw materials can also contribute to the embodied carbon. Therefore, there is also a need to use locally available waste materials in order to achieve true sustainability in the construction sector.

It is estimated that the total potential of agriculture biomass in Vojvodina is cca 9 million tons per year [3]. Using this potential can significantly reduce the use of fossil fuels. Unfortunately, a smaller part of harvest residues is used as a substitute for fossil fuels and represents a renewable source of energy, while large amounts of harvest residues and industrial plant processing residues remain unused. Biomass ash, generated by combustion of harvest residues, is most commonly deposited in regulated or "wild" landfills, which has an unfavorable impact on the environment. Literature review revealed that some types of biomass ashes, such as rice husk [4], cob corn [5], sugarcane bagasse ash [6] and wheat straw [7], under some conditions (chemical composition and level of fineness), can be utilized as SCMs.

Over 20 large and small brick factories for the production of clay-based construction products are active in Vojvodina. During the production process of brick elements, a large amount of brick debris remains, which is unusable for further marketing. Part of this waste is returned to the production process, but still a non-negligible amount of waste remains unused. One way to provide a new use value of this waste material, in a powder form, is to use it as an active mineral additive in cement composites.

This paper includes data on the availability of locally available waste materials, originating from agriculture and ceramic industry in Vojvodina and their characterization as potential SCMs. Substitution of cement with such materials would contribute to preserving natural resources, lowering waste share on landfills and reducing greenhouse gases emission.

2. AVAILABILITY OF CERAMIC INDUSTRY AND AGRICULTURAL WASTE IN VOJVODINA

2.1. Availability of biomass ashes

A market analysis revealed that two major biomass ash producers in Vojvodina are companies Soya Protein in Bečej and Almex Ipok in Zrenjanin. Collected data on the available types and quantities of generated biomass ashes are provided in Table 1.

Table 1 - Available quantities of biomass ashes in two major producers in Vojvodina

Company	Biomass type	Temperature of combustion	Types of biomass ashes	Produced quantities per year (tons)
Soya Protein Bečej (BA1)	wheat straw, soya straw, silo waste, sunflower husk	700-900°C	1. ash from boiler furnace 2. ash from multiciklon 3. fly biomass ash	1100
Almex-IPOK Zrenjanin (BA2)	cob corn, soya straw	700-900°C	1. ash from boiler furnace 2. ash from multiciklon 3. fly biomass ash	1100

2.2. Availability of ceramic powder

Data from three factories that produce ceramic products for construction purposes, located in the Vojvodina region were collected. A brief overview of the types and available quantitites of ceramic waste is shown in Table 2.

Table 2 - Available quantities of ceramic waste in some factories of ceramic products in Vojvodina

Company	Type of ceramic products	Temperature of combustion	Produced quantities of ceramic waste per year (tons)
AD Polet IGK, NEXE Novi Bečej (CP1)	roof tiles	cca 1020°C	3600
Ciglana Stražilovo (NEXE, Sremski Karlovci) (CP2)	masonry block, ceiling block	cca 880°C	1500
WIENERBERGER doo Kanjiža,(CP3)	roof tiles	1040-1070°C	1000

Samples of waste materials were gathered in all companies. In order to obtain a material with a satisfactory level of fineness (powder form, similar to cement), biomass ashes and ceramic waste were ground in a laboratory ball mill for 6h – Figures 1 and 2.


Figure 1 – Storage of biomass ashes in Soya Protein and ground biomass ash


Figure 2 – Ceramic debris and ground ceramic powder

3. CHARACTERIZATION OF MATERIALS

3.1. Chemical composition

The chemical composition of collected materials was determined using energy dispersive X-ray fluorescence spectrometer in accordance with SPRS EN 196-2:2015 and ISO 29581-2:2010. The results are given in Table 3.

Table 3 - Chemical composition of biomass ashes and ceramic powders

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	P_2O_5	SiO_2+ Al_2O_3+ Fe_2O_3
BA1	20.21	1.83	1.74	13.42	8.30	0.00	23.09	2.88	7.78	23.78
BA2	45.76	5.92	3.37	14.08	8.30	0.00	13.10	1.26	2.81	55.05
CP1	60.86	16.38	6.81	9.38	3.89	0.77	2.39	0.80	0.14	**84.05**
CP2	61.88	16.46	7.40	4.90	3.66	1.63	2.81	0.08	0.20	**85.74**
CP3	59.03	15.81	6.64	5.65	4.20	1.50	2.50	0.07	0.16	**81.48**

The content of oxides SiO_2, Al_2O_3, and Fe_2O_3 has the greatest significance for the potential pozzolanic activity of cementitious materials. Obtained chemical composition indicates the relatively high participation of major oxides in all ceramic powders, moderate amount in BA2, while BA1 is characterized with low silica content, which is expected to influence its pozzolanic reaction.

3.2. Level of fineness

The specific surface area, as an indicator of fineness, was determined according to the Blaine air permeability method given in SRPS EN 196-6:2019. The results are given in Table 4.

Table 4 – Specific surface area of biomass ashes and ceramic powders

Material	PC	BA1	BA2	CP1	CP2	CP3
Specific surface area (cm^2/g)	4000	8120	8090	13815	11064	6200

After grinding in a laboratory ball mill for 6 h, the specific surface area (Blaine) of all tested cementitious materials significantly exceeded the reference cement value of 4000 cm^2/g. Hence, all SMCs are characterized with satisfactory level of fineness (finer particles implies greater reactivity).

3.3. Pozzolanic activity

The pozzolanic activity was tested on samples prepared according to the procedure given in SRPS B.C1.018:2015. The results are demonstrated in Figure 3.

The results confirm the pozzolanic activity of all tested materials, whereas BA2 and ceramic powders CP1 and CP2 displayed higher activity and greater pozzolanicity class. As a consequence of lower silica content, BA1 provided the minimum values of compressive and flexural strength of mortar prisms prepared with this type of waste material.

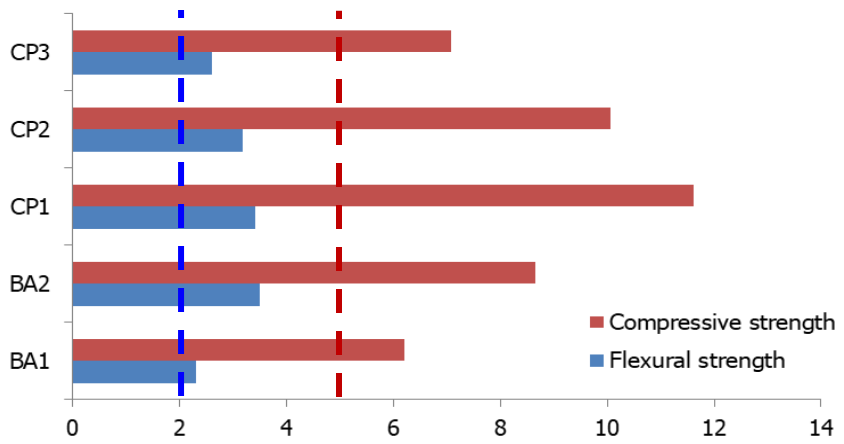

Figure 3 – Pozzolanic reactivity of collected waste materials

3.4. Activity index

The activity index was examined according to SRPS EN 450-1:2014 and the results are illustrated in Figures 4 and 5. According to the criteria given in standard, the activity index at 28 days and at 90 days shall not be less than 75% and 85%, respectively.

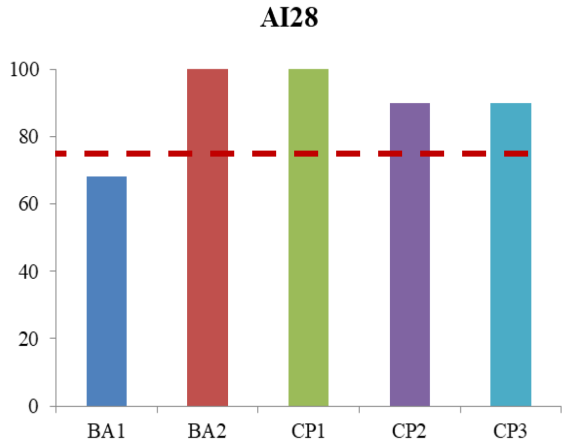

Figure 4 – Activity index of collected waste materials at the age of 28 days

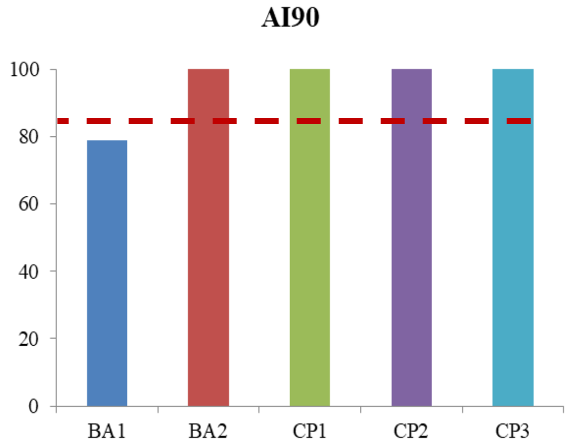

Figure 5 – Activity index of collected waste materials at the age of 90 days

The data clearly shows that BA2 and all ceramic waste powders met requirements after 28 and 90 days, achieving values greater than 75% and 85%, respectively. Only BA1 exhibited both activity index values below the required limits. Although the value obtained for this ash after 90 days shows certain delayed pozzolanic activity, the results in total are not satisfactory due to a lack of reactive silica.

4. SUMMARY OF OBTAINED RESULTS AND ENVIRONMENTAL BENEFITS

Summarized characterized results and evaluation for tested properties of selected waste materials are given in Table 5.

Table 5 – Characterization of biomass ashes and ceramic powders – evaluation

Material	BA1	BA2	CP1	CP2	CP3
Specific surface area (cm^2/g)	+	+	+	+	+
Silica content	Low	Moderate	High	High	High
Pozzolanic activity	+	+	+	+	+
Activity index	-	+	+	+	+

Based on the results, provided in Table 5, it can be concluded that all selected waste materials, apart from BA1, satisfy all tested properties and, therefore, can be used as SCMs in cement-based composites production.

Considering available quantity of ceramic powders and BA2 (7200 tons) and assuming that all collected waste would be utilized as a cement replacement, following environemtal benefits could be achieved:

- reduced amount of raw materials used to produce equivalent cement amount:.2700 tons of clay and 8100 tons of limestone, i.e. natural resources preserved;
- lowered CO_2 emission (7200 tons);
- landfill cleared of 7200 tons of waste.

5. CONCLUSION

This research aimed to highlight the importance of using waste materials, originating from agriculture and brick manufacture industry to create more sustainable building materials, as cement substitues, meeting the principles of sustainable development in civil engineering practice. The following conclusions can be drawn from the study:

- Two major companies, using harvest residues as energy sources, produce 1100 tons of biomass ash, each, as a byproduct, while three dominant ceramic industry companies generate more than 6000 tons of ceramic debris; mechanical processing of these waste products provides materials with satisfactory level of fineness, close to cement;
- The chemical characterization of BA2, CP1, CP2, and CP3 indicates the potential of using these SCMs as cement substitutes due to sufficient reactive silica content in the chemical composition;
- All tested materials satisfied criteria for pozzolanic activity;
- Regarding activity index, BA2 and ceramic powders met requirements after 28 and 90 days, achieving values greater than 75% and 85%, respectively. BA1 exhibited activity index below the required limits.

Based on the obtained results, it can be stated that all ceramic powders and biomass ash generated by combustion of cob corn and soya straw can be effectively utilized as SCMs, i.e. cement substitutes in cement-based composites. Exact amount of replacement should be experimentally verified for each SCM and type of composite.

ACKNOWLEDGEMENT

The research has been conducted within the project "Scientific theoretical and experimental research and improvement of educational process in the field of civil engineering", developed at the Department of Civil Engineering and Geodesy, Faculty of Technical Sciences, University of Novi Sad, Serbia.

6. REFERENCES

[1] Rosković, R.; Bjegović, D.: *Role of mineral additions in reducing CO_2 emmission*, Cement and Concrete Research 35(5), 2005. pp. 974-978.

[2] Mehta, PK., Monteiro, PJM.: *Concrete: microstructure, properties, and materials*, 3rd ed. New York: McGraw-Hill, 2006.

[3] Šupić, S.; Malešev, M.; Radonjanin V.; Bulatović, V.; Milović, T.: *Reactivity and Pozzolanic Properties of Biomass Ashes Generated by Wheat and Soybean Straw Combustion*, Materials, Volume 14, doi: 10.3390/ma14041004, 2021.

[4] Liu, C.; Zhang, W.; Liu, H.; Zhu, C.; Wu, Y.; He, C.; Wang, Z.: *Recycled aggregate concrete with the incorporation of rice husk ash: Mechanical properties and microstructure*, Construction and Building Materials, 351, doi: 10.1016/j.conbuildmat.2022.128934, 2022.

[5] Shaokouri, M.; Exstrom, C.L.; Ramanathan, S.; Suraneni, P.: *Hydration, strength, and durability of cementitious materials incorporating untreated corn cob ash*, Construction and Building Materials, 243, doi: 10.1016/j.conbuildmat.2020.118171, 2020.

[6] Abdalla, T.A.; Koteng, D.O.; Shitote, S.M.; Matallah, M.: Mechanical and durability properties of concrete incorporating silica fume and a high volume of sugarcane bagasse ash, Results in Engineering, 16, doi: 10.1016/j.rineng.2022.100666, 2022.

[7] Šupić, S.; Bulatović, V.; Malešev, M.; Radonjanin V.; Lukić, I.: *Sustainable masonry mortars with fly ash, blast furnace granulated slag and wheat straw ash*, Sustainability, 13, doi: 10.3390/su132112245, 2021.