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THE IMPACT OF WASTE GENERATED FROM THERMAL TRANSFORMATION OF MUNICIPAL WATE ON SELECTED PROPERTIES OF CEMENT MORTAR

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Abstract: The article analyzes the possibility of using two types of waste from the thermal transformation of municipal waste in the production technology of cement mortars. Fly ash and dust were used in amounts of 5, 10, 15, 20, 25 and 30% of the cement mass as a replacement for sand. In total, 11 series of cement mortars were prepared: a standard control mortar and 10 series of mortars modified with individual waste. The following tests were performed for the prepared samples: bending and compressive strength after 7 and 28 days of maturing, water absorption and consistency testing for fresh mortars. Based on the results obtained, it can be concluded that the use of waste dust and fly ash in the amount of 30% as a replacement for sand reduces the compressive strength by 24.0% and 8.0%, respectively, and the bending strength by 23.6% and 21.5%, respectively.
Keywords: cement mortar, ash, dust, municipal waste

1. INTRODUCTION

According to the latest data provided by the Central Statistical Office (GUS) for 2022, the amount of municipal waste collected in Poland amounted to 13,420.3 thousand. tone, which was recorded as a decrease of 1.9% compared to the previous year (13,673.6 thousand tons in 2021). Over 86% (11.6 million Mg) of this waste came from households. Of the total amount of waste collected, as much as 61.1% (8,199.1 thousand tons) was subjected to the recovery process. Within this process, recycling accounted for 26.7% (3,585.4 thousand tons), biological processes (composting or fermentation) accounted for 14.2% (1,899.5 thousand tons), and thermal transformation with energy recovery reached 20.2% (2,714.1 thousand tonnes). On the other hand, 38.9% of waste (5,221.2 thousand tons) went to the disposal process, where 0.8% (113.0 thousand tons) was thermal transformation without energy recovery, and 38.1% (5 108.2 thousand tons) is storage.

In recent years, the waste transfer process has become more and more attractive and available in waste. It makes it possible to reduce the amount of waste stored in landfills while generating electricity and heat. Hazardous waste resulting from this process, such as combustion slag or fly ash, is classified as biological waste (190107* and 190113*) according to the waste catalog, which results in the need for effective management (Wielgosiński and Wasiak, 2015; Francois and Criado, 2007; Wielgosiński, 2016). The only way that belongs to them is to use them in the technology of proceedings. Concrete, in the context of modern construction, is a leftover material, which causes a systematic increase in the demand for natural aggregates necessary for its production. Considering that the minerals they supply contribute to environmental degradation, research on alternative marine production facilities, including waste materials, is of particular importance.

In recent years, many research centers have been conducting research on the possibility of using various materials, including waste materials, to produce concrete and cement mortars. According to the literature review, recyclates from household ceramics (Halicka et al., 2016; Ulewicz and Halbiniak, 2016; Aggarwal and Siddique, 2014) and CRT glass (Walczak el al., 2015) are successfully used for the production of concrete mix. or glass (Dębska el al., 2020). The results showed that for both mortars and concretes modified with ceramic waste, a higher compressive strength was achieved compared to the control series. The highest compressive strength (an increase of 5.0% compared to the control sample) was found for cement mortars using ceramic waste with fragmentation smaller than 0.2 mm. The highest compressive strength (about 12.3%) compared to the control sample is shown by concrete in which 30% of the natural aggregate was replaced with ceramic waste. Additionally, using up to 30% ground ceramics in concrete reduces its water absorption capacity.

Waste polymeric materials are of great interest (Albano, 2009; Mounanga, 2008; Rashad, 2016; Tavakoli et al., 2018; Sharma and Bansal, 2016, Pietrzak and Ulewicz, 2021, 2023; Helbrych, 2023; Czajkowska et. al. 2023). Literature reports show that the most frequently tested material for use in concrete technology is polyethylene terephthalate (PET), polyethylene and polypropylene (Gu and Ozbakkaloglu, 2016). The addition of PET waste material to concrete, as most authors have shown, reduces the compressive strength, tensile and flexural strength of concrete and the modulus of elasticity, regardless of the tested consistency and water-cement ratio. EPS regranulate was used in amounts ranging from 10% to even 100% as a replacement for fine or coarse aggregate. The composite obtained in this way was characterized by low density and better thermal parameters compared to ordinary concrete. The density of modified concrete decreases as the amount of EPS added increases. In the case of the addition of 70% EPS recyclate, the density of concrete decreased by up to 31%. EPS and PS waste was used to modify both cement concrete and polymer concrete, using it as an admixture that plasticizes and reduces the amount of water in the concrete mixture.

The technology for producing these materials also uses waste fly ash, silica dust, ground blast furnace slag, and ash from biofuels (Jura and Ulewicz, 2017, 2021; Pribulova et al., 2016; Jura 2020, 2023; Kalak et al., 2023; Popławski 2019; Cardoso, 2022). The work (Kalak et al., 2023) shows that the addition of SSFA as a by-product of the combustion of municipal sewage sludge did not reduce the compressive strength, therefore it can be successively used. The conducted research shows that the compressive strength increases with a decrease in the sand content (from 990 kg to 620 kg) and a decrease in the sand point value (from 0.54% to 0.32%). However, the compressive strength increased with the increase in the amount of gravel 2/8 (from 360 kg to 562 kg) and 8/16 (from 468 kg to 670 kg). The authors (Popławski and Lelusz, 2023) examined the influence of fly ash generated during biomass combustion, sifted through a sieve with a mesh diameter of 63 μm and 125 μm, on the properties of fresh and hardened cement mortar. Screening increased the CaO content by 9.3 percentage points (pp) in the oxide composition of fly ash. 28-day endurance activity rates increased by 24.9 percentage points. A 25% cement replacement rate with fly ash sieved through a 63 μm sieve increased the 2-day compressive strength of the mortars by 24% compared to untreated fly ash.

In addition, a number of other wastes were used for mortars and concretes, including Biosilica (Muradyan et al., 2023), waste materials from cement mortars, slag ashes and aggregates from recycled concrete (Kalinowska-Wichrowska et al., 2022), agricultural and industrial waste (Martinez-Molina,2021), hemp (Šadzevičius et al., 2023).

Research into alternative raw materials for concrete production and the development of effective waste treatment processes in the construction sector are key to achieving sustainable development goals, and at the same time constitute an important step towards building a more environmentally friendly society. Integrating these innovations into construction practice can contribute to more sustainable and efficient construction solutions.

The aim of this article was to investigate the impact of waste generated from thermal processing of municipal waste on selected properties of cement mortars, i.e. consistency, compressive and flexural strength, water absorption.

2. MATERIALS AND RESEARCH METHODOLOGY

The following materials were used to produce the tested cement mortars: Portland cement CEM I 42.5R from CEMEX, standard quartz sand in accordance with the PN-EN 196-1 standard, water, ash (W1) and dust (W2) generated after burning municipal waste in one of the incinerators in Poland (Fig. 1). The composition of waste W1 and W2 characterized by waste codes 190113* (fly ash containing hazardous substances) and 190107* (solid waste from waste gas treatment) is presented in Table 1.

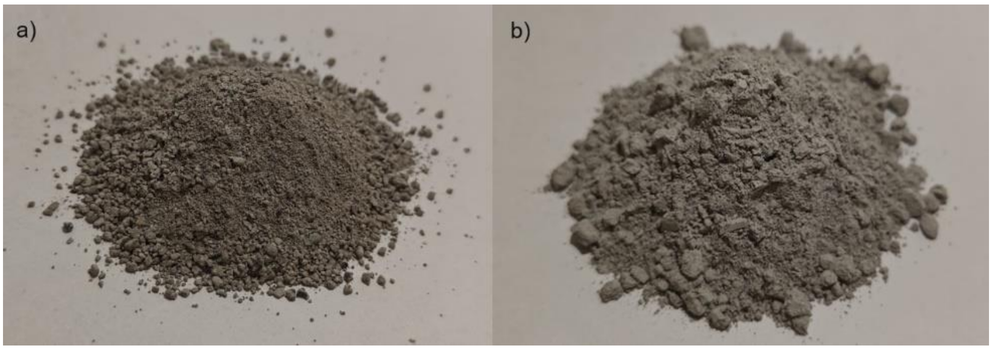

Fig. 1. Waste used for testing: a) combustion ash from the incineration of municipal waste (W1), b) dust after burning municipal waste (W2)

Source: own study

Table 1

Chemical composition of waste used, %

Waste	Chemical composition (%(m/m))										
	SiO_2	Al_2O_3	CaO	K_2O	MgO	Fe_2O_3	Na_2O	SO_3	P_2O_5	Cl^-	Other
Ash (W1)	11.35	7.31	25.49	1.05	2.95	2.55	-	8.77	1.49	3.35	35.79
Dust (W2)	3.76	3.48	33.12	2.97	1.63	0.52	4.66	8.34	0.26	15.39	25.87

Source: own study

The chemical composition was determined on a Spectro XEPOS D XRD-ED microscope. In addition, sieve analysis (Fig. 2) and specific density for the waste used were determined. The specific density was determined according to the PN-EN 196-6 standard and amounted to 2.54 g/cm3 for ash and 2.14 g/cm3 for dust. Sieve analysis showed that waste W1 has a uniform grain size of 0-2 mm, while waste W2 has a predominance of grains with a fraction of 0-0.125 mm, which constitute 94.55% of the grain size.

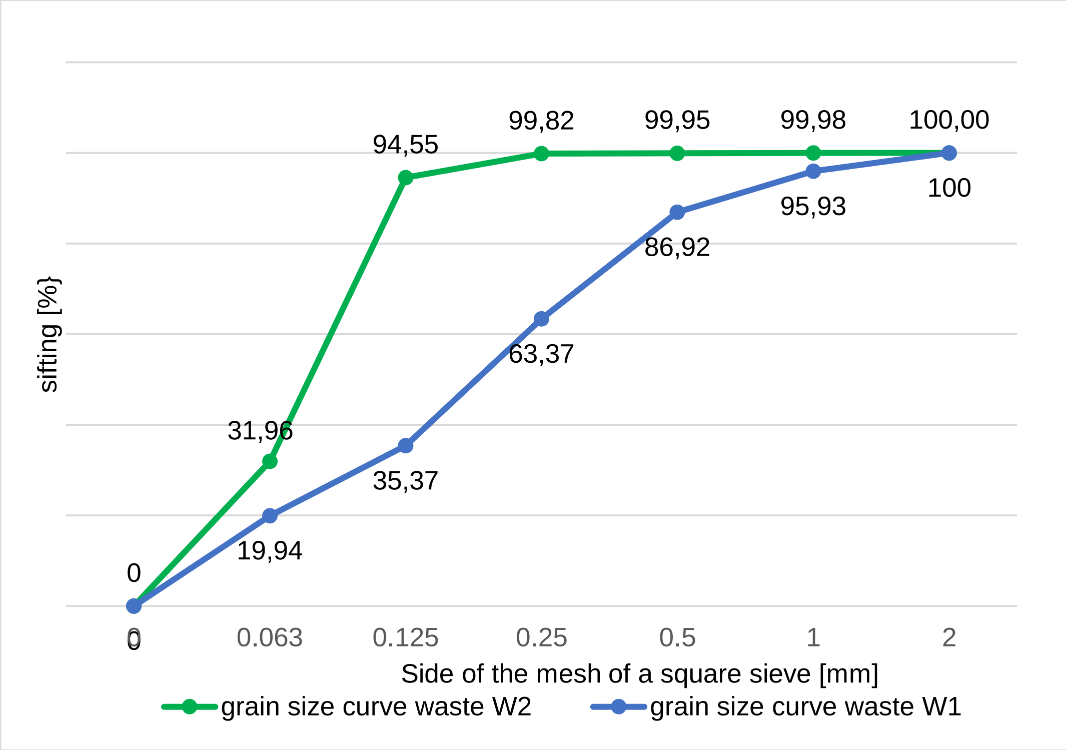

Fig. 1. Particle size curves of the waste used

Source: own study

A series of control beams (ZK) were made as a standard mortar based on Portland cement CEM I 42.5R. In the modified series, the presented waste was used as a replacement for sand in the amount of 5, 10, 15, 20 and 30% of the cement mass, introducing a volume correction of sand (Table 2). The waste was dosed individually into the mortars. A total of 10 series of mortars modified with W1 and W2 waste were made. For each series of mortars, 9 samples were made and subjected to the following tests.

The determination of compressive and bending strength was performed in accordance with the PN-EN 196-1 standard. The tests were carried out on bars with dimensions of 40x40x160 mm. The bars were stored in the mold for 24 h in an air-conditioned room at a temperature of (20 ± 1)°C and a relative humidity of at least 90%, and after unmolding, they were stored in water at a temperature of (20 ± 1)°C until testing.

Compressive and bending strength tests were performed after 7 and 28 days of sample maturation.

The bending strength test was performed on 3 trabeculae, increasing the load by 50 ± 10 N/s until the trabecula broke (Fig. 2b).

The compressive strength test was performed on the trabeculae halves (Fig. 2a). The increase in compressive force was uniform and amounted to 2400 ± 200 N/s.

The absorbability of mortars was tested using the soaking method in accordance with PN-B-04500:1985. Three bars with dimensions of 40 mm × 40 mm × 160 mm made of individual mortars were used for the test.
The consistency of fresh cement mortar was tested using a flow table in accordance with the PN-EN 1015-3 standard.

Table 2
Composition of tested cement mortars

Series (O1; O2)%	Cement CEM I 42.5R [g]	Water [cm^3]	Standarized sand [g]	Waste used	
				Ash - O1 [g]	Dust - O2 [g]
ZK	450	225	1350	-	-
Z1			1326.53	-	22.5
Z2			1303.05	-	45.0
Z3			1279.58	-	67.5
Z4			1256.1	-	90.0
Z5			1200.30	-	135.0
Z6			1322.10	22.5	-
Z7			1294.20	45.0	-
Z8			1266.30	67.5	-
Z9			1238.39	90.0	-
Z10			1182.59	135.0	-

Source: own study

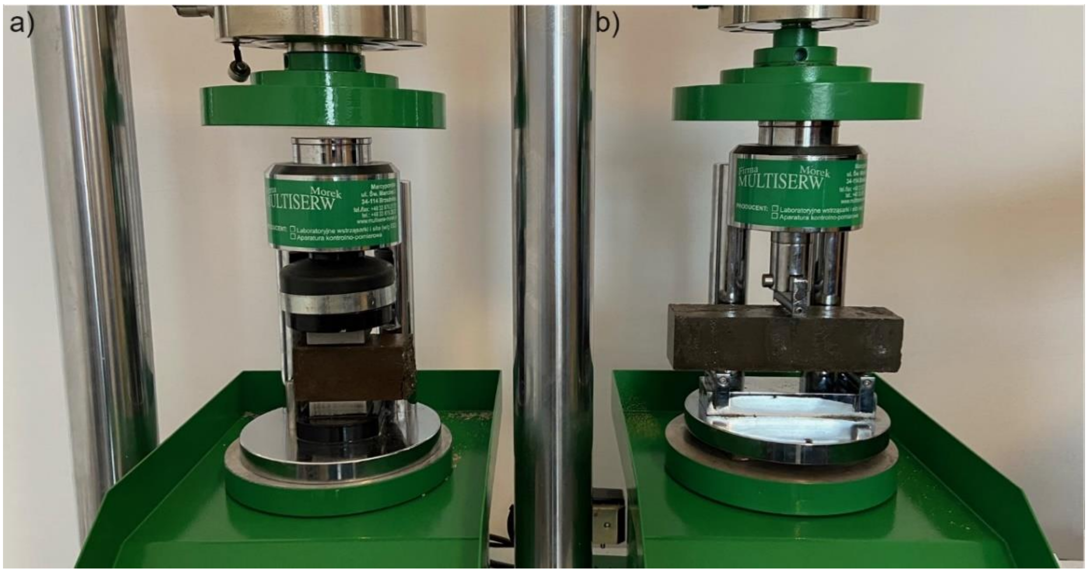

Fig. 2. Test: a) compressive strength, b) bending strength
Source: own study

3. RESULTS

The first stage of the research included determining the consistency of freshly prepared cement mortars using the flow table method (Table 3). As the W1 and W2 waste increased, the consistency of the modified mortars deteriorated and their plasticity decreased.

Table 3
Results of consistency and water absorption tests

Series / Test	ZK	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Mortar consistency [mm]	15.9	15.55	15.10	13.50	11.85	10.85	15.25	14.90	14.65	14.65	14.40
Water absorption [%]	8.07	9.10	9.29	9.72	9.79	9.78	9.60	9.78	9.89	9.98	9.82

Source: own study

The second stage of the research included determining the bending strength of cement mortars. The control mortar (ZK) after 7 days of maturing was characterized by an average bending strength of 7.54 MPa, and after 28 days of maturing it was 8.88 MPa (Fig. 3). For all series of modified mortars, a decrease in the average bending strength tested after 7 days of maturing was noted compared to the control mortar. The greatest decrease (36.26%) was recorded for the Z5 mortar modified with ash in the amount of 30% of the cement mass. The smallest decrease in bending strength tested after 7 days of maturation was recorded for the Z3 series, this decrease amounted to 20.7%. For the remaining series, the decrease in bending strength was 25.9 – 33.6%. Also, the test performed after 28 days of maturing showed that all modified series had lower bending strength compared to the control mortar. The lowest decrease was recorded for the series where sand with 5% ash was used as a replacement. This decrease was 12.5%. However, the highest decrease in bending strength was recorded for the Z4 series - 29.5%.

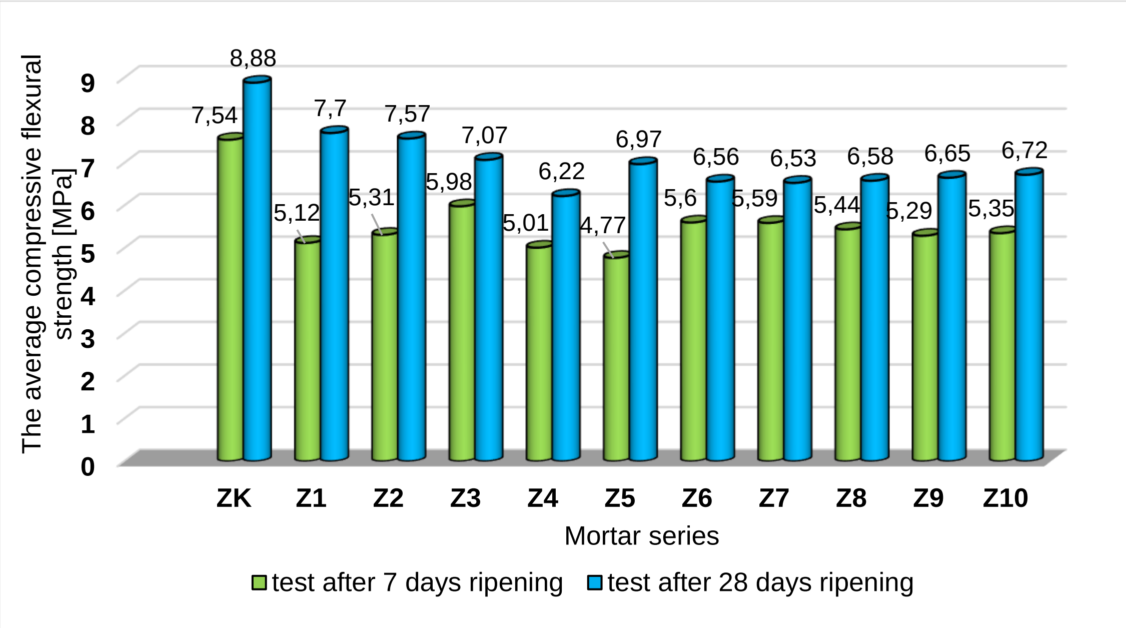

Fig. 3. The average flexural strength of the mortar

Source: own study

In the next stage of the research, the compressive strength of cement mortars was determined after 7 and 28 days of sample maturation (Fig. 4). For the control mortar, the average compressive strength tested after 7 days was 40. MPa, while the average compressive strength tested after 28 days was 51.2 MPa. For the Z3 mortar, where 15%

of ash was added as a replacement for sand, a higher average strength was obtained after 28 days of curing. The increase in strength compared to the control series was 4.5%. For the remaining series modified with W1 waste, the decrease ranged from 2.7% to 7.8%. However, all series achieved the required compressive strength imposed by the PN-EN 197-1 standard using CEM I 42.5 R class cement. This range is 42.5 MPa to 62.5 MPa. However, for all series where waste in the form of dust was added, both the 7 and 28-day compressive strength was lower than for the control series. The decrease in compressive strength tested after 7 days of sample maturation ranged from 17.8 to 36%. However, the decrease in the average 28-day compressive strength compared to the control series ranged from 24% to 38.4%. It should be noted, however, that the highest compressive strength result was obtained for the series where 30% of W2 waste was used.

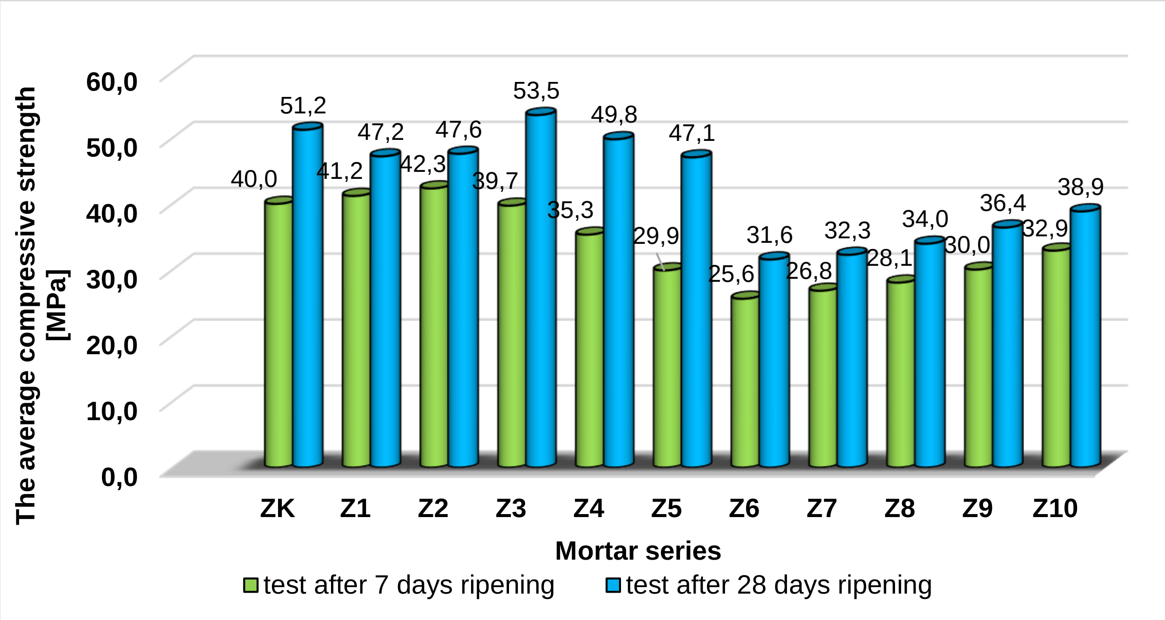

Fig. 4. The average compressive strength of the mortar

Source: own study

3. CONCLUSIONS

The analysis of the obtained test results for mortars containing the addition of dust and ash resulting from thermal processing of municipal waste allows the following conclusions to be drawn:

• increasing these wastes in the cement mortar results in deterioration of workability and reduced flow,

• the use of dust and ash increases the absorbability of modified mortars from 13.9% to 24.6%,

• the use of dust in amounts ranging from 5 to 30% as a replacement for sand reduces the compressive strength by up to 38.4% and the bending strength by up to 29.5% compared to the strength parameters of the control mortar,

• adding fly ash in an amount from 5% to 30% of the cement mass as a replacement for sand resulted in a decrease in strength parameters compared to the control mortar (compressive strength up to 7.8% and bending strength up to 36.3%). It should be noted that the results obtained for mortars modified with ash had lower strength parameters, but they met the standard requirements when using a given cement.

REFERENCES

Aggarwal, Y., Siddique, R., 2014. *Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates,* Construction and Building Materials, 54, 210-223.

Czajkowska, A., Raczkiewicz, W., Ingaldi, M. 2023. *Determination of the linear correlation coefficient between Young's modulus and the compressive strength in fibre-reinforced concrete based on experimental studies*, Production Engineering Archives, 29(3), 288-297, DOI: 10.30657/pea.2023.29.33

Cardoso, W., di Felice, R., Baptista, R.C., Machado, T.A.P., de Sousa Galdino, A.G., 2022. *Evaluation of the use of blast furnace slag as an additive in mortars*, REM, Int. Eng. J., Ouro Preto, 75(3), 215-224

Dębska B., Krasoń J., Lichołai L., 2020. *The evaluation of the possible utilization of waste glass in sustainable mortars,* Construction of Optimized Energy Potential, vol. 9 (2), 7-15, DOI: 10.17512/bozpe.2020.2.01

Francois, D., Criado, C., 2007. *Monitoring of leachate at a test road using treated fly ash from municipal solid waste incinerator*, Journal of Hazardous Materials, 2007, 543-549

Gu, L., Ozbakkaloglu, T., 2016. *Use of recycled plastics in concrete: A critical review,* Waste Management., 51, 19–42

Halicka, A., Ogrodnik, P., Zegardlo, B., 2013. *Using ceramic sanitary ware waste as concrete aggregate,* Construction and Building Materials, 48, 295–305

Helbrych, P., 2019. *Recycling of sulfur polymers derived from the purification process of copper and other non-ferrous metals in concrete composites,* Construction of Optimized Energy Potential, 8(1), 131-136 DOI: 10.17512/bozpe.2019.1.14

Jura, J., 2020. *Influence of Type of Biomass Burned on the Properties of Cement Mortar Containing Fly Ash,* Construction of Optimized Energy Potential, 9(1), 77-82

Jura, J., Ulewicz, M., 2021. *Assessment of the Possibility of Using Fly Ash from Biomass Combustion for Concrete*, *Materials, 14*, 6708, DOI: 10.3390/ma14216708

Jura, J., 2023. *Influence of Waste Ashes from Biomass Combustion on Frost Resistance of Cement Mortars*, Scientific Journals of the Maritime University of Szczecin, 75(147), 35-41

Kalak, T., Szypura, P., Cierpiszewski, R., Ulewicz, M., 2023. *Modification of Concrete Composition Doped by Sewage Sludge Fly Ash and Its Effect on Compressive Strength*, *Materials*, 16, 4043, DOI: 10.3390/ma16114043

Kalinowska-Wichrowska, K., Pawluczuk, E., Bołtryk, M., Jimenez, J.R., Fernandez-Rodriguez, J.M., Suescum Morales, D., 2022. *The Performance of Concrete Made with Secondary Products—Recycled Coarse Aggregates, Recycled Cement Mortar, and Fly Ash–Slag Mix.* Materials, 15, 1438.

Martinez-Molina, W., Chavez-Garcia, H.L., Perez-Lopez, T., Alonso-Guzman, E.M., Arreola-Sanchez, M., Navarrete-Seras, M.A., Borrego-Perez, J.A., Sanchez-Calvillo, A., Guzman-Torres, J.A., Perez-Quiroz, J.T., 2021. *Effect of the Addition of Agribusiness and Industrial Wastes as a Partial Substitution of Portland Cement for the Carbonation of Mortars.* Materials, 14, 7276

Muradyan, N.G., Arzumanyan, A.A., Kalantaryan, M.A., Vardanyan, Y.V., Yeranosyan, M., Ulewicz, M., Laroze, D., Barseghyan, M.G., 2023. T*he Use of Biosilica to Increase the Compressive Strength of Cement Mortar: The Effect of the Mixing Method.* Materials *2023,* 16*, 5516,* DOI: 10.3390/ma16165516

Pietrzak, A., 2019. *The effect of ashes generated from the combustion of sewage sludge on the basic mechanical properties of concrete*, Construction of Optimized Energy Potential, 8(1), 29–35, DOI: 10.17512/bozpe.2019.1.03

Popławski, J., Lelusz, M., 2023. *Assessment of Sieving as a Mean to Increase Utilization Rate of Biomass Fly Ash in Cement-Based Composites*. *Applied Sciences*, 13, 1659.

Popławski, J., 2020. *Influence of biomass fly-ash blended with bituminous coal fly-ash on properties of concrete*, Construction of Optimized Energy Potential, 9(1), 89-96, DOI: 10.17512/bozpe.2020.1.11

Pribulov'a. A., Futas. P., Baricova, D., 2016. *Processing and utilization of metallurgical slags*, Production Engineering Archives, 11/2, 2–5

PN-EN 197-1 Cement – część 1. *Skład, wymagania i kryteria zgodności dotyczące cementów powszechnego użytku*

PN-EN 1015-3 *Metody badań zapraw do murów*

PN-EN 196-1:2016-7 *Metody badania cementu -- Część 1: Oznaczanie wytrzymałości*

Rashad, A.M., 2016. *A comprehensive overview about recycling rubber as fine aggregate replacement in traditional cementitious materials,* International Journal of Sustainable Built Environment, 5, 46–82.

Sharma, R., Bansal, P.P., 2016. *Use of different forms of waste plastic in concrete—A review,* Journal of *Cleaner Production*, 112, 473–482

Šadzevičius R., Gurskis V., Ramukevičius D., 2023. Research on the properties of concrete with hemp shives, Construction of Optimized Energy Potential (CoOEP), 12, 25-32, DOI: 10.17512/bozpe.2023.12.03

Tavakoli, D., Hashempour, M., Heidari, A., 2018. *Use of Waste Materials in Concrete: A review, Pertanika Journal* of *Science & Technology*, 26, 499–522

Ulewicz, M., Jura J., 2017. *Effect of fly and bottom ash mixture from combustion of biomass on strength of cement mortar*, *E3S Web of Conferences* 18, DOI: 10.1051/e3sconf/20171801029.

Ulewicz, M.; Halbiniak, J. Application of waste from utilitarian ceramics for production of cement mortar and concrete. Physicochem. Probl. Miner. Process. 2016, 52, 1002–1010.

Ulewicz, M., Pietrzak, A., 2021. *Properties and Structure of Concretes Doped with Production Waste of Thermoplastic Elastomers from the Production of Car Floor Mats*, Materials, 14, 872

Ulewicz, M., Pietrzak, A., 2023. *Influence of Post-Consumer Waste Thermoplastic Elastomers Obtained from Used Car Floor Mats on Concrete Properties*, Materials, 16, 2231

Walczak, P., Małolepszy, J., Reben, M., Rzepa, K., 2015. *Mechanical properties of concrete mortar based on mixture of CRT glass cullet and fluidized fly ash*, Procedia Engineering, 108, 453 – 458

Wielgosiński G., Wasiak D., 2015. *Wtórne odpady z procesu spalania odpadów*, Nowa Energia, 45-56.

Wielgosiński G., 2016. *Termiczne przekształcanie odpadów komunalnych - wybrane zagadnienia*, Wydawnictwo „Nowa Energia", Racibórz

https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/srodowisko/ochrona-srodowiska-w-2022-roku,12,6.html