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DEVELOPMENT OF LOW CARBON AND ENERGY-EFFICIENT GEOPOLYMER-BASED PAVING BLOCKS

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Abstract:

The development of energy-efficient and low-carbon geopolymer-based paving blocks made from waste, as an environmental-friendly material, was evaluated. Ground concrete (GC) and solid brick (SB) powder, as the representatives of construction and demolition waste (C&DW), with the addition of fly ash (FA) and silica fume (SF), were used. Waste samples were characterized in terms of surface functional groups and radioactivity. The FT-IR spectra showed the required amorphous or semi-crystalline alumino-silicate structure. The gamma spectrometry confirmed waste samples' radiological safety. Hardened geopolymer samples were subjected to physical-mechanical investigation comprising of density, water content, compressive and flexural strengths determination. Based on strength characteristics, the three best prototype mixtures were selected and subjected to further compressive strength determination and durability assessment. Prototype sample SBFASFp1, with a compressive strength of 18.7

MPa, was shown the highest value of all samples, almost the same as the corresponding SBFASF1 sample. Freeze-thaw and the subsequent carbonation tests, as durability indicators, showed that the SBFASF1 sample had the slightest strength decrease, making it most durable in these conditions. These satisfactory test results showed the favorable effects of alternatives to cementitious materials, encouraging their utilization and contributing to the sustainability of the construction sector.

Keywords: *alkali activation; construction and demolition waste; fly ash; silica fume; sustainability.*

1. Introduction

The utilization of paving blocks dates back to the Roman Empire when natural stone was used to pave roads. Modern concrete paver blocks were first used in the Netherlands (according to which they are named Holland stones) in the 1950s [1]. Namely, after World War II, the deficiency of clay for paving bricks led to the concrete paving block invention as an alternative construction product. Nowadays, concrete paving blocks are economically affordable solutions for outdoor applications (ground-level arrangement of sidewalks, pedestrian pathways, plateaus, inter-block spaces, industrial complexes, a surface layer of internal roads, or parking areas), giving the best price-quality ratio. Owing to a variety of concrete paver blocks, their undemanding application and adjustment are feasible. Additionally, they absorb stress (e.g. earthquakes, freeze-thaw cycles, and bending erosion), increase strength and durability, reduce shrinkage and cracking, and have low water absorption (natural drainage) [1]. Still, the increasing demand for concrete paving blocks as a precast product has resulted in increased cement quantities for their manufacture.

The total world production of cement reached 4.1 billion tons in 2019 [2], and it might exceed 6 billion tons by 2025, i.e. almost one ton per inhabitant of the planet annually [3]. Cement production is an energy-intensive process that consumes large quantities of raw materials and thermal energy. The production process requires heating to high-temperature levels, e.g. up to 1500°C in a kiln, and therefore has to be almost exclusively powered by the thermal energy produced from fossil fuels (coal, pet coke, and natural

gas, frequently blended with alternative fuels including waste materials, tires, etc.) and electricity. Approximately 4 to 6 GJ of energy is used nowadays per ton of cement clinker produced, and the energy cost accounts for up to 40% of total production cost. Since the production of cement itself yields approximately 7% of the total CO_2 emission, enhancing the greenhouse effect, and consumes around 5% of global industrial energy worldwide, it is recognized as energy-inefficient and one of the major environmental concerns due to global warming and climate change [3]. Moreover, its accelerated production affects the consumption of natural resources, e.g. aggregates or clinker. Due to the growing pressure for carbon emissions reduction and the prerequisite utilization of fossil fuels in cement production, the need for alternatives to cementitious materials become one of the research trends. The materials commonly used for concrete paving blocks are replaced by waste materials and by-products to reduce the impact on environmental pollution offering so-called energy-efficient, low-carbon, and green paver blocks.

However, a more environmentally friendly alternative to conventional concrete represents geopolymer concrete since its production does not require cement. Geopolymers, i.e. alkali activated materials, can be produced at ambient or slightly elevated temperatures, contributing to the reduction of carbon footprint, unlike cement which requires a high-temperature clinkering [4-5]. Furthermore, geopolymerization has shown advantages in reusing various types of waste, ensuring less consumption of raw materials, and dealing with problems related to waste disposal. The particular limitation is the sufficient amount of reactive silica and aluminosilicate [6]. Compared to conventional construction materials, the synthesized geopolymers show adequate physico-mechanical properties, such as high strength and durability [7-8].

The aim of this study is to investigate the development of energy-efficient and low-carbon geopolymer-based paving blocks made from waste, as an environmental-friendly material. For this purpose, construction and demolition waste (C&DW), as the largest part of waste with a share of almost 75% of the total waste amount [9], was used. In addition, fly ash and silica fume were used to achieve better characteristics of geopolymer paver blocks. Eligibility was assessed by physico-mechanical and durability tests of the geopolymer mixture and finished unit – prototype. According to the available literature, there are deficient experimental studies related to the use of these waste materials in geopolymer paver blocks, especially their mix. Additionally, results of this promising

technology in paver block manufacture are scarce and need to be integrated more into engineering applications. The proposed study is expected to provide benefits of such paver block development by integrating cementitious materials alternatives that would reduce the burden on conventional cementitious materials, and thus contribute towards sustainable practice in the construction sector. Namely, the benefits arising from this concept include energy consumption, carbon footprint, and waste reduction with the preservation of a substantial quantity of raw materials which undoubtedly would result in production costs decrease.

2. Materials and Experimental Procedures

2.1. Materials

The following materials were used for sample preparation:

1. Ground concrete (GC) and solid brick (SB) powder (as representatives of C&DW) from an illegal landfill near Viline vode, Belgrade, Serbia;
2. Fly ash (FA) from thermal power plant ‘‘TE Nikola Tesla B”, Obrenovac, Serbia;
3. Silica fume (SF), Sika fume – HR, Sika Group, Serbia;
4. Sodium hydroxide, Merck, USA;
5. Water glass (sodium silicate), Sigma-Aldrich, USA;
6. Sand, fraction 0/4; from the Danube River, NUTO co., Belgrade, Serbia,
7. Superplasticizer, Cementol Hiperplast 463, TKK, Slovenia,
8. Water.

GC and SB were crushed by Jaw crusher JC 15, Wibrotechnik, Russia, milled by Planetary Ball Mill PBM 1-4 (Wibrotechnik, Russia), and sieved to a fine fraction with particle size 0.3-0.6 mm by Test Sieve, Retsch, Germany (Fig. 1).

Fig. 1. Waste samples: a) GC, b) SB, c) FA, and d) SF

2.1.1. Waste Materials Characterization

FT-IR spectroscopy

To investigate the surface chemistry and identify important functional groups in GC, SB, FA, and SF samples, Fourier-transformed infrared (FTIR) spectroscopy was employed.

The analysis was conducted under ambient conditions using a Nicolet iS5 FTIR spectrometer, Thermo Fisher Scientific, USA. The FTIR spectra were recorded in the attenuated total reflection (ATR) mode within the range of 4000 – 400 cm^{-1}. A resolution of 4 cm^{-1} with 32 scans was utilized for optimal spectral accuracy.

Spectrometry of γ-emitters

Gamma spectrometric measurements were performed using HPGe Canberra detectors. Calibration of detectors was performed using a silicone resin matrix in the geometry of the plastic Marinelli beaker spiked with a series of radionuclides (^{241}Am, ^{109}Cd, ^{139}Ce, ^{57}Co, ^{60}Co, ^{203}Hg, ^{88}Y, ^{113}Sn, ^{85}Sr, and ^{137}Cs). The background spectrum was recorded before sample counting. The spectra were analyzed using the program GENIE 2000. The activities of ^{226}Ra and ^{232}Th were determined by their decay products: ^{214}Bi (609 keV, 1120 keV, and also 1764 keV), ^{214}Pb (295 keV and 352 keV), and ^{228}Ac (338 keV and 911 keV), respectively. ^{235}U was determined via 186 keV corrected for ^{226}Ra. The activities of ^{40}K and ^{137}Cs were determined from their 1460 keV and 661 keV γ−energy, respectively. The results are given at a 95% level of significance.

2.2. Geopolymer Mixture Preparation

2.2.1. Laboratory Samples Fabrication

The experimental samples were produced by mixing C&DW (CG and/or SB) powders, FA, and SF with alkali activators, a sufficient quantity of water for the workability of the mixtures, and a superplasticizer. The used alkaline activators were a mixture of ~ 10 M NaOH solution (Merck, 99 wt%) and water glass, i.e. sodium silicate solution (Na_2O: 7.5 – 8.5 %; SiO_2: 25.5 – 28.5 %; Supelco).

The mass ratios of waste and supplementary materials in the sample series are shown in Tables I and II. All samples contained the same amount of each supplementary material for easier comparison of prepared mixture characteristics.

Tab. I Waste materials amount in the samples

Tab. II Supplementary materials for sample preparation

The masses of materials were measured with an Electronic precision balance 572-57, Kern, Germany. The geopolymer pastes were mixed in a Rilem-Cem mixer, Tonindustrie Pruftechnik, Italy for a total of 3 minutes as follows: 60 s at 145 rpm and 120 s at 285 rpm. The samples were molded and subjected to vibration for 30 s in the electric vibrating table AEG TIP VT 355/560 - C, Tonindustrie Pruftechnik, Germany to remove trapped air (Fig. 2).

Fig. 2. Sample preparation

Two types of molds, complying with the standards SRPS EN 196-1:2017 [10] and SRPS EN 12390-1:2021 [11], were used for the sample preparation: cubic, 100 mm and prismatic, 160 x 40 x 40 mm (Fig. 3). Subsequently, the entire sample series were cured for 1 day in the air at room temperature, covered with a polyethylene coating that allows evaporation control.

Fig. 3. Laboratory samples

2.2.2. Paver Block Prototype Fabrication

The pilot sample mixtures for specific product applications were selected based on the previously obtained physico-mechanical investigations. According to custom Holland stone pavers [12], sample dimensions of 100 x 100 x 60 mm of corresponding mixtures (Fig. 4) were produced following the procedure described in 2.2.1.

Fig. 4. Paver block prototype samples

2.3. Geopolymer Mixture Examination

2.3.1. Laboratory Samples Testing

Density

Following volume calculation (after sample dimension measurement) and weighing, the densities of the samples in fresh and hardened state were calculated: the total density in the fresh state (γ_t), the initial density after 7 days of drying in the mold (γ_0), and the density after demolding and 28 days of total air drying (γ_{28}). The procedure was performed

according to the standards SRPS EN 12350-6:2019 [13] and SRPS EN 12390-7:2019 [14].

Water Content

The amount of water that the material contains in its pore system, water content (H_a), was calculated for the cubic samples according to the procedure defined by ASTM C 642 – 97 [15]. It represents the ratio between the water content in the sample and the mass of the dry sample after 28 days of total air drying. The water content in the sample was recorded as the difference between the mass of the sample in ambient conditions after 7 days of curing in the mold and the mass of the dry sample. The masses of samples were measured with an Electronic precision balance 572-57, Kern, Germany.

Compressive and Flexural Strengths

The strength tests were performed on 28-days-old cubic and prismatic samples. Cubic samples were tested for compressive strength by a 2 MN manual (manual correction of oil pressure in press) hydraulic press Amsler&Sohn, Germany, while the prismatic samples were examined for compressive and flexural strength by a manual 200 kN hydraulic press CMC, Amsler&Sohn, Germany.

The compressive strength tests were performed according to the standard SRPS EN 12390-3:2019 for cubic samples [16], and according to the standard SRPS EN 196-1:2017 for the prismatic sample halves [17], following the flexural strength test. The flexural strength determination was conducted through a ‘‘three-point bending” test on the prismatic samples, with a span of 10.67 cm (L) according to SRPS EN 196-1:2017 [17]. The tests were performed in duplicate, and the results are shown as mean values.

2.3.2. Paver block prototype testing

Compressive and Flexural Strength

The paver block prototypes were tested for compressive and flexural strength following the same procedures as for the laboratory samples.

Durability Assessment

Durability assessment, i.e. resistance to freeze-thaw and carbonation of prototype mixtures was carried out according to EN 15304:2012 [18] for determination of the freeze-thaw resistance on prismatic samples, in order to obtain results that can be correlated with other materials of the same standardized shape. Exposure to freeze and

thaw cycles serves to investigate the influence of future exploitation of novel paver block (dominantly atmospheric conditions). Same as previous, the prismatic samples were made and left to dry for after 28 days in the air at room temperature. Thereafter samples were subjected to freeze-thaw cycles in the climatic chamber C700BCXPRO, FDM, Italy, between two temperatures: -20°C (for 18 hours) and +20°C (for 6 hours). After this treatment, compressive and flexural strength were investigated. For further durability evaluation, the samples were afterward subjected to accelerated carbonation in the carbonation chamber Memmert ICH 260 C, Germany, with climate including 2% carbon dioxide and 50% humidity, and another comparative assessment of the carbonation effects on both the compressive and flexural strength was performed.

3. Results and Discussion

3.1. Waste Materials Characterization Results

3.1.1. FT-IR

Infrared spectroscopic analysis with Fourier transformation (FT-IR) identified the main functional groups on the surface of the waste materials. FT-IR spectrums of all used waste materials are shown in Fig. 5.

Fig. 5. FT-IR spectrum of waste samples

Spectrograms of all samples showed the presence of picks and bands only in the fingerprint region. The presence of peaks in the range 1090 – 990 cm^{-1} is observed in the spectra of all samples, which can be attributed to T-O-Si asymmetric stretching vibration where T represents Si or Al atom [8,19]. Symmetric stretching vibrations of Si-O-Si bridges are present in SB and FA samples in the range 800 – 780 cm^{-1} [19], while in SF spectra at 798.59 cm^{-1} a distinctly sharp peak characteristic of this material was observed [20]. Additionally, in the range 800 – 500 cm^{-1}, in addition to the symmetric stretching vibrations of Si-O-Si, weak peaks of symmetric stretching vibrations of Al-O-Si bonds also appear describing the formation of an amorphous to semi-crystalline alumino-silicate materials [21]. The spade on 872 cm^{-1}, the characteristic of the carbonate group, is present

in the GC sample [22]. A peak at 592 cm^{-1} in the FA sample can be attributed to the symmetric stretching vibration of Si-O-Si and Al-O-Si [19]. Peaks at 1406 and 872 cm^{-1} are present in a GC sample. They are characteristic of O-C-O stretching vibration and out-of-plane vibration, respectively, and therefore are associated with calcite ($CaCO_3$ polymorph) [19,22]. In the zone below 500 cm^{-1}, the bending vibrations distinctive to Si-O-Si and O-Si-O groups are present in the spectra of all samples.

3.1.2. Gamma spectrometry

The presence of radionuclides in building materials can increase internal radioactive exposures to humans. Knowledge of the radioactivity level in these materials is important in order to assess radiological hazards and to develop the standards for safety use. Building materials and fly ash, derived from earthen materials, contain significant amounts of natural radionuclides originating from uranium-238 and thorium-232 series, and potassium-40 [23-24]. Measured activity concentrations of radionuclides in samples GC, SB, and FA are presented in Table III, while the SF sample was not investigated since silica fume is classified as a radiologically safe material [25-26].

Tab. III Measured specific activities of γ-emitters (Bq/kg)

Natural radionuclides ^{226}Ra, ^{232}Th, and ^{40}K were identified while artificial radionuclide ^{137}Cs was not detected. The obtained results for GC and SB are in good agreement with the worldwide average concentrations of natural radionuclides in the building materials: ^{226}Ra (50 Bq/kg), ^{232}Th (50 Bq/kg), and ^{40}K (500 Bq/kg) [27]. Fly ash, produced in the coal combustion process, has higher values of natural radionuclides concerning coal since the radionuclide enhancement factor in ash is about 10 [27]. The use of fly ash for building construction results in radiation exposure from both direct irradiation and radon exhalation. The most significant exposure pathways are ingestion and inhalation of the isotopes ^{210}Pb and ^{210}Po [27]. In order to estimate the radiological hazards in the case of using investigated materials in construction, the gamma index, the internal hazard index, and the radium equivalent activity were calculated [28-29]. The hazard indices were estimated based on the obtained concentrations of radionuclides ^{226}Ra, ^{232}Th, and ^{40}K. The calculated gamma index was 0.26 for GC, 0.50 for SB, and 1.12 for FA. The material,

for which it is determined to have a gamma index equal to or greater than 1, may cause an increase in the reference level (1 mSv/y). This higher value for FA should not pose a health problem when these materials constitute a relatively small portion of the materials used in the building. The internal hazard index was less than unity for GC and SB, and for FA was 1.25. The value of internal indices must be less than unity for the radiation hazard to be acceptable. However, similar to the previous one, when it comes to small shares in the construction material, the result should not represent a risk. Calculated radium equivalent activity values for the investigated samples were lower than 370 Bq/ kg, which is the maximum permissible value for safe use.

3.2. Physico-mechanical Properties of Geopolymer Mixtures

3.2.1. Density and Water Content

The results of the density measurements and water content are presented in Table IV.

Tab. IV Densities and water content of all series

The obtained densities ranged from 1286 kg/m^3 for GCSBFASF1, up to 2175 kg/m^3 for GCSBFASF2, with an average of 1851 kg/m^3 which are slightly lower compared to the usual values for concrete (2000 – 2300 kg/m^3) [30]. A connection between the used materials and their densities cannot be established, as density values of all three series with GC and SB ranged widely. The combination of these materials might have made an impact on their particles packing in the geopolymer, resulting in very different densities. As for the water content values, they ranged from 1.6 to 3.4%. The lowest values were connected to the series with SB (1.6%, 2.0%, and 2.2%). These values are considered as acceptable, knowing that the absorptions of common concrete materials reach values as high as 6 – 8% [31].

3.2.2. Compressive and Flexural Strength and Prototype Testing

Compressive and flexural strengths obtained from the cubic and prismatic samples are shown in Table V.

Tab. V Compressive and flexural strength of the investigated series for the cube and prism-shaped samples

The samples SBFASF1, GCSBFASF1, and GCSBFASF2 showed the highest compressive and flexural strength results in the case of both cubes and prisms.
The best strength results designated the composition of the prototype samples. Thereby, the mixtures SBFASF1, GCSBFASF1, and GCSBFASF2, now marked as SBFASFp1, GCSBFASFp1, and GCSBFASFp2, respectively, indicating the prototype samples, were subjected to further investigation and comparison.
The results are shown in Table VI.

Tab. VI Compressive strength of the novel paver blocks

As seen in Table VI, the sample SBFASFp1 exhibited the highest strength value of all samples, almost the same as the corresponding SBFASF1 sample.
The obtained strengths are higher than in samples obtained by SF geopolymerization, where the maximum compressive strength after 28 days was up to 15 MPa, and the flexural strength was 1.5 MPa [32]. This can be partially explained by the higher aluminosilicate share of the other present components. On the other hand, the results were lower than in geopolymer mortars obtained by a combination of FA and SF [33], where compressive strength after 28 days was max 40 MPa. It could be explained by a higher proportion of FA with more favorable aluminosilicate content. Comparing the results for Holland stones made of Portland cement, it can be seen that there was a smaller drop in compressive strength values considering that results did not excede 37.28 and 9.99 MPa for compressive strength and flexural strength, respectively [34], although concrete paving units are governed by a solid concrete paving unit standard specification ASTM C936/C936M that requires a minimum average compressive strength of 55 MPa regardless of size or configuration [12]. However, the Indian Standard specifies much lower compressive strength values of 30 MPa for non-traffic applications and 40 MPa for

medium-traffic applications [34]. Consequently, the obtained values can be considered as satisfactory for further research. Additionally, the advantage of such novel paver units represents the complete absence of cement as an energy-inefficient or environmentally unfriendly material.

3.2.3. Durability assessment

These three corresponding mixtures were also chosen for durability assessment and the results are shown in Fig. 6.

Fig. 6. Durability investigation – results of the compressive (comp) and flexural (flex) strength tests after freeze-thaw (fr-th) and the subsequent carbonation (carb) treatment

Compressive strength decrease was recorded for all of the series after carbonation due to the freeze-thaw treatment, reaching 26.6%, 29.8%, and 30.2% for SBFASFp1, GCSBFASFp1, and GCSBFASFp2, respectively. The values of the SBFASFp1 sample decreased less in comparison to the samples made both with GC and SB, most probably due to the better structure without pores [1][1]. Namely, samples with GC had lower strength because they did not achieve a similarly good structure, and it was therefore prone to cracking. Further treatment by carbonation led to a further decrease of compressive strength of 9%, 4%, and 8% for SBFASFp1, GCSBFASFp1, and GCSBFASFp2, respectively. The lowest strength decrease can most probably be attributed to the higher content of calcium hydroxide in the mixtures with GC, which led to the refinement of the pore system due to the $CaCO_3$ formation in the CO_2-rich environment [5]. Nevertheless, this content was not enough to improve the structure of the GCCBFASFp2 sample, where the presence of FA and SF had an adverse effect in comparison to the GCSBFASFp1 sample.

4. Conclusions

The aim of this study was to investigate the energy-efficient and low-carbon geopolymer-based paving blocks made from waste, as an environmental-friendly material. Ground concrete (GC) and solid brick (SB) powder, as the representatives of construction and

demolition waste (C&DW), with the addition of fly ash (FA) and silica fume (SF) for improving characteristics of geopolymer paver blocks were used. Waste samples were characterized in terms of surface functional groups and radioactivity. The FT-IR spectra showed the required amorphous or semi-crystalline alumino-silicate structure, while the gamma spectrometry confirmed the radiological safety of waste samples.

The eligibility of new paver blocks was assessed by physico-mechanical tests: density calculation, water content, as well as compressive strength, following the flexural strength test.

Based on previous strength characteristics three best prototype mixtures were selected, prepared as sample dimensions of 100 x 100 x 60 mm, according to custom Holland stone pavers, and subjected to compressive strength determination and durability assessment and another comparative evaluation of the effects on both the compressive and flexural strength was performed.

The densities ranged from 1286 kg/m^3 for GCSBFASF1, to 2175 kg/m^3 for GCSBFASF2, with an average of 1851 kg/m^3, which are moderately lower than concrete with values of 2000 – 2300 kg/m^3. Water content values are considered as acceptable, knowing that the absorptions of common concrete materials reach values as high as 6 – 8%. Mixtures SBFASF1, GCSBFASF1, and GCSBFASF2 showed the highest compressive and flexural strength results in the case of both – cubes and prisms: 18.9 and 19.2 MPa; 18.3 and 18.8 MPa; 17.1 and 17.9 MPa, respectively.

Prototype sample SBFASFp1, with a compressive strength of 18.9 MPa, was shown the highest value of all samples, almost the same as the corresponding SBFASF1 sample (18.9 MPa). This can be partially explained by the higher aluminosilicate share of the other present components. Freeze-thaw and the subsequent carbonation tests, as durability indicators, showed that the SBFASF1 sample had the slightest strength decrease, making it most durable in these conditions. The obtained values can be considered satisfactory for further research. Additionally, the advantage of such novel paver units represents the complete absence of cement as an energy-inefficient or environmentally unfriendly material.

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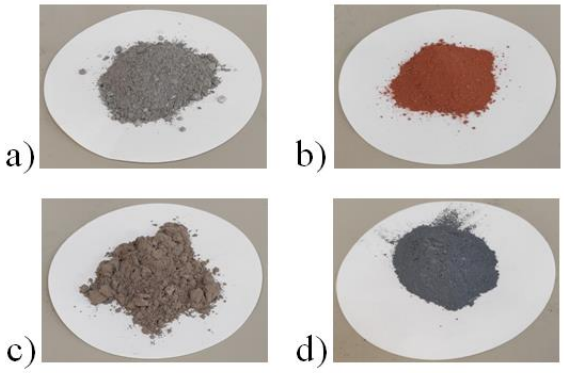

Fig. 1. Waste samples: a) GC, b) SB, c) FA, and d) SF

Tab. I Waste materials amount in the samples

Sample	Waste materials amount [g]			
	GC	SB	FA	SF
GCFASF1	1200	-	100	50
GCFASF2	900	-	100	50
GCFASF3	600	-	100	50
SBFASF1	-	1200	100	50
SBFASF2	-	900	100	50
SBFASF3	-	600	100	50
GCSBFASF1	600	600	100	50
GCSBFASF2	450	450	100	50
GCSBFASF3	300	300	100	50

Tab. II Supplementary materials for sample preparation

Supplementary material	Sodium hydroxide, 10M	Water glass	Sand, fraction 0/4	Water	Superplasticizer
Quantity [g]	73	169	120	20	4

Fig. 2. Sample preparation

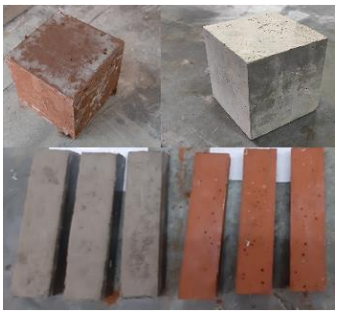

Fig. 3. Laboratory samples

Fig. 4. Paver block prototype samples

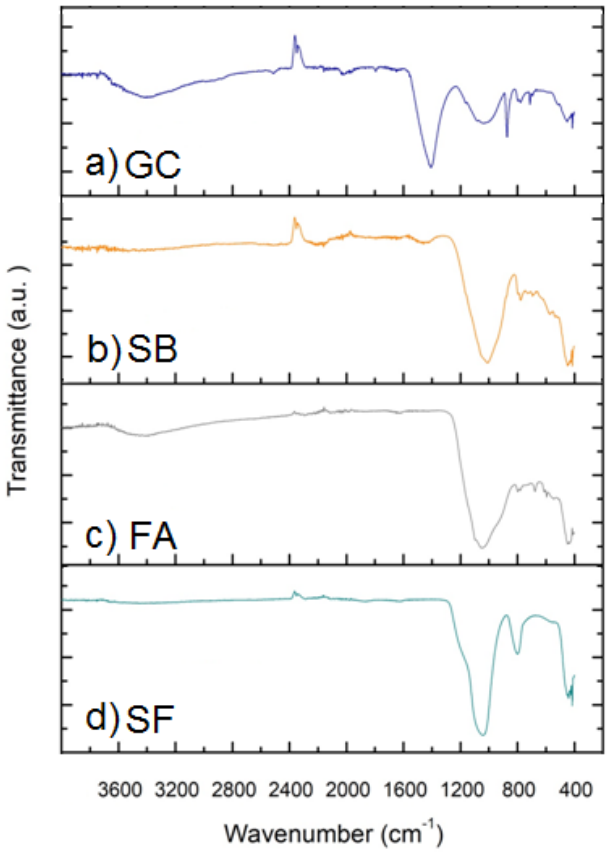

Fig. 5. FT-IR spectrum of waste samples

Tab. III Measured specific activities of γ-emitters (Bq/kg)

Sample	^{226}Ra	^{232}Th	^{40}K
GC	19 ± 3	18 ± 6	310 ± 50
SB	63 ± 9	20 ± 8	580 ± 80
FA	144 ± 10	100 ± 7	420 ± 30

Tab. IV Densities and water content of all series

Sample	Density [kg/m^3]	H_a [%]
GCFASF1	2077	2.2
GCFASF2	2012	2.8
GCFASF3	1516	3.4
SBFASF1	1630	1.6
SBFASF2	1900	2.0
SBFASF3	1992	2.2
GCSBFASF1	1286	2.5
GCSBFASF2	2175	2.3
GCSBFASF3	2074	3.1

Tab. V Compressive and flexural strength of the investigated series for the cube and prism-shaped samples

Sample	Compressive strength, cubes [MPa]	Compressive strength, prisms [MPa]	Flexural strength, prisms [MPa]
GCFASF1	8.8	9.8	1.0
GCFASF2	4.1	4.6	0.6
GCFASF3	1.9	2.4	0.5
SBFASF1	18.9	19.2	1.8
SBFASF2	15.2	15.9	1.5
SBFASF3	9.9	10.2	1.0
GCSBFASF1	18.3	18.8	1.7
GCSBFASF2	17.1	17.9	1.7
GCSBFASF3	9.9	10.8	1.0

Tab. VI Compressive strength of the novel paver blocks

Sample	Compressive strength [MPa]
SBFASFp1	18.7
GCSBFASFp1	18.1
GCSBFASFp2	17.2

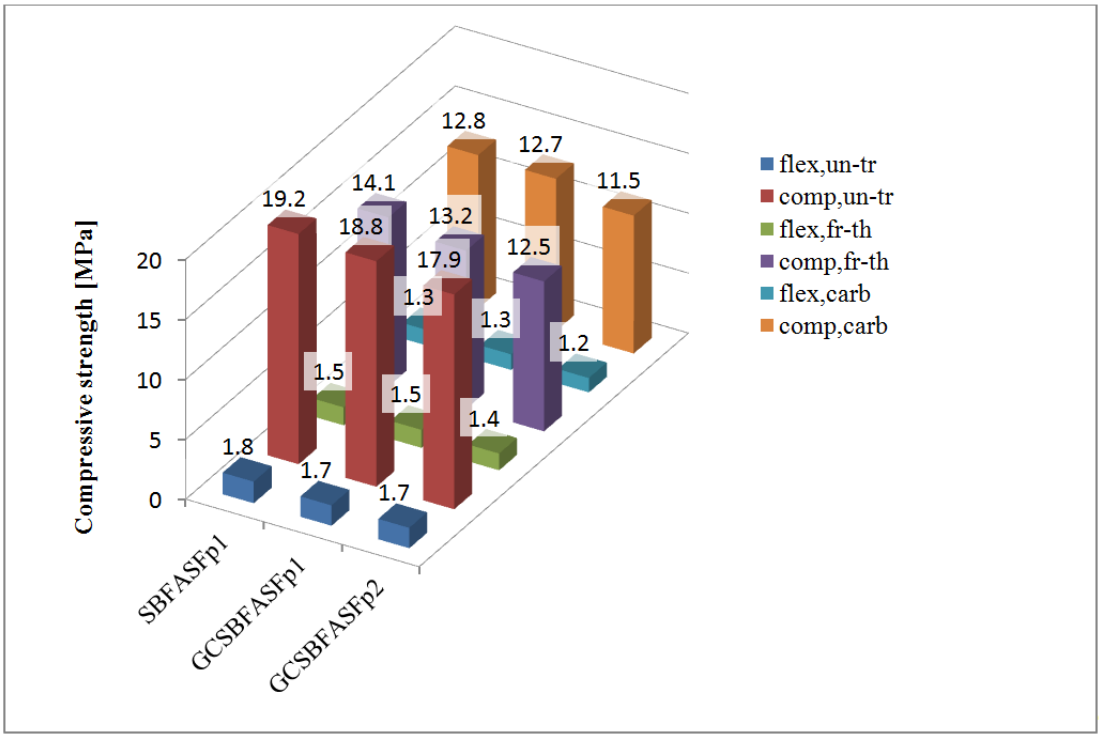

Fig. 6. Durability investigation – results of the compressive (comp) and flexural (flex) strength tests after freeze-thaw (fr-th) and the subsequent carbonation (carb) treatment

Апстракт:

Извршена је процена развоја енергетски ефикасних и ниско-угљеничних блокова за поплочавање на бази геополимера добијених од отпада, као еколошки прихватљивог материјала. Коришћени су млевени бетон (GC) и прах пуне опеке (SB), као представници грађевинског отпада (C&DW), са додатком летећег пепела (FA) и силикатне прашине (SF). Узорци отпада су окарактерисани у погледу површинских функционалних група и радиоактивности. FT-IR спектри су показали потребну аморфну или полукристалну алуминосиликатну структуру. Гама спектрометрија је потврдила радиолошку сигурност узорака отпада. Очврсли узорци геополимера су подвргнути физичко-механичком испитивању које обухвата одређивање густине, садржаја воде, чврстоће на притисак и чврстоће при затезању савијањем. На основу карактеристика чврстоће изабране су три

најбоље прототипне мешавине које су подвргнуте даљем одређивању чврстоће на притисак и процене трајности. Прототип узорка SBFASFp1, са чврстоћом на притисак од 18,7 MPa, показао је највећу вредност од свих узорака, скоро исту као и одговарајући узорак SBFASF1. Замрзавање-одмрзавање и каснији тестови карбонизације, као показатељи издржљивости, показали су да је узорак SBFASF1 имао најмањи пад чврстоће, што га чини најиздржљивијим у датим условима. Ови задовољавајући резултати показали су повољне ефекте алтернатива цементним материјалима, подстичући њихову употребу и доприносећи одрживости грађевинског сектора.

Кључне речи: *алкална активација; грађевински отпад; летећи пепео; силикатна прашина; одрживост.*