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Influence of type of biomass burned on the properties of cement mortar containing fly ash

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Abstract: The paper presents the issues related to the excessive use of natural resources and the possibility of its reduction through the use of ash deposited in landfills. Two different ashes from the combustion of various types of biomass (coconut shell and sunflower) were used and compared with each other. As part of the tests, the chemical composition of the ashes used was checked and samples of cement and standard mortars were made using the two types of fly ash. The research shows that the chemical composition is similar to the volatile chemical composition of conventional burning pavilions. It should be noted that the type and origin of the ash used for the results obtained is important. The use of ashes as a partial substitute for standard sand increased the compressive strength of all tested samples from 1 to over 17%. Ash additions reduced the compressive strength drop after frost resistance testing by 3 to 15%, and slightly increased the absorbency by 2 to 6% relative to control samples. An important advantage is that the use of ash as a substitute for standard sand allows you to reduce the consumption of natural resources.

Keywords: sustainable construction, cement mortar, fly ash

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Introduction

In recent years, the construction sector has been primarily focused on effectively reducing the consumption of energy and natural resources in line with sustainable development policies. According to this principle, the design, manufacture of building materials, construction and use of buildings should take into account environmental protection requirements for the present and for future generations.

It is important to reduce the use of natural resources in the production of building materials, which by using the latest technologies, can be replaced by waste materials from the recovery process or recycling of construction waste (e.g. debris, ceramics) (Jura & Ulewicz, 2015; Rashid et al., 2017; Wójcik et al., 2017) or waste materials from other industries, such as glass cullet (Walczak et al., 2015), slag (Senani et al., 2018), fly ash from coal or lignite combustion and co-firing (Popławski & Lelusz, 2018; Siddique et al., 2018), or sewage waste (Pietrzak, 2019). Large amounts of waste are available that currently have no practical use, including fly ash and bottom ash from the combustion of biomass which effective development opportunities are still being sought.

One possible use for this type of waste, taking into account the need to protect natural resources, is the production of composite materials with a cement matrix. Initial tests were also carried out to check the effect of similar materials on cement mortars (Jura & Ulewicz, 2017b). The research results presented in the article are aimed at checking the possibility of using fly ash, which is waste generated during the combustion process of biomass in a fluidized bed boiler. Most works compare ashes with each other mainly in terms of chemical composition, while the tests were also aimed at checking whether it is possible to use such an additive in exchange for a part of the standard sand, which would reduce the consumption of natural resources. A comparison was made of the use of two ashes produced from different biomasses.

1. Materials and research methodology

Two types of fly ash from biomass combustion were used in the study. The first ash came from burning 80% wood and 20% coconut shells (PKS), the second from burning 80% wood and 20% sunflower (PS). Both types of biomass were burned in a circulating fluidized bed boiler. As part of the tests, the ashes were tested in accordance with PN EN 450 1: 2012 for fly ash used for concrete. PKS ash roasting losses amounted to 3.5% while PS 2.9%. The elemental composition of tested homogeneous ash samples was determined using an XRF X-ray spectrometer. The oxide and elemental composition of fly ash is shown in Table 1. Silicon oxide is more than half the composition of both ashes (PK – 57.5%, PS – 50.2%). The ashes also contain calcium oxide (17 and 11%), aluminium oxide, which in the PKS ash was less than 5% while in the PS ash over 12%. In addition, PS ash contains almost 8% potassium oxide with 4% in PKS ash. The remaining compounds are below 4%, of which most oxides and elements are found only in trace amounts. For testing CEM I 42.5 R portland cement was used. Standard sand in accordance with PN EN 196-1, certified by the Institute of Mineral Building Materials, was used for the testing of the cement mortars.

In the study, six samples for each series were made. Control samples were made according to standard mortars (PK) and samples containing 10, 20 and 30% addition of fly ash used as a partial substitute for sand (Table 2).

As part of the experiments, tests were carried out on the basic properties of hardened cement mortar, i.e. compressive strength, water absorption and frost resistance. The samples for testing the compressive strength were made in accordance with

PN-EN 196-1, and the test was carried out on the basis of PN-EN 1015-1. The compressive strength test was carried out using 40 x 40 x 160 mm prism shaped samples on a Toni Technik strength testing machine. The mortar was mixed mechanically using an automatic cement mortar mixer and compacted in a mold on a shaking table for cement beam samples. The bars in the molds were stored for 24 hours in a humid environment and from the moment of demolding to the compressive strength test they were stored in water. The value of the destructive force was noted as the result and presented as the average of six samples.

Table 1. Percentage of oxides and elements in fly ash (*own research*)

Element / Oxide	PKS ash	PS ash
	[%]	
SiO_2	57.54	50.20
CaO	17.26	11.82
K_2O	3.93	7.99
Al_2O_3	4.82	12.29
MgO	2.32	3.34
Fe_2O_3	2.94	1.46
P_2O_5	2.01	2.04
Na_2O	0.39	0.44
MnO	0.51	0.28
TiO_2	0.30	0.30
Cl	1.06	1.63
Others	6.92	7.21

Table 2. Composition of the different series of cement mortars (*own research*)

Ingredient	Mortar series						
	PK	PKS10	PKS20	PKS30	PS10	PS20	PS30
Cement [g]	450	450	450	450	450	450	450
Standard sand [g]	1350	1301.7	1253.4	1205.16	1299.3	1248.5	1197.8
Water [cm^3]	225	225	225	225	225	225	225
PKS ash [g]	–	45	90	135	–	–	–
PS ash [g]	–	–	–	–	45	90	135

The absorbency of the cement mortars was determined according to PN-B-04500 standard. The test was carried out on six 40 x 40 x 160 mm prisms. The property is determined by measuring the mass of water absorbed by the mortar sample when immersed in water under atmospheric pressure. Water absorption was calculated as the ratio of the weight of saturated samples to the weight of dry samples, presented in %. The final result is the arithmetic mean of the test results of three samples.

Frost resistance tests of cement mortars were carried out on 12 samples in accordance with PN-EN 196-1, and frost resistance tests in accordance with PN-B-04500. Samples after ageing for 28 days from the time of processing were weighed and subjected to 25 cycles of freezing at (–18±2°C) for 4 hours, followed by thawing in water at (+18±2°C) for 4 hours. Then the samples were weighed again and subjected to compressive strength tests at normal temperature. The obtained results were presented as the percentage decrease in compressive strength and percentage weight loss after frost resistance tests in relation to samples not subjected to freezing and thawing during that time.

2. Results and analysis

As part of the tests, the compressive strength of the cement mortars was checked. The results were presented as the average of six tested samples. The standard mortar obtained a compressive strength of 60.3 MPa (Fig. 1). All tested samples from the series of mortars containing the addition of both fly ashes obtained higher values of average compressive strength and the value increased with the increase of ash addition. The highest average compressive strength was obtained by samples of the mortar series containing 30% fly ash from wood burning together with sunflower at almost 71 MPa, which was higher by over 17% compared to the control sample.

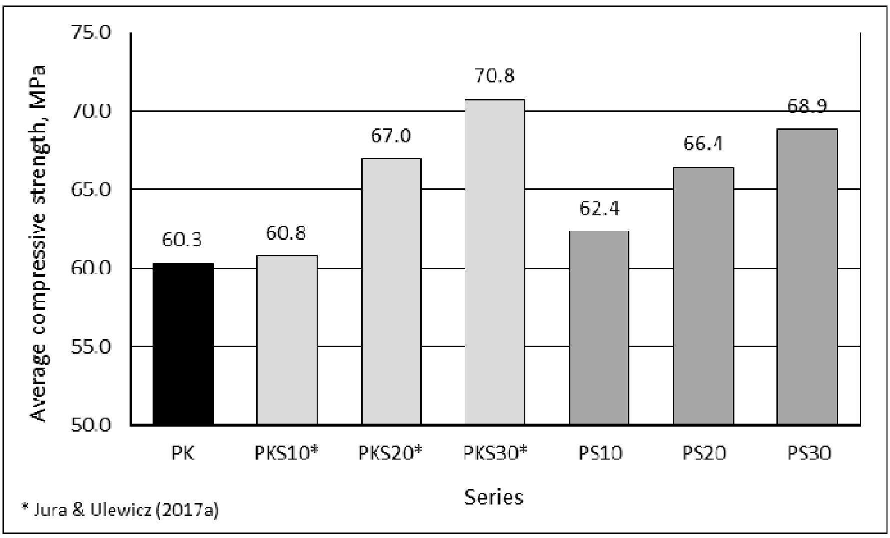

Fig. 1. Average mortar compressive strength after 28 days of curing (*own research*)

Water absorption tests were also carried out on the obtained samples. The absorbency of the control samples was 9.59% (Fig. 2). Samples containing the addition of any of the ashes caused an increase in absorbency and increased as the amount of additive in the sample increased. The lowest absorbency of the samples with addition was found in the PS10 series, and the highest in PKS30.

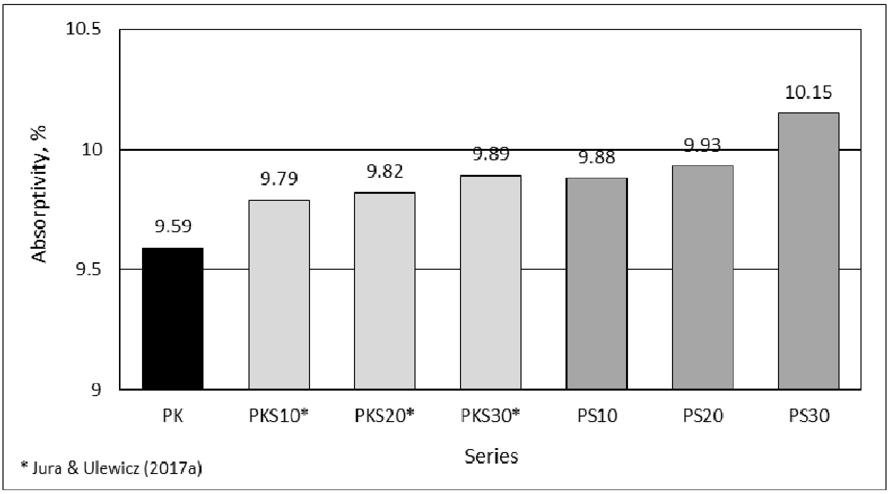

Fig. 2. Average absorption of cement mortars (*own research*)

The tested series were also subjected to a 25 cyclic freezing and thawing process. The decrease in compressive strength for the control series was more than 15% (Fig. 3). The addition of both PKS and PS ash mitigated the decrease in compressive strength after the frost resistance tests. The addition of ash from burning wood with coconut mitigated the drop in compressive strength to 10.5-12.4%, while the addition of ash from burning wood with sunflower to 0.5-6.5%. The use of ash resulted in a slightly larger weight loss of frozen samples (PK 0.1%; PKS 0.35-0.44%; PS 0.22-0.3%).

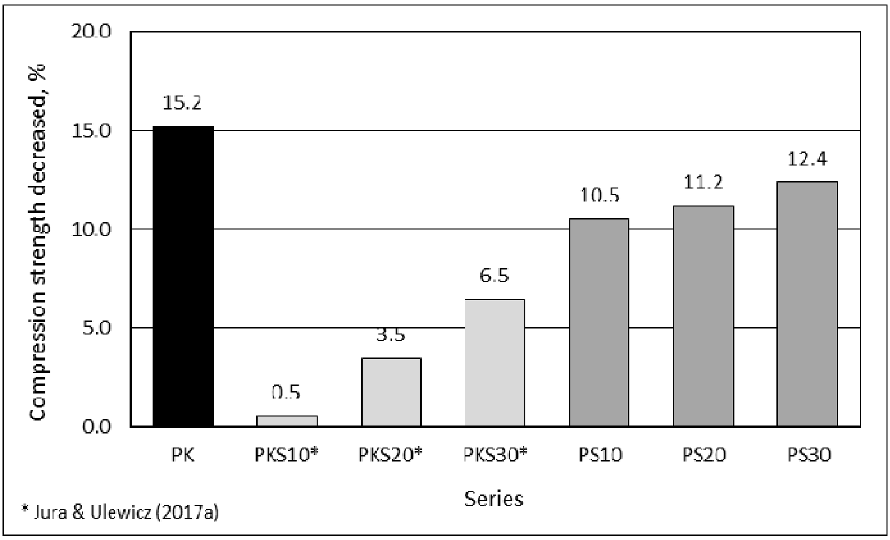

Fig. 3. Compression strength decreased after frost resistance tests (*own research*)

Conclusions

The conducted research shows that after determining the chemical composition and preliminary tests, it is possible to use the ash from the combustion process of biomass for the production of cement mortars. The waste material has a similar chemical composition to materials commonly used in cements and cement mortars. The results of the basic properties of synthesized cement mortars show that the use of this type of waste material as a partial replacement for standard sand increases the compressive strength of cement matrix products by up to 17%. In addition, the use of fly ash has a very positive effect on the impact of frost damage on the cement material obtained. The use of ash from biomass mitigated the decrease in compressive strength by over 15% for the control sample to even 0.5% for samples with the addition of PS ash. The use of tested additives also slightly influenced the increase of the absorbency of the samples. The presented tests clearly show that for the production of cement mortars it is possible to use ashes from biomass burning and that this addition can significantly improve some of the material's properties. It should also be noted that the origin of ash and its storage are important. An important conclusion is also that waste ash can be used as a substitute for standard sand, and thus reduces the amount of natural resources consumed, resulting in a positive affect for the natural environment.

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