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Review Paper

Harvest residues ash as a pozzolanic additive for engineering applications: a review and the catalogue

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ABSTRACT

Biomass ashes originating from wood and harvest residues combustion may be considered as one of the prospective environmentally friendly candidates for supplementary cementitious materials (SCM) production. In the region of Vojvodina province, biomass waste is becoming increasingly important as “green” fuel, thus allowing the reduction of the environmental impact of waste disposal, lowering the expensive fossil fuels application and its subsequent greenhouse gasses emission. In the light of the above, the present paper surveys the experimental studies of harvest residues ash (HRA) as a pozzolanic additive for engineering applications. Thus far conducted research on the HRA possible application in cementitious systems, worldwide and in the studied region, has been summarized and the benefits of such approaches outlined. Finally, locally available types of wheat straw, soya straw, sunflower husk, silo waste, oil rapeseed - based ashes were collected, characterized both physically and chemically, evaluated and presented through catalogue. The reactivity results, depending on the amorphous silica content and the achieved level of fineness, are very promising in terms of the potential reuse of these ashes in cementing systems.

1 Introduction: biomass as res

Using biomass to provide energy services is one of the most versatile options for increasing the share of renewable energy in the global energy system. Biomass for energy production may be obtained from a diverse range of sources, the most important of which are energy crops, agricultural and forestry residues, wastes, and existing forestry. There is a wide dispute about the most important factors affecting the contribution biomass might make to primary energy supply. These include the availability of arable land (agricultural land may be expanded at the expense of forested areas; or lost due to soil degradation or urbanization etc.), the productivity of the biomass grown on the land (climate change) and competition for alternate uses of the land (waste landfilling).

On the other hand, some scenarios assume that increases in food demand will primarily be met through increases in crop yields, which should be particularly required in developing countries. Forecasting models indicate that developing countries will account for most of the rapid urban population increase by 2050, hence the percentage of global energy used in cities is expected to increase considerably. Although cities continue to use fossil

fuels as the main source of energy, biomass acts for a growing renewable energy source (RES) with high growth potential, due to its wide availability as a by-product of many industrial and agricultural processes.

As previously mentioned, the global economy is primarily based on fossil fuels to produce electricity, heat, fuels and energy, whereas they account for 81% of the total primary energy supply; nuclear energy produce 5% and RES 14% (of which the contribution of biomass is about 70%) [1]. The use of RES in the EU has grown from 13.2% in 2010 to 18.0% in 2018 [2]. Biomass is today used primarily for: 1) feed, 2) food and 3) energy, fuels and chemical feedstock production and, based on its availability and ever increasing demands, could act as an alternative to fossil resources by its conversion into food, feed, and bioenergy. Despite the large consumption of biomass as an energy source, enormous quantities remain in landfills as unused waste/raw materials.

Biomass-based materials are characterized by lower emissions of greenhouse gases than those from non-renewable sources, such as oil and coal. Combustion of biomass results in pollutant emissions, but not as much as in case of fossil fuels. Therefore, an increase in biomass

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renewable energy consumption reduces CO₂ emissions and cuts the demand for fossil fuels and their associated greenhouse gases (GHG) emission.

The potential of Serbia in RES is estimated at 6 million tons per year, whereas biomass accounts for 64%, i.e. 3.3 million tons annually. In the structure of planned primary energy production in Serbia for 2014, RES participated with 1,819 million tons per year, which accounted for about 17% of domestic primary energy production. In this, the highest share had solid biomass - 58%. Greatest potential of biomass in Serbia lies in the agricultural residue and wood biomass, a total of about 2.7 million tons (1.7 million tons in the remains of agricultural production and about 1 million tons in wood biomass) [3]. The utilization possibility of biomass as a fuel can be evaluated through its low thermal power - Table 1. Apart from these two sources of biomass, further major source is the residue of livestock production. Another group of biomass sources includes energy plants (e.g. miscanthus, fast-growing poplar and the like), and

plants that serve as raw material for biodiesel and bioethanol (rapeseed, sunflower, corn, etc.).

It is estimated that the total potential of biomass from agriculture in Serbia is about 12.5 million tons per year. In 2019, the share of crop production in the total value of agricultural production equaled 66.0%, and that of livestock production equaled 34.0% [6]. When compared to 2018 the net index of physical volume of agricultural production decreased by 1.2%. There are many small individual landowners in Serbia, who deal with production of cereals or industrial plants, like sunflower or soya. A lot of crop farming production, almost 75% is achieved in small or medium size private ownership, while only about 25% of crop farming production belongs to agricultural companies of relatively larger size [7]. It is estimated that about half of harvest residues at large agricultural farms can be used for energy purposes, while only about 20% harvest residues, generated on relatively small private farms, can be used for energy purposes. Total quantities of harvested crops in Serbia for the period 2015-2019 are listed in Table 2.

Table 1 - The energy potential of biomass production [4], [5]

Agricultural biomass	Low thermal power (MJ/kg)	Woody biomass		Low thermal power (MJ/kg)	Other fuels	Low thermal power (MJ/kg)
Wheat straw	14,4	Beech	bark	18,0	Brown coal	22,5
Barley straw	14,2		wood	18,8	Charcoal	28,8
Oat straw	14,5	Oak	bark	19,7	Light fuel oil	42,1
Rye straw	14		wood	18,4	Light fuel oil	41,8
Corn	13,5	Spruce	bark	21,2	Petrol	42,0
Sunflower stem	14,5		wood	19,7		
Sunflower shell	17,55	Fir	bark	21,0		
Soya straw	15,7		wood	19,5		
Rapeseed straw	17,4	Pine	bark	20,6		
Stalks of tobacco	13,85		wood	21,2		

Table 2 - Harvested crops in Serbia for the period 2015-2019 [6]

Crop	Harvested quantity (in tons) per year				
	2015.	2016.	2017.	2018.	2019.
Wheat	2 428 203	2 884 538	2 275 623	2 941 601	2 534 643
Maize	5 454 841	7 376 737	4 018 370	6 964 770	7 344 542
Soya	454 431	576 446	461 272	645 607	700 502
Sunflower	437 084	621 127	540 590	733 706	729 079
Rapeseed	33 402	39 404	48 740	135 422	84 311
Tobacco	8 776	7 811	7 173	7 169	7 992
Sugar beet	2 183 194	2 683 859	2 513 495	2 325 303	2 305 316
Total	10 999 931	14 189 922	9 865 263	13 753 578	13 706 385

Table 3 - Main indicators of forestry in Serbia, 2015-2019 [6]

	Total forest exploitation Felled wood stock, gross volume, thousand m ³	Regular artificial forestation, ha		
		Total	Conifers	Broadleaved
2015	2928	1736	668	1068
2016	3134	1280	585	695
2017	3192	1984	654	1330
2018	3220	1547	694	853
2019	3313	3077	604	2473

The total area of forests in the Republic of Serbia extends over 2 237 511 ha. The state sector holds 963 458 ha, which is about 43% of the total forested area, and the remaining 57% is in private ownership. When compared to 2018, in 2019 artificial afforestation increased for 1 530 ha, which presents a growth of about 199%. The total area that was afforested in 2019 extended over 3 077 ha - Table 3 [6]. Woody biomass, especially wood pellets, is increasingly used for heating and power production and in light of relatively low external costs to reduce GHG emissions.

The main processes generating the energy obtained from biomass, both agricultural and woody, include direct combustion, pyrolysis, gasification, hydro gasification, liquefaction, alcoholic fermentation etc. Large amounts of biomass ashes are produced as waste products within these processes. They are most commonly disposed of in landfills or recycled on agricultural fields. Considering that the disposal costs of waste materials are ever-increasing, a sustainable ash management has to be established.

Globally, the imposing number of studies has successfully proved the viability of employing biomass ashes, such as: rice husk ash, wood ash, corn cob ash, as pozzolanic admixtures in cement composites, and have consequently encouraged the utilisation of blended cements with biomass waste, moving towards the utilization of more sustainable construction materials. Most of the studies on different types of harvest residues ashes (HRA) or wood ashes (WA) are carried by supplementing and adding as an additive in the place of binding material and/or fine aggregate and observed different changes in the properties because of influence of the pozzolana action.

The use of biomass ashes as building materials in engineering practice in Serbia has been scarcely investigated so far. Previous studies, conducted mostly on cement mortars blended with HRA [8,9,10,11], have documented that mortars, blended with wheat straw ash and soya straw ash, show a promising performance in strength, depending on the level of fineness and chemical composition of these ashes. However, very few studies have dealt with the reactivity and pozzolanic properties of other available biomass ashes in Serbia.

Therefore, the present study is to give a brief review on the usage of different HRA, both globally and in Serbia, based on the type of the ash. In addition, locally available waste materials, originating from agriculture in Serbia, are explored and systematically presented through catalogue for possible SCM application for the first time.

2 Literature review on the application of different biomass ashes

The properties of biomass ashes, generated by biomass combustion, vary widely and heavily depend on: 1) biomass type; 2) combustion technology and temperature; 3) the location where the ashes are collected (fly ash, bottom furnace ash); 4) further treatment of the ashes (grinding processing). These contributing factors influence two major elements of potential biomass ashes application as SCMs: amorphous silica content and the level of fineness.

Below is a brief overview of the different types of biomass ashes used in the experimental research worldwide and the results obtained therein.

2.1 Rice husk ash

Rice husk ash (RHA) is a combustion by-product of grain husks of rice, as waste agricultural material. India is the world's second rice producer, immediately after China, with 104 million tons of rice produced annually. Annually, nearly 3.7 million tons of rice husks are produced. The rice husk contains about 50% cellulose, 25-30% lignin and 15-20% silicate gel. Several studies have been carried out to evaluate the feasibility of RHA. These studies have shown that

- RHA can be used as low cost building material, improving the durability of the cementitious system and producing high strength concrete [12];
- After combustion (the optimum combustion temperature for obtaining highly reactive RHA is 600°C), the ash is primarily composed of reactive silica and is characterized with high level of fineness [13];
- By using RHA, as replacement of part of the cement, consistency of fresh concrete is reduced due to the large specific surface area of the ash, hence a higher amount of water is required for concrete to maintain the same consistency. As a result of the reduced amount of cement and pozzolanic activity, the setting time is prolonged;
- Due to the filler effect (fine particles of RHA), a very dense structure is formed, with reduced permeability, decreased drying shrinkage and improved mechanical properties. Studies in which up to 20% of cement was replaced with RHA showed up to 89% lower permeability to penetration of chlorides. Also, RHA application, as a substitute for a part of cement in concrete, the frost resistance and the alkali-silicate reaction is shown to be

significantly increased [14]. Therefore, the usage of this type of ash contributes to the improved physical, mechanical and durability properties of cement composites.

2.2 Sugarcane bagasse ash

Sugarcane bagasse ash (SCBA) is an industrial by product produced in the sugar mills after the extraction of sugar from the sugarcane, whereas fibrous material (bagasse) is obtained. India, along with Brazil, is the largest sugarcane producer in the world. Approximately 380 million tons of sugar cane is produced annually in India, disposing a large amount of waste or ash, thereby. Optimum combustion temperature for obtaining highly reactive ash is estimated at 600-800°C [15]. Conducted studies revealed a favourable chemical composition of the ash in terms of its pozzolanic activity, primarily due to the high content of amorphous silica ($\approx 78\%$) [16]. The authors summarized following observations regarding the properties and use of SCBA as SCM:

- The bulk density of SCBA is lesser than OPC; the volume occupied for a supposed mass will be higher, hence ash particles fill the small pores of concrete making it less permeable [17];
- Due to high level of fineness the concrete containing SCBA require higher amount of super-plasticizing as compared to the control mix to achieve the same workability [18];
- OPC replacement of 10% by weight of SCBA allows obtaining concrete with excellent mechanical performance and durability properties [19];
- The use of SCBA is efficient in the production of self-compacting concrete [20].

2.3 Palm oil fuel ash

Palm oil fuel ash (POFA) is a waste material resulting from the combustion of palm fibres and leaves for the generation of electricity. Currently, in Malaysia, oil palm plantations spread over three million hectares of land, whereby more than 15 million tons of palm oil is produced annually, generating 2.6 million tons of ash, thereby. Uncontrolled disposal of this type of ash occupies valuable land, but also leads to pollution of the environment and disruption of human health. The summarized knowledge on the applications of the ash in engineering practise includes:

- The appropriate fineness could be achieved by using a grinding mill;
- Due to a relatively high content of silica (55-65%), it can be extremely reactive, depending on the adjusted level of fineness [21];
- Along with ordinary pozzolanic materials, POFA reduces the consistency, lowers the heat of the hydration and prolongs the setting time of the concrete;
- Most of the researchers obtained the compressive strength of concrete containing 10–30% POFA higher than that of control concrete [22]. The early age increase is attributed to the filler effect of the fine ash particles, while at the later stages; the subsequent formation of C-S-H products improves the interfacial bonding between the pastes and the aggregates and thus increases the strength.

2.4 Corn cob ash

Over 500 million tons of corn is produced annually in the world. The United States is the largest producer of corn with 43%, followed by Africa with 7%. There is a significant opportunity to burn the waste parts of corn plant (cobs and stover) after harvest, and use the ash as a potential cement replacement. A review of the literature shows mixed results regarding the inclusion of corn cob ash (CCA) in concrete:

- CCA contains more than 65% reactive silica [23];
- Many researchers reported a significant reduction in the compressive strength as a result of replacing OPC with CCA [24, 25];
- Concrete incorporating CCA exhibits lower water absorption and shows better resistance to sulphate attack compared to the reference concrete [26];
- Authors outline mixed results regarding the influence of CCA on the fresh properties of concrete, as well. Some reported the reduced concrete slump with the addition of CCA, while others found that CCA increases the concrete slump.

The mixed results can be connected with a variety of factors, such as: the use of different watering regimens (irrigated vs. non-irrigated corn), type of fertilizer, and the species of corn, in addition to aforementioned indicators.

2.5 Wheat straw ash

Wheat is one of the primary sources of food. The current utilization of wheat straw is associated with energy source, pulp and paper, nano-materials, bioethanol, fertilizer, additive for mud houses. Considerable amounts of wheat straw ash (WSA), which has been investigated to a small extent as a potential pozzolanic material, are generated in the process of straw combustion. According to the literature results on the reactivity and possible WSA application in cementitious systems, following observations were noted:

- The chemical composition of WSA (obtained in Serbia) is characterized by high alkali content (20%) and significant amorphous silica content (52%) [27];
- Mechanical processing, such as grinding in lab ball mill, could significantly reduce the particle size, increase the level of fineness and amplify the amorphousness of WSA [28];
- WSA fulfils criteria for pozzolanic materials, including: activity index, setting time and soundness of powder fly ash materials, given in EN 450-1 [29];
- Optimum cement replacement level, determined by [29], was estimated at 15%, whereas the mortar containing 15% WSA has shown comparable strength to that of control mortar at 7 days, and even higher strength at ages of 28 and 91 days, respectively. Similar trend was registered by Dehane et al. [30]. At the age of 28 days, the strength of the mortar with 12,5% WSA exceeded the strength of the reference mortar, and this difference, due to the pozzolanic reaction, increased over time. This mortar was characterized by a smaller water absorption compared to the absorption of the OPC mortar at the age of 28 days (due to the filler effect of small WSA particles);
- Optimum cement replacement level with WSA in cement mortars is determined to be 30%, without any adverse effect on its mechanical properties [9].

2.6 Other biomass ashes

Few researchers have provided the information on far less utilized biomass ashes, such as: oyster shells ash [31], groundnut shells ash [32], bamboo leaf ash [33], sunflower stalk ash [34], sunflower husk ash [35], miscanthus ash [36], barley ash [37], olive husk ash [35], coconut shell ash [38], rape straw ash [39] and eucalyptus biomass ash [40].

The major factor for the valorization of biomass ashes lies in the fact that they contain high amounts of reactive silica, which makes them suitable as cement substitutes. Silica content of different types of biomass ashes, used as cement substitutes worldwide, as well as recommended replacement level, by authors, is given in Table 4.

3 Harvest residues ash - potential in APV, Serbia

The first step in preparing catalogue of available biomass ashes is to summarize collected information. In the region, which is involved in the research (Bačka, Srem and Mačva), within the realization of the project IPA Interreg ECO Build, cooperation was established with eleven companies that use harvest residues as an energy source for obtaining heat energy. A brief overview of the available types and quantities of generated biomass ashes in AP Vojvodina is presented in Table 5. Samples of biomass ashes were taken and basic data on generated ashes were collected, including:

- types of used biomass,
- combustion technology,
- achieved combustion temperatures in boiler furnace,
- generated quantities of biomass ash per year,
- disposal of biomass ash, as generated by-product.

Based on the gathered information, most of the harvest residues ashes produced are either disposed of in landfill or recycled on agricultural fields or forest, while the companies which combust biomass pay considerable price for the transportation and landfilling of these ashes.

Table 4 - Silica content and recommended cement replacement level of various biomass ashes

	Silica content (%)	Reference	Recommended cement replacement level
Rice husk ash (RHA)	80-95	Siddika et al. [41]	30%
Corn cob ash (CCA)	60-70	Adesanya et al. [42]	10%
Wheat straw ash (WSA)	50-70	Šupić et al. [9]	30%
Palm oil fuel ash (POFA)	55-80	Thomas et al. [22]	20%
Sugar cane straw ash (SCSA)	35	Khalil. et al. [19]	20%
Sunflower stalk ash (SSA)	25	Aksog˘an O. et al. [43]	10%
Bamboo leaf ash (BLA)	75-85	Cociñaa E.V. et al. [44]	20%
Groundnut shell ash (GSA)	40-50	Alaneme K.K. et al. [45]	8%
Oyster shell ash (OSA)	5	Gengying Li et al. [46]	more research necessary
Miscanthus ash (MA)	50-60	Wigley F. et al. [47]	more research necessary
Barley husk ash (BHA)	70-80	Khalil et al. [48]	20%
Sunflower husk ash (SHA)	30-60	Demirbas A. et al. [49]	15%
Olive stone (pit) ash (OSA)	5	Font et al. [50]	more research necessary
Coconut shell ash (CSA)	65	Opeyemi J. et al. [51]	more research necessary
Rape straw ash (RSA)	35	Masiá T.A.A. et al. [52]	more research necessary
Eucalyptus biomass ash (EBA)	1-5	Teixeira A.H.C. [53]	more research necessary

Table 5 - Available quantities of biomass ashes in AP Vojvodina

Company	Biomass type	Temperature of combustion	Types of biomass ashes	Produced quantities of ash per year (tons)
Mitrosrem Sremska Mitrovica	wheat straw soya straw	600-650°C	1. ash from boiler furnace 2. ash from multiciklon 3. fly biomass ash	15
Soya Protein Bečej	wheat straw soya straw silo waste melasa	700-900°C	1. ash from boiler furnace 2. ash from multiciklon 3. fly biomass ash	1100
The Veterinary Institute Subotica	agro pellets of wheat straw and soya straw	450-550°C	1. ash from boiler furnace 2. ash from multiciklon 3. fly biomass ash	240
Hipol Odžaci	agro pellets of soya straw	800-1000°C	1. ash from boiler furnace 2. ash from multiciklon 3. fly biomass ash	700
Victoria Starch Zrenjanin	agro pellets of wheat straw and soya straw	unknown	1. ash from boiler furnace	9
Almex-IPOK Zrenjanin	agro pellets of wheat straw and soya straw sunflower husk	700-900°C	1. ash from boiler furnace 2. ash from multiciklon 3. fly biomass ash	1100
KNOT- AUTOFLEX Bečej	wheat straw soya straw	unknown	1. ash from boiler furnace	60
Fishery Lovćenac	soya straw	unknown	1. ash from boiler furnace 2. ash from multiciklon	9
Victoria Oil Šid	sunflower husk	700-1000°C	1. ash from boiler furnace 2. ash from multiciklon	720
Sava Kovačević Vrbas	cob corn	500°C	1. ash from boiler furnace	30
PTK Panonija Mecker farm	wheat straw soya straw	500°C	1. ash from boiler furnace	60
Total				≈ 5.000 tons

4 Properties and catalogue of harvest residues ashes in APV Vojvodina

4.1 Materials and Methods

4.1.1 Materials

Cement

Ordinary Portland cement (OPC), originating from Lafarge cement factory in Beočin, Serbia, was used. The cement has a specific gravity of 3.1 g/cm³ and the Blaine fineness of 4.000 cm²/g.

Biomass ashes

For experimental investigation of chemical and physical properties and pozzolanic activity of biomass ashes, the following materials were collected and tested:

- Wheat straw ash (WSA), "Mitrosrem" Sremska Mitrovica,
- Mixed wheat and soya straw ash (WSSA-1), "Soya-protein" Bečej,
- Mixed wheat and soya straw ash (WSSA-2), "IPOK" Zrenjanin,
- Soya straw ash (SSA), "HIPOL" Odžaci,
- Silo waste ash (SWA), "Soya-protein" Bečej,
- Oil rapeseed ash (ORA), "Knot-Autoflex" Bečej,
- Mixed wheat straw and sunflower husk ash (WSSHA), "Soya-protein" Bečej,
- Sunflower husk ash (SHA), "Victoria Oil" Šid.

The ashes were roughly sieved (apart from SHA), through a 4mm sieve, in order to separate un-burnt straw and other large impurities. In order to obtain a material with satisfactory specific surface area, ashes were further ground in a laboratory ball mill for 6h.

4.1.2 Methods

The chemical composition of collected ashes was determined using energy dispersive X-ray fluorescence spectrometer (EDXRF 2000 Oxford instruments) according

to EN 196-2, 2015 and ISO 29581-2, 2010. The representative samples (100 g) were pulverized in a laboratory vibratory mill prior to the testing. The loss on ignition (LOI) was determined as a weight difference between 20 °C and 950 °C.

Specific surface area of biomass ashes was determined according to Blaine air permeability method given in EN 196-6, 2011, which is widely used for the fineness determination of hydraulic cement. The test is based on the principle of resistance to air flow through a partially compacted sample of powder material.

Soundness of biomass ashes was determined in accordance with EN 196-3, 2010. The method is used for assessing whether this physical property of a SCM material is in conformity with the requirements given in EN 450-1.

The pozzolanic activity was studied on samples prepared according to the procedure given in SRPS B.C1.018, 2015. Mortars were prepared with biomass ash, slaked lime and standard sand, with the following mass proportions: $m_{sl}:m_{bash}:m_{qs}=1:2:9$ and water – binder ratio 0.6 (where: m_{sl} – mass of slaked lime; m_{bash} – mass of biomass ash; m_{qs} – mass of CEN standard sand). After compacting, the samples were hermetically sealed and cured for 24 h at 20 °C, then for 5 days at 55 °C. Subsequently, 24h period was allowed for samples cooling process to reach 20 °C, followed by compressive and flexural strength tests.

The activity index of biomass ashes was examined according to EN 450-1, 2014. Activity index is defined as a ratio (in percent) of the compressive strength of mortar prepared with 75% test cement plus 25% ash by mass, and the compressive strength of standard cement mortar, when tested at the same age. The preparation of mortar test specimens and determination of the compressive strength were carried out in accordance with EN 196-1, 2018.

4.2 Chemical composition

The chemical compositions of OPC and selected biomass ashes are given in Table 6. Obtained chemical composition of pure WSA indicates the relatively high participation of major oxides $SiO_2+Al_2O_3+Fe_2O_3$ ($\approx 70\%$), as well as reactive silica (67%).

Table 6. Chemical composition of OPC and biomass ashes

Material (%)	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	SO ₃	P ₂ O ₅	LOI	SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃	Reactive SiO ₂
Cement	21.25	5.55	25.3	61.6	2.37	0.25	0.72	3,75	-	1.77	52,1	-
WSA	69.13	1.12	0.73	5.78	2.50	0.11	13.03	0.20	1.72	5.18	70,98	67
WSSA-1	56.36	2.03	1.53	7.13	3.54	0.20	20.02	0.18	3.72	4.85	59,92	41
WSSA-2	54.01	3.51	2.06	8.09	3.22	0.27	19.16	0.38	1.26	7.72	59,58	44
SSA	32.62	4.58	1.46	15.78	8.33	0.85	20.96	0.47	3.72	10.73	38,66	25
SWA	43.66	5.41	2.06	15.89	5.05	0.97	14.09	0.76	4.82	6.41	51,13	25
ORA	32.37	6.32	2.45	14.00	2.91	0.89	17.85	3.78	1.44	17.61	41,14	15
WSSHA	44.12	1.99	1.93	10.94	4.91	0.26	16.24	0.45	5.43	13.05	48,04	35
SHA	5.34	1.19	1.03	12.96	9.94	0.68	44.76	9.71	-	12.64	7,56	5

5 Catalogue of harvest residues ashes in APV Vojvodina

After biomass ashes preparation (sieving, grinding), along with determination of chemical composition test, the following testing were conducted for the purpose of catalogue creation:

- Specific gravity,
- Blaine fineness,
- Soundness,
- The pozzolanic activity,
- The activity index.

The obtained results of listed HRA properties are presented through the catalogue, given below.

Based on the results of an own experimental research [7-11,54-55], as well as the conclusions the other authors derived [43,49,52,56], a possible cement replacement level with tested types of HRA was estimated for their application in mortar and concrete. These values are also showed in the catalogue.

Considering the high amount of water-soluble potassium oxide in sunflower husk ash, this type of ash can be potentially utilized as the alkali solution for the activation of silica and alumina rich precursor and the production of alkali activated materials. However, more research regarding this assumption is inescapable.

5.1 Wheat straw ash: basic properties and possible application

Wheat straw ash, before sieving and grinding

Wheat straw ash, after sieving and grinding

Ash origin	Mitrosrem, Veliki Radinci
Basic data on the ash	Bottom ash, roughly sieved through a 4mm sieve
Available amount per year	15 tons
Reactive silica content	67%
Specific gravity	2380 kg/m ³
Blaine fineness	950 m ² /kg
Soundness	satisfactory
The pozzolanic activity	Class 10
The activity index	I ₂₈ =104% I ₉₀ =108%
Recommended cement replacement level in mortar	up to 50% (from the aspect of achieved mechanical properties of concrete)
Recommended cement replacement level in concrete	up to 50% (from the aspect of achieved mechanical properties of mortar)

5.2 Mixed wheat and soya straw ash: basic properties and possible application

Mixed wheat and soya straw ash, before sieving and grinding

Mixed wheat and soya straw ash, after sieving and grinding

Ash origin	Soja Protein, Bečej
Basic data on the ash	Bottom ash, roughly sieved through a 4mm sieve
Available amount per year	300-1100 tons
Reactive silica content	41%
Specific gravity	2370 kg/m ³
Blaine fineness	1550 m ² /kg
Soundness	satisfactory
The pozzolanic activity	Class 5
The activity index	I ₂₈ =92% I ₉₀ =92%
Recommended cement replacement level in mortar	up to 30% (from the aspect of achieved mechanical properties of concrete)
Recommended cement replacement level in concrete	up to 30% (from the aspect of achieved mechanical properties of mortar)

5.3 Mixed wheat and soya straw ash: basic properties and possible application

Mixed wheat and soya straw ash, before sieving and grinding

Mixed wheat and soya straw ash, after sieving and grinding

<i>Ash origin</i>	IPOK, Zrenjanin
<i>Basic data on the ash</i>	Bottom ash, roughly sieved through a 4mm sieve
<i>Available amount per year</i>	1100 tons
<i>Reactive silica content</i>	44%
<i>Specific gravity</i>	2380 kg/m ³
<i>Blaine fineness</i>	610 m ² /kg
<i>Soundness</i>	satisfactory
<i>The pozzolanic activity</i>	Class 10
<i>The activity index</i>	I ₂₈ =95% I ₉₀ =102%
<i>Recommended cement replacement level in mortar</i>	up to 50% (from the aspect of achieved mechanical properties of concrete)
<i>Recommended cement replacement level in concrete</i>	up to 50% (from the aspect of achieved mechanical properties of mortar)

5.4 Soya straw ash: basic properties and possible application

Soya straw ash, before sieving and grinding

Soya straw ash, after sieving and grinding

<i>Ash origin</i>	Hipol, Odžaci
<i>Basic data on the ash</i>	Bottom ash, roughly sieved through a 4mm sieve
<i>Available amount per year</i>	700 tons
<i>Reactive silica content</i>	25%
<i>Specific gravity</i>	2400 kg/m ³
<i>Blaine fineness</i>	520 m ² /kg
<i>Soundness</i>	satisfactory
<i>The pozzolanic activity</i>	Insufficient
<i>The activity index</i>	$I_{28}=70\%$ $I_{90}=69\%$
<i>Recommended cement replacement level in mortar</i>	up to 10% (from the aspect of achieved mechanical properties of concrete)
<i>Recommended cement replacement level in concrete</i>	up to 10% (from the aspect of achieved mechanical properties of mortar)

5.5 Silo waste ash: basic properties and possible application

Silo waste ash, before sieving and grinding

Silo waste ash, after sieving and grinding

<i>Ash origin</i>	Soja Protein, Bečej
<i>Basic data on the ash</i>	Bottom ash, roughly sieved through a 4mm sieve
<i>Available amount per year</i>	300-1100 tons
<i>Reactive silica content</i>	25%
<i>Specific gravity</i>	2390 kg/m ³
<i>Blaine fineness</i>	1180 m ² /kg
<i>Soundness</i>	satisfactory
<i>The pozzolanic activity</i>	Class 5
<i>The activity index</i>	I ₂₈ =90% I ₉₀ =100%
<i>Recommended cement replacement level in mortar</i>	up to 30% (from the aspect of achieved mechanical properties of concrete)
<i>Recommended cement replacement level in concrete</i>	up to 30% (from the aspect of achieved mechanical properties of mortar)

5.6 Oil rapeseed ash: basic properties and possible application

Oil rapeseed ash, before sieving and grinding

Oil rapeseed ash, after sieving and grinding

<i>Ash origin</i>	Knot Autoflex, Bečej
<i>Basic data on the ash</i>	Bottom ash, roughly sieved through a 4mm sieve
<i>Available amount per year</i>	60 tons
<i>Reactive silica content</i>	15%
<i>Specific gravity</i>	2320 kg/m ³
<i>Blaine fineness</i>	610 m ² /kg
<i>Soundness</i>	satisfactory
<i>The pozzolanic activity</i>	Insufficient
<i>The activity index</i>	I ₂₈ =86% I ₉₀ =85%
<i>Recommended cement replacement level in mortar</i>	up to 30% (from the aspect of achieved mechanical properties of concrete)
<i>Recommended cement replacement level in concrete</i>	up to 30% (from the aspect of achieved mechanical properties of mortar)

5.7 Mixed wheat straw and sunflower husk ash: basic properties and possible application

Mixed wheat straw and sunflower husk ash, before sieving and grinding

Mixed wheat straw and sunflower husk ash, after sieving and grinding

Ash origin	Soja Protein, Bečej
Basic data on the ash	Bottom ash, roughly sieved through a 4mm sieve
Available amount per year	300-1100 tons
Reactive silica content	35%
Specific gravity	2185 kg/m ³
Blaine fineness	1065 m ² /kg
Soundness	satisfactory
The pozzolanic activity	Insufficient
The activity index	I ₂₈ =76% I ₉₀ =83%
Recommended cement replacement level in mortar	up to 30% (from the aspect of achieved mechanical properties of concrete)
Recommended cement replacement level in concrete	up to 30% (from the aspect of achieved mechanical properties of mortar)

5.8 Sunflower husk ash: basic properties and possible application

Sunflower husk ash (grinding processing was not necessary)

<i>Ash origin</i>	Victoria Oil, Šid
<i>Basic data on the ash</i>	Fly ash
<i>Available amount per year</i>	720 tons
<i>Reactive silica content</i>	5%
<i>Specific gravity</i>	2200 kg/m ³
<i>Blaine fineness</i>	610 m ² /kg
<i>Soundness</i>	satisfactory
<i>The pozzolanic activity</i>	Insufficient
<i>The activity index</i>	$I_{28}=0$ $I_{90}=0$
<i>Recommended cement replacement level in mortar</i>	Not recommended as SCM
<i>Recommended cement replacement level in concrete</i>	Not recommended as SCM

6 Conclusions and further research

The aim of this study was to collect and analyze the ashes originating from harvest residues combustion, locally available in Vojvodina. Novel and useful information on the characteristics of wheat straw, soya straw, sunflower husk, oil rapeseed and silo waste based ashes is presented through the catalogue, which is the first step in defining an environmentally friendly route for this type of waste, offering an opportunity for the creation of new sustainable cement-based composites, thereby. Experimental research of HRA as potentially building materials should result in guidelines relevant for their further use of as mineral/inert additives in cementitious systems. To achieve this goal, further investigations will include determination of HRA influence on

basic properties of mortars, concretes and other composites. The results of such experimental research should verify the possibility to obtain biomass ash-based ECO composites with comparable or better physical and mechanical properties than those of the reference composites. As the catalogue demonstrated a high variability of HRA properties, other directions of the ashes application (construction of roads and embankments, alkali-activated materials, etc.) are also possible and up for research, depending on the type of the ash. These composites will be characterized by a lower consumption of cement, thus reducing the CO₂ emissions and meeting the principles of sustainable development.

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