SUSTAINABILITY ASPECT OF POSSIBLE MATERIAL SUBSTITUTION IN CONSTRUCTION INDUSTRY

by

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Original scientific paper
https://doi.org/10.2298/TSCI230225128R

While creating the sustainable construction systems it is crucial to innovate in production of construction materials by maximizing recycling and reuse of the materials during production and use of the buildings. The intention of this paper is to provide new insights and better understanding of sustainable oriented innovation in production of construction materials, in particular substitution of cement in mortar with waste material, fly ash, bearing in mind its huge negative impact on the environment. Previous investigations of possible use of fly ash have proven the possibility of its use for the production of cement for lightweight concrete, bricks, asphalt fillers, however the use of the fly ash in cement screeds was not considered. The aim of this work was to examine at first, justification of substitution of cement in mortar with fly ash due to its newly gained properties as change of density, compressive strength and water absorption. In order to take into account aspect of environmental protection the newly gained mechanical properties of the materials were tested in terms of its convenience for use in cement screeds.

Key words: *sustainability in construction industry, substitution, cement, fly ash, cement screed*

Introduction

Sustainable development, by merging environmental performance, is seen as imperative in development of nations. Recent expansion of development in energy efficiency of the buildings encourages greater environmental responsibility in the process of sustainable development. Sustainability in construction industry goes towards positive long term environmental impact by, at the same time, improving the technologies in all parts of the construction process. The innovation in the process is basically linked with these technologies [1]. The idea behind sustainable development is to promote social and economic progress while preserving the health of the social and ecological systems that support the economy. It serves as the cornerstone of the sustainable development goals (SDG), the most important global framework for international collaboration, and the 2030 Agenda for Sustainable Development. It is important to create society with affordable and clean energy (SDG 7), successful industry with innovation, and good infrastructure (SDG 9), to have responsible consumption and production (SDG 12) in creating the sustainable cities and communities (SDG 11), having in mind actions that can

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influence on climate (SDG 13) [2]. In the last decade, fewest documents have been accepted at the EU level in order to define a common action policy to achieve and create prosperous society with protection of natural resources, public health and environment. The framework for strategic actions for development of environmental policy was defined by the EU in 2013 with the adoption of the 7th EU Environment Action Program until 2020 [3]. All Member States in the field of waste management set the program with specific objectives with obligation turn waste into resource based on the strict application of the principle of the waste management hierarchy. It was obligatory to reduce waste generation and total waste generation, to reduce the disposal of recyclable and reusable waste [4].

Coal is the basic energy raw material in Serbia. It is consumed only in thermal power plants over 35933752 tons of coal per year. Depending on the site, that is, on the type and quality of coal, and the content of admixtures, the amount of ash and slag that remains after the energy produced is between 15% and 26%. This practically means that every year as a by-product of energy production from coalin Serbia, it creates about 7 millions of ash and slag [5].

Environmental Protection Agency gives an overview of the waste generated in Republic of Serbia in 2020. Based on the data approximately 68000 tons of hazardous waste has been generated. Thermal energy facilities are the largest waste producers. Ash, slag and dust together with fly ash from coal combustion generate the amount of 7.78 millions that is 81% of the total waste produced.

Currently, the fly ash is used for the needs of cement production. Some amount of gypsum from the process of desulphurisation is exported, representing by-product. Out of the total waste produced, the amount of 1763052 tons (18%) was reported, while 7812437 tons (82%), which is mainly pulverized coal, remained at the locations where the waste was produced [4].

Due to decades of disposal of by-products generated in thermal power plants, there are millions of deposited tons of ash occupying and degrading thousands of hectares of land. The amount of 8.379.777 tons of waste from thermal processes is given in the Report made by Environmental Protection Agency related with the Quantities of waste generated in the Republic of Serbia in 2020 [6]. These enormous quantities of solid waste despite ongoing regulation and monitoring, cause a variety of environmental issues, including air pollution, soil pollution, surface and subterranean water contamination, and loss of plant cover. Additionally, it is proved that dumping of this waste generated in thermal processes impacts human health. By product from the thermal power plants is electro-filter ash. Electro-filter ash, referred to as fly ash, is a fine-grained material, granulated into small-size granules, obtained through burning coal dust in thermal power plants (during generation of electricity or heat) conveyed by flue gas, and collected by electrostatic precipitators or mechanical collecting devices (cyclones). The amount of generated ash depends on the installed capacity of thermal power plants and varies within very wide limits-from about one ton per day to several tons per minute [7].

Although electro-filter ash has a certain negative impact, it may also be employed as a supplementary raw material in the construction industry. Because electro-filter ash has pozzolanic qualities and a relatively high grinding fineness, this powdered material can be used as a mineral additive in the production of cement, *i.e.*, it may be a partial replacement for Portland cement in composite materials like mortar and concrete.

Since fly ash has pozzolanic properties, whose activity is defined as the ability to produce materials with hydraulic properties in the presence of water and lime $Ca(OH)_2$, and a relatively high grinding fineness, this powdered material can be used as a mineral additive in the production of cement, *i.e.* it may be a partial replacement for Portland cement in composite materials.

According to 2015 statistics, $4.6 \cdot 10^9$ tons of cement were produced across the globe, which is equivalent to 626 kg of cement *per capita* [8]. At least 5-7% of total CO_2 emissions in the atmosphere are attributed to the cement industry [9]. If present development trends in the construction industry continue uninterrupted, cement manufacture may be responsible for generating 24% of the total world CO_2 emissions by 2050 [10]. The cement industry contributes about 5% to global anthropogenic CO_2 emissions, and is thus an important sector in CO_2-emission mitigation strategies. The CO_2 is emitted from the calcinations process of lime stone, from combustion of fuels in the kiln, and from the coal combustion during power generation. Strategies to reduce these CO_2 emissions include energy efficiency improvement, new processes, shift to low carbon fuels or waste fuels in cement production, increased use of additives in cement production, alternative cements, and CO_2 removal from flue gases in clinker kilns [11].

The concrete-cement industry is responsible for 8% of total CO_2 emissions on the planet, accompanied by steel industry, which is responsible for 5%. Besides the reduction of overall consumption of concrete, it is possible to reduce the amount of cement in the mixture by simultaneously increasing the amount of aggregate and reducing the amount of water [12].

The importance of ash deposit is shown by an extensive research program that has been conducted with the aim to investigate the processes of ash deposit formation and combustion of pulverized fuel in order to find criteria for estimating the tendency of particular fuel (coal and biomass) to form deposits and also to find aerodynamic, thermal and construction parameters which minimize the rate of deposit formation [13]. The use of electro-filter ash in the construction sector seems highly relevant from the perspective of environmental protection and sustainable development, since the emission of CO_2 and the exploitation of non-renewable natural resources (limestone, clay, river, and crushed aggregate) may be reduced in this way. This fulfils one of the fundamental European objectives for conservation and sustainable use of natural resources-the seventh criterion concerning construction [14]. The use of electro-filter ash is the basis for designing new building materials on the principle of reusing the leftovers.

The use of electro-filter ash in construction

For a long time, electro-filter ash has been used in a variety of applications across the world, often after being changed by several additives to strengthen its capabilities as a binding material or aggregate. Electro-filter ash may be employed in the production of cement, mortar, concrete, brick, tile, and asphalt. The technical standards for using fly ash in concrete are set forth in the European Standard EN 450, particularly specifying silicate ash utilization.

McMillan and Powers [15] first discussed using electro-filter ash in concrete and following investigations by Davis *at al.* [16] elaborated on this idea.

According to British research published in the late 1940's, the Lednock, Clatworthy, and Lubreoch dams were built in the 1950's using electro-filter ash as a partial replacement for cement.

Given that its composition is like that of clay, electro-filter ash is used in the production of brick goods. Numerous techniques have been developed worldwide for the manufacturing of artificial ash-based aggregates. Two of them sintering and cold-bonding have reached the stage where they are employed in commercial applications. The aggregates produced in this manner may be used for a number of construction applications, including masonry components, prefabricated concrete elements, bituminous concrete, and other similar products [17]. Large quantities of ash may be used in civil engineering, particularly in road construction. In the middle of the twentieth century, Carpenter [18] and Zimmer [19] published papers on the feasibility of electro-filter ash incorporation into asphalt mixtures. Similarly, using ash to stabilize soil may have the potential to deliver various benefits, including reduced negative environmental consequences and expenses, as well as improved soil quality. Over the preceding few decades, research activities in this industry have been stepped up considerably. Some of the research concerns the use of electro-filter ash in the production of concrete [20, 21, 7] and bituminous mortar [22-24].

When it comes to producing building materials that contain electro-filter ash, China is the world's leading producer with the production of 1.7 billionns of fly ash each year. Amongst 15 countries in the EU, 18 million metric tons of fly ash are used, with around 14 millions used in the production of concrete cement, and approximately 23% used in the construction of roads [25].

Throughout the world, there are numerous examples of ash being used as a building material, including the *Kasto*r and *Pollux* towers in Frankfurt, the *Picasso* tower in Madrid, the tallest building in the world *Burj Khalifa* in Dubai, *The Petronas Tower* in Kuala Lumpur, the tunnel beneath the English Channel, the *East Bridge*-bridge connecting the islands in Denmark, *Puylauren*t-one of the largest arch dams in France (the quantity of ash used in the entire construction is 10000 tons), the *Planatovryssi* dam in Greece, the cooling tower of the thermal power plant (950 MW) in Niederaussem, Germany, silos for storage fly ash of thermal power plant *Genk-Langerlo*, Belgium, oil storage Genk-Langerlo Gravity Base Structure, England, and many others.

Properties of Electro-filter ash

Physical Characteristics of Electro-filter ash

Electro-filter ash is composed of filled or hollow powder particles that are mostly spherical in shape and glassy in texture (amorphous). The carbon component of electro-filter ash is made up of angular particles. A microscopic examination reveals that the electro-filter ash particles vary in size from 1-200 μm. Depending on particle size, ashes are classified as:
- fine fraction (particles smaller than 45 μm in size) and
- coarse fraction (particles greater than 45 μm in size) [26].

The specific mass of electro-filter ash usually ranges from 2.1-3.0 g/cm^3, whereas the specific surface area (as measured by Blain's air permeability method) may range from 170-1000 m^2/kg. Fly ash has a volume weight varying between 540 kg/m^3 and 860 kg/m^3 when loosely bound, and between 1120 kg/m^3 and 1500 kg/m^3 when compacted [27].

The color of electro-filter ash is not a reliable indicator of its chemical composition. Ash from lignite or partially bituminous coal is often light or pale brown in color, indicating low carbon content as well as the presence of lime or calcium. Electro-filter ash produced from bituminous coal is grayish in color. Lighter shades of grey indicate better ash quality, while dark grey and black colors denote a higher unburned carbon content.

The minerals present in electro-filter ash are determined by the kind of fuel used (coal), the combustion temperatures achieved, and the cooling method. Electro-filter ash is formed in high temperature zones, between 1000 °C and 1200 °C, and less frequently up to 1700 °C [27], causing softening and even melting in unburned mineral particles, which then reach a relatively low temperature zone (around 250 °C). Because of the heat stress, the ash from the electro-filter develops a glassy structure, and surface tensions force it to form into balls or pieces of irregular shape. This ash consists mostly of glassy materials and mullite, with smaller amounts of hematite, magnetite, goethite, and coal components.

Particle size of fly ash produced in Kolubara basin shows that the grain size used in the experiment is less than 1.0 mm ($Y = 99.66\%$).

Chemical properties of electro-filter ash

The chemical properties of electro-filter ash are largely influenced by coal content, air pollution control strategies in thermal power plants, and techniques used for handling and storage. Depending on chemical composition, ashes are classified into four groups:

- acidic: 50% SiO_2; 25% Al_2O_3; 7-9% Fe_2O_3; 5-7% CaO; 1-3,3% SO_3,
- aluminosilicate: 40-50% SiO_2; 17-25% Al_2O_3; 9-22% CaO; and 0.5-5% SO_3,
- basic: 40-50% CaO; 2-5% SiO_2; 7-8% Al_2O_3; 6-8% Fe_2O_3; 9% SO_3, and
- highly sulphated and highly basic: 26% SO_3, 33% CaO, 4% MgO, 4% Al_2O_3, and 3% SiO_2 [7].

The American Society for Testing and Materials (ASTM C618) classifies ash as belonging to the following classes:

- F (produced by the combustion of anthracite and bituminous coals) and
- C (produced by the combustion of lignite or sub-bituminous coals).

The key criteria for determining whether electro-filter ash is classified as class F or class C are the percentages of calcium, SiO_2, Al_2O_3, aluminum oxide, and iron. In class F ash, the total concentration of calcium ranges from 1-12%, mostly in the form of calcium hydroxide, calcium sulphate, and glass components combined with SiO_2 and Al_2O_3. Class C ash, on the other hand, contains 30-40% CaO [28]. The amount of alkali (combined sodium and potassium) and sulphate (SO_4) that can be found in class C ash is larger than that in class F.

Even though classes F and C are supposed to be strictly used for electro-filter ash that meets the requirements of ASTM Standard C 618, these designations are sometimes used more widely to determine class depending on the CaO source or its quantity.

The standard chemical ingredients of electro-filter ash produced from bituminous coal, partially bituminous coal and lignite are shown in tab. 1. Ashes from lignite and partially bituminous coal have higher calcium oxide content and lower loss on ignition (LOI) compared to ash from bituminous coal. For example, ash from lignite and partially bituminous coal may contain more than ash from bituminous coal. The LOI is a measure of the amount of residual carbon retained in the fly ash.

Following table is giving chemical analysis of fly ash from the thermal power plants (TPP) from Kolubara, Kostolac and Kosovska basins.

Table 1. Chemical composition of the fly ash samples

Investigated composition	Fly ash sample			
	Kolubara	Kostolac B1	Kostolac B2	Kosovo
SiO_2	62.13	46.85	45.56	19.28
Al_2O_3	17.20	23.20	22.90	5.67
Fe_2O_3	5.95	12.14	13.66	4.85
CaO	5.67	8.26	8.93	42.92
MgO	2.0	2.77	2.68	4.31
SO_3	0.67	1.48	1.79	19.41
LOI at 1000 °C	2.88	4.44	3.34	2.30
Total	96.50	99.10	98.87	98.74

Although some studies have shown that the level of natural radionuclides in the coal that is burned in the boilers of the Kolubara Basin and the ash that is created during combustion allows its disposal into the environment, and the maintenance of large deposited areas certainly threatens the ecosystem. Ash is divided into radioactive and neutral, with the use of neutral being permitted in the construction industry [29]. Standard chemical compound in electro-filter ash are shown in tab. 2.

Table 2. Standard chemical compound content found in electro-filter ash produced from the combustion of several types of coal (expressed as a percentage per unit mass) [30]

Chemical compound	Bituminous coal [%]	Partially bituminous coal [%]	Lignite [%]
SiO_2	20-60	40-60	15-45
Al_2O_3	5-35	20-30	10-25
Fe_2O_3	10-40	4-10	4-15
CaO	1-12	5-30	15-40
MgO	0-5	1-6	3-10
SO_3	0-4	0-2	0-10
Na_2O	0-4	0-2	0-6
K_2O	0-3	0-4	0-4
LOI	0-15	0-3	0-5

Consequently, according to AASHTO or ASTM specifications, the loss-on-ignition for classified ash can range between 5% and 6%. Because changes in the carbon content may affect how the concrete mixture behaves and the quantity of air in it, loss-on-ignition can indicate whether ash can be used as a cement replacement in concrete.

In addition its chemical composition and loss-on-ignition, the quality of electro-filter ash is primarily determined by its fineness and consistency, which impact its reactivity. The fineness of electro-filter ash exceeds that of Portland cement and lime. The ash used to produce concrete should be consistent, *i.e.*, change-resistant, so that the concrete mixture may be preliminary tested.

Experimental research

The goal of the experiments described in this paper was to determine how adding electro-filter ash to cement mortar may affect its volume mass, compressive strength, and water-absorption capacity, given that these are all important characteristics of these materials. The particular tests were carried out in the accredited Laboratory for Materials and Structures at the Belgrade Faculty of Civil Engineering according to the standard SRPS ISO/IEC 17025:2006, ATC decision on accreditation No. 217 from 29.02.2012. Through this study, landfill ash was used from TPP Kolubara Veliki Crnjani without any changes to its chemical composition properties in order to examine the practical viability of its direct application.

To conduct experiments, two different mortar mix combinations were formulated: A is the cement mix with pure Portland cement as a binder and B is the cement mix with electro-filter ash, as a partial cement replacement, and a super plasticiser.

Throughout the aforementioned experiments, the series of specimens were either manually inserted or installed by vibration on a vibrating table. Based on that, the labels that were selected are: 1 – manually inserted and 2 – installed by vibration.

The subject composites were made with pure Portland cement, enabling comparison with a series of composites created using electro-filter ash as a partial cement replacement.

Research conducted by other authors revealed that 20% of electro-filter ash was the optimal replacement for cement [31].

Components used in the experiment

The following types of materials were used in the experimental research:
- cement, CEM I (PC 42,5R), LAFARGE Beočin, γ_{sc} = 3100 kg/m^3,
- aggregate, river aggregate Moravac, fraction 0/4 mm γ_{sa} = 2600 kg/m^3,
- electro-filter ash, TPP Kolubara Veliki Crnjani, $\gamma_{s,el}$ = 2190 kg/m^3,
- chemical additive – plasticizer Sika Estriplast, Switzerland, γ_s = 1130 kg/m^3, and
- water from the city water supply.

For the purposes of scientific research, different test procedures can be applied, while respecting the provisions of the relevant domestic (SRPS), European (EN), German (DIN), American (ASTM), international (ISO), or some other standards, as well as various non-standard laboratory methods in the absence of adequate standardized procedures for testing individual properties of composite materials.

Installed molds are made for testing purposes, dimensions 40 cm × 40 cm × 4.5 cm. After installation, the molds are placed in a room where the temperature is 20 ±2 °C and the relative humidity is at least 30%, where they remain for 24 hours. After this time, the samples are removed from the molds and tested.

Defining mortar mix compositions

The process of designing a recipe for the mix, which includes calculating the proportion of ingredients [kgm^{-3}], consists of multiple iterative steps: designing the mix for the mixture, experimentally evaluating the properties of the mixture, making any necessary adjustments to the composition, and finally establishing the composition.

When preparing mortar mixtures for cement screeds, the water-cement ratio is determined empirically. Hence, the consistency should correspond to the description *wet as earth*. As a result, the lowest predicted water-cement factor of 0.38 was used as the starting point for the design phase of combining. Materials required for production of mortar mixtures with quantities are shown in tab. 3.

Table 3. Materials required to produce m^3 of mortar mixtures A and B, in the respective quantities

Material	Quantity for 1 m^3 of fresh mortar mixture A [kg]	Quantity for 1 m^3 of fresh mortar mixture B [kg]
Concrete	479.5	382.69
Electro-filter ash	–	95.67
Plasticiser Sika Estriplast	–	4.8
Aggregate	1438.5	1435.1
Water	182	181.8

Following the mixing of the components, the specimens are poured into molds designed for testing, with measures 40 cm × 40 cm × 4.5 cm. Compared to the specimens indicated with 1, which were filled with mass, levelled and pargeted, the specimens marked with 2 were filled with mass, vibrated on a vibrating table, and smoothed with a trowel.

Evaluation of properties of a mortar mixture in the hardened state

Although the properties of hardened cement mortars depend on a variety of influencing parameters, they are a function of the realized structure of the composite. The quantity, proportion, and quality of component materials, care, especially in the initial stage of the composite, environmental conditions, method of processing, *etc.*, all have a significant effect on the properties of hardened mortar. The compressive strength of cement screed mortar mixtures was evaluated using extracted cylinders-cores diameter of ⌀50mm, in accordance with the current technical regulations, in particular the provisions of relevant SRPS standards and internal methods of the Institute for Materials and Structures of the Faculty of Civil Engineering in Belgrade. Specimens of varied compositions were installed by various methods in boxes-molds. From each of the boxes 9 cylinder-cores with nominal diameters of 50 mm were extracted on the second, seventh, and twenty-eighth days, and afterwards tested, see fig. 1.

Figure 1. Pouring the mortar mixture (a), extracting cylinders from molds (b), and (c) appearance of the specimens

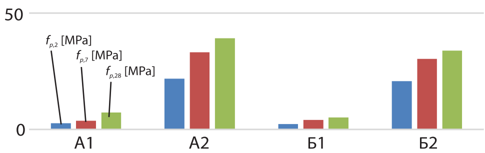

Figure 2. Compressive strength of the samples aged 2, 7 or 28 days

The most informative compressive strength test is done after the specimen has aged for 28 days. However, earlier tests at 2, 7, or 14 days of age, as well as potential strength tests at ages older than 28 days may also be undertaken to achieve the functional dependence $f_p = f_p(t)$. Table 4 and fig. 2 show the results of measuring the compressive strength of the specimens.

Table 4. Compressive strength of specimens aged for 2, 7 or 28 days

Specimen	$f_{p,2}$ [MPa]	$f_{p,7}$ [MPa]	$f_{p,28}$ [MPa]
A1	2.58	3.90	7.33
A2	21.73	33.27	39.30
B1	2.25	4.25	5.23
B2	20.65	30.31	33.71

where $f_{p,2}$ is the average value of compressive strength of samples at age of 2 days,
$f_{p,7}$ – the average value of compressive strength of samples at age of 7 days, and
$f_{p,28}$ – the average value *f* compressive strength of samples at age of 28 days.

The density of the mortar in the hardened state, obtained using the average value of 3 test results, is given in the following table, tab. 5 and fig. 3. for the age of the samples of 2, 7 and 28 days.

The compressive strength test is mandatory at the age of 28 days, but it is possible to perform this test at younger (2.7 days) or older ages, which makes it possible to determine the

Table 5. Density of the specimens and structural advantages coefficients *K*, at the age of 2, 7, and 28 days

Sample	Density, γ_2 [kgm^{-3}]	K_2 [MPam^3 per ton]	Density, γ_7 [kgm^{-3}]	K_7 [MPam^3 per ton]	Density, γ_{28} [kgm^{-3}]	K_{28} [MPam^3 per ton]
A1	1474.89	1.75	1536.15	2.54	1455.76	5.03
A2	2091.11	10.39	2080.55	15.99	2075.63	18.93
B1	1396.88	1.61	1383.77	3.07	1365.90	3.82
B2	2033.15	10.16	2014.31	15.04	2011.89	16.76

where γ_2 is the average value of the density of 2 days old specimens, γ_7 – the average value of the density of 7 days old specimens, and γ_{28} – the average value of the density of 28 days old specimens.

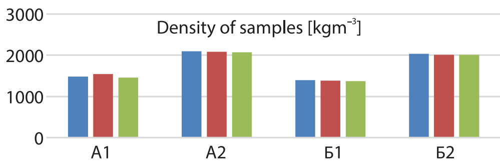

Figure 3. Density of the samples aged 2, 7 or 28 days

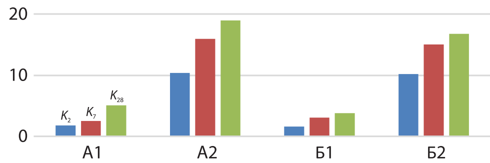

Figure 4. Structural advantages coefficient *K* [MPa m³ per ton] of the samples aged 2, 7 or 28 days

functional dependence $f_p = f_p(t)$, change in strength as a function time, in analytical or graphic form, which can be significant for the application of the plaster in question.

From each mold-box, in which samples of cement liners of different composition and different methods of installation were made, 9 cylinder-cores, nominal diameter ⌀50 mm, were taken out on the second, seventh and twenty-eighth day, which were tested, fig. 4, in accordance with the procedure described in standard SRPS U.M1.049:2000.

On the basis of the measured compressive strength and well-known density of samples, the values of structural advantages coefficients *K* were obtained by calculation, which represents the ratio of material compressive strength f_p [MPa] according to its density γ [t/m^3], tab. 5 and fig. 4:

$$K = \frac{f_p}{\gamma} \ [\text{MPam}^3 \ \text{per ton}]$$

Water absorption, which has a negative effect through a many important physical-mechanical characteristics of cement composites (reduction in strength, wear resistance and frost resistance), was tested by the capillary water absorption method during 73 hours, by measuring changes in the mass of samples for characteristic measurement times. Standard that was used was Capillary absorption of water, in accordance with the procedure described in the standard SRPS U.M8.300.

In the case of 1-D water absorption into the mass of an initially dry specimen, the amount of absorbed water may be related to time using the empirical equation [32]:

$$w_{av} = A/\sqrt{t}$$

where A [kgm^3] is the average value of capillary water absorption, t [second] – the time, w_{av} [kgm^{-2} per second] – the coefficient of absorbed liquid.

The obtained results are presented in tab. 6 and fig. 5.

Table 6. Capillary water absorption w_{av} [kgm^{-2}], for characteristic measuring times

Specimen	Capillary water absorption w_{av} [kgm^{-2}]										
	t = 0 h	t = 0.017 h	t = 0.083 h	t = 0.25 h	t = 0.5 h	t = 1 h	t = 4 h	t = 9 h	t = 25 h	t = 49 h	t = 73 h
A1	0.000	5.364	5.651	5.757	5.772	6.013	6.119	6.255	6.285	6.467	6.512
A2	0.000	0.468	1.012	1.843	2.266	2.493	3.128	3.823	4.578	4.608	4.654
B1	0.000	8.038	8.552	8.733	8.778	8.869	8.960	9.050	9.201	9.322	9.353
B2	0.000	0.181	0.468	0.604	0.861	1.118	1.904	2.674	3.943	4.729	4.820

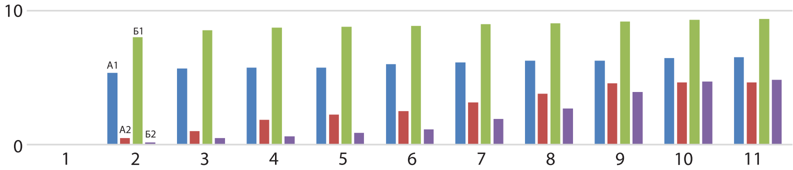

Figure 5. Capillary water absorption w_{av} [kgm^{-2}]

Results and discussion

Based on the experimental research following findings, that are clear justification of the substitution of cement in mortar with electro-filter ash, have been made:

- A better workability of the surface of the fresh mortar mixture, which is dependent on the granulometric composition, the shape and surface of the aggregate grain, and the quantity of cohesive mortar paste, exhibit series B mixtures with electro-filter ash, due to the presence of fine particles and plasticisers.
- The density of manually placed specimens (marked-1) range between about 1400 kg/m^3 to 1700 kg/m^3, while the density of specimens placed by vibration (marked-2) are around 2000 kg/m^3. The electro-filter ash added to the Series B mixes reduces their density by 11.3 %.
- Compressive strength functionally correlates with density and is higher in specimens with larger density (vibrated specimens), as found in the studies by other authors [33].
- The compressive strength of the series containing electro-filter ash as a partial replacement for cement (Series B) is about 15% lower than the series using solely cement as a binder (Series A), as this is demonstrated by studies of other authors [34].
- The structural advantages coefficients in Series B mixes incorporating electro-filter ash is about 20% lower (and thus more favourable) than in series A mixes, which may be taken for serious consideration given that lower density of ash compared to cement (900 kg/m^3 *vs.* 3100 kg/m^3) [35].
- The specimens in series B (B1), which were manually placed, seem to have the highest coefficient of absorbed liquid; it is about 45% higher than the specimens of series A1. The difference in the coefficient of absorbed liquid between the manually inserted specimens and the specimens placed by vibration is greater for the series B specimens (specimens with electro-filter ash) and may reach up to 60%, while this difference is about 30% for the Series A specimens.

Beside all of these, some obvious comments concerning environmental impact are:

- Analyzing current situation and potential of the use of electro-filter ash in the field of waste management clearly minimize the impact on the environment and increase resource efficiency.
- Use of this waste material will influence on better control of waste generation, waste recovery and incentives to promote economic opportunities from waste.

– Reducing environmental pressure and ensuring better quality of life.
– Creating clear and cleaner environment supporting sustainable development perspective.
– Increasing eco-efficiency in industry.
– Main effects of the implemented would be less pollution of groundwater and surface water due to possible leaking of unprotected waste disposal fields.

Conclusions

Based on the conducted experimental studies, it can be concluded that fly ash, which is an industrial waste material, can be successfully used as a replacement for part of the cement in mortars for cement screeds, which is one of the ways to influence the preservation of natural non-renewable resources, reducing energy consumption, reduction of emissions of harmful gases, protection of the environment from the creation of landfills, pollution of surface and underground-water, air, soil and plant cover.In addition examining the influence of cement substitution with fly ash on the physical-mechanical properties of cement screeds, the paper discussed different methods of installation (manual and vibrating) in order to prove that these properties of cement composites are primarily dependent on the achieved structure.

Series of composites with fly ash incorporated by vibrating achieve compressive strengths lower by 16.58% compared to series made of pure Portland cement, which is completely satisfactory considering that strengths after 28 days greater than 30 MPa were achieved.

Likewise, it can be observed that the samples of mortar mixtures containing 20% fly ash, as a substitute for cement, have a lower volumetric mass by 5-10% compared to the standard, which is expected considering that the specific mass of fly ash ash (2190 kg/m^3) is significantly lower than the specific mass of cement (3100 kg/m^3).

Due to the ash's contribution increased plasticity and better cohesiveness, batches containing fly ash have lower stiffness. In addition, the plasticizer, which must be added to mixtures with mineral additives, due to the creation of a thin film around the grains of cement and fly ash, acts as a *lubricant* and significantly reduces friction in the mass. The presence of fly ash affects the decrease in the volumetric mass value in the mixtures of Series B, which have fly ash in their composition (Series B1 records a decrease of 3.17% compared to A1, Series B2 has a decrease of 6.57% compared to A2), which is convenience when making cement screeds.

The coefficient of construction convenience *K*kp is more favorable for series with fly ash, which is an advantage of using cement liners made of these materials.

The results of capillary absorbed water depending on time, expressed through the coefficient of absorbed liquid, of samples made of pure potland cement compared to the results of samples with the participation of ash as a substitute for cement, show almost the same values when installing by vibrating. As a final conclusion, it can be stated that with the use of fly ash, in addition lower compressive strengths, which are priority properties in the construction industry, mortars with satisfactory performance are obtained for the production of screeds and other building elements. Likewise, the advantages brought by the use of ash, such as construction convenience and better workability, make this mineral additive successful for in construction industry.

Nomenclature

A – capillary water absorption [kgm^{-3}]
f_p – compressive strength, [MPa]
K – structural advantages coefficients, [MPam^3 per ton]
w_{av} – coefficient of absorbed liquid, [kgm^{-2} per second]

Greek symbols

γ_s – specific mass, [kgm^{-3}]
γ – density, [kgm^{-3}]

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Paper submitted: February 25, 2023
Paper revised: April 26, 2023
Paper accepted: April 28, 2023