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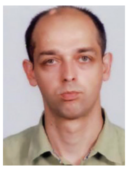
Possibility of using bottom ash in precast concrete products

Authors:

[1]Full.Res.Prof. **Ksenija Janković**, PhD. CE
ksenija.jankovic@institutims.rs



[1]**Dragan Bojović**, PhD. CE
dragan.bojovic@institutims.rs

[1]**Ljiljana Lončar**, B.Sc. CE
ljiljana.loncar@institutims.rs

[1]**Marko Stojanović**, MSc. CE
marko.stojanovic@institutims.rs

[1]**Lana Antić**, MSc. CE
lana.antic@institutims.rs

[1]Institut for Materials Testing - IMS Serbia

Professional paper

Ksenija Janković, Dragan Bojović, Ljiljana Lončar, Marko Stojanović, Lana Antić

Possibility of using bottom ash in precast concrete products

Chemical, physical and mechanical properties of bottom ash from two thermal power plants were analysed in order to evaluate the quality of bottom ash and to determine the possibility of its use in composite materials. It was found that the bottom ash samples from both power plants show good properties enabling their practical use, and that they also meet most of the criteria specified for fly ash. Samples in which 4, 8, 12 and 16% of fine aggregate was replaced with bottom ash were tested. The results meet criteria of applicable regulations for concrete, which justifies the use of bottom ash in construction industry.

Key words:
bottom ash, thermal power plant, concrete, durability, sustainable development

Stručni rad

Ksenija Janković, Dragan Bojović, Ljiljana Lončar, Marko Stojanović, Lana Antić

Mogućnosti upotrebe pepela s dna peći u betonskim predgotovljenim proizvodima

Kako bi se ocijenila kvaliteta pepela s dna peći i utvrdila mogućnost njegove upotrebe u kompozitnim materijalima, provedeno je ispitivanje njegovih kemijskih, fizikalnih i mehaničkih svojstava iz dvije termoelektrane.Utvrđeno je da uzorci pepela s dna peći iz obje elektrane pokazuju dobra svojstva koja upućuju na mogućnost njihove praktične primjene te da ispunjavaju većinu kriterija propisanih za leteći pepeo. Ispitani su uzorci s 4 %, 8 %, 12 % i 16 % zamjene sitnog agregata pepelom. Rezultati su zadovoljili kriterije propisa za beton, što opravdava upotrebom pepela s dna peći u građevinskoj industriji.

Ključne riječi:
pepeo s dna peći, termoelektrana, beton, trajnost, održivi razvoj

Fachbericht

Ksenija Janković, Dragan Bojović, Ljiljana Lončar, Marko Stojanović, Lana Antić

Möglichkeit der Verwendung von Asche vom Ofenboden in vorgefertigten Betonprodukten

Um die Qualität der Asche vom Ofenboden zu bewerten sowie die Möglichkeit ihrer Verwendung in Verbundwerkstoffen festzustellen, wurde eine Untersuchung ihrer chemischen, physikalischen und mechanischen Eigenschaften aus zwei Wärmekraftwerken durchgeführt. Festgestellt wurde, dass die Ascheproben vom Ofenboden aus beiden Kraftwerken gute Eigenschaften aufzeigen, die auf die Möglichkeit ihrer praktischen Verwendung hindeuten, und dass sie die meisten der für Flugasche vorgeschriebenen Kriterien erfüllen. Untersucht wurden Proben mit 4%, 8%, 12% und 16% Ersatz des kleinen Aggregats durch Asche. Die Ergebnisse erfüllten die für Beton vorgeschriebenen Kriterien, was die Verwendung von Asche vom Ofenboden in der Bauindustrie rechtfertigt.

Schlüsselwörter:
Asche vom Ofenboden, Wärmekraftwerk, Beton, Dauerhaftigkeit, nachhaltige Entwicklung

1. Introduction

The use of coal bottom ash in concrete, and the influence of coal bottom ash on the properties of concrete such as workability, compressive strength, bleeding, setting times, split tensile strength, flexural strength, shrinkage, and durability, are presented in this paper. Bottom ash has been shown to be a potentially viable material for producing durable concrete when used as fine aggregate. Its use may prove beneficial in protecting the environment around thermal power plants [1].

Relevant research has shown that traditional Portland cement production is not sustainable due to huge consumption of natural resources and energy and significant CO_2 emissions. Significant increase in the volume of industrial waste has generated a number of economic and environmental problems. The incorporation of industrial waste in cementitious materials may be operated using various traditional methods [2].

Zhang et al. investigated properties of cement based composites with fly ash. They concluded that the compressive strength and crack width increase with the decrease in fly ash content [3].

The possibility of using red mud and coal industry by-products as a raw material for the production of cement based materials was investigated by Yao et al. They found that the designed cementitious composite had higher strength than reference composite at the age of 6 and 12 months [4].

Cement mortar containing 8 % of ultrafine fly ash (UFFA) as a partial replacement of cement showed 27 % improvement in compressive strength at 7 days when compared to the control cement mortar [5]. This can be explained by accelerated hydration due to highly specific surface and pozzolanic activity of UFFA.

Siddique tested properties of self-compacting concrete (SCC) made with various proportions of coal bottom ash. The water absorption and sorptivity of SCC decreased and abrasion resistance increased with the decrease in the percentage of fine aggregate replacement by bottom ash [6].

The properties of cementitious materials are influenced by the compatibility of cement and admixtures and their proportions. The freeze-thaw resistance of cement mortars containing an air-entraining admixture and different types of superplasticisers was investigated by Ozturk and Erdem [7].

Singh and Siddique studied the use of coal bottom ash (CBA) as fine aggregate in concrete. River sand was replaced with different percentages of CBA. The compressive strength of concrete with bottom ash was not strongly affected at the curing age of 28 days. The pozzolanic activity of coal bottom ash influenced compressive strength after 28 days, and concrete with bottom ash had greater compressive strength than the reference concretea [8].

The influence of the type of crusher on the properties of aggregate and concrete was tested by Ozturk et al. They found that better compressive strength is exhibited by concrete with aggregate produced by impact crushers compared to aggregate produced in vertically shafted crushers [9].

Aggarwal and Siddique investigated the way in which concrete properties are influenced by equal quantities of waste foundry sand and bottom ash as a substitute of fine aggregate. The results showed that the concrete with 30 % replacement of natural fine aggregate with industrial by-product aggregate exhibited greater increase in compressive strength, splitting tensile strength, and flexural strength as compared to conventional concrete [10].

Test results shown in [11] indicate that, when compared to conventional concrete, bottom ash concrete exhibited better dimensional stability and slightly better resistance to sulphuric acid attack, and better resistance to chloride ion penetration.

Kim concluded that the workability of the mixtures with bottom ash powders was significantly higher when compared to mixtures including only cement and fly ash, although compressive strength values at 3 and 28 days were similar [12].

Concrete with 80 % of coal bottom ash can be used in the production of highway noise barriers [13].

In the investigation made by Singh and Siddique, the coal bottom ash was used as a substitute of river sand at 0, 30, 50, 75 and 100 % replacement levels by mass in concrete. They found that the use of coal bottom ash in concrete did not influence compressive strength and pulse velocity at 28 days. Water absorption and initial rate of water absorption by capillary action increased [14].

Wan Ibrahim et al. studied the effect of coal bottom ash as a partial replacement of fine aggregate in SCC by focusing on the effect of coal bottom ash on the split tensile strength. The test involved different proportions of coal bottom ash (CBA), i.e. 0 %, 10 %, 20 % and 30 %, with variations of water cement ratio (0.35, 0.40 and 0.45). The split tensile strength and density of SCC reduced with an increase in CBA replacement levels. On the other hand, the split tensile strength of SCC reduced with an increase in water cement ratio [15].

A detailed examination of chemical, physical and mechanical properties of samples originating from the TENT B and TEKO B silos was conducted in order to evaluate the quality of bottom ash and to estimate possibilities of its use in composite materials. Current standards for dry fly ash (SRPS EN 450-1:2014 and SRPS.B.C1.018) were used in the examination, because the standards for bottom ash are not as yet available.

2. Experimental work

2.1. Bottom ash

According to its chemical composition (Table 1), the tested bottom ash from the thermal power plant "Nikola Tesla" B, Obrenovac (TENT B) and Thermal power plant Kostolac B (TEKO B) meets the criteria as per SRPS EN 450-1 for: loss on ignition ≤5 % (corresponds to category A ash); content of total oxides $SiO_2+Al_2O_3+Fe_2O_3$ ≥70 %; MgO content ≤4 %; SO_3 content ≤3 %; and total alkali content ≤5 %. The reactive CaO content meets the prescribed criteria, while the content of reactive SiO_2 in the bottom ash from TENT B fails to meet the criteria. The bottom ash from TEKO B meets the criteria set for fly ash.

Table 1. Chemical composition of bottom ash from TENT B and TEKO B silos

Chemical composition of bottom ash [%] / Thermal power plant	TENT B	TEKO B
Loss on ignition at 1000 °C	2.90	3.13
SiO_2	63.42	50.28
Al_2O_3	15.16	22.34
Fe_2O_3	12.34	12.10
CaO	3.33	8.94
MgO	1.32	1.94
SO_3	0.36	0.29
S	0.00	0.00
Na_2O	0.30	0.33
K_2O	0.96	0.66
MnO	0.00	0.00
Vlaga na 105 °C	0.50	1.08
CO_2	0.55	0.52
Insoluble residue of HCl/Na_2CO_3	73.33	69.09
Insoluble residue of HCl/KOH	50.38	13.72
Reactive SiO_2 content	19.12	43.60
Reactive CaO content	2.38	8.14

Although heavy metals present a relatively low fraction in bottom ash, they are a subject of research due to their accumulation tendency, long lifespan, migration capability, and very high toxicity to the environment. Test results of heavy metal content indicate that the concentrations in bottom ash samples from both TPPs are within the limits or significantly below the prescribed values for EFA (European fly ash).

The heavy metal content in the eluates from both bottom ash samples is within the limits given in the *Regulation on categories, testing and classification of waste*, Official Gazette RS 56/2010 for inert waste. The obtained low heavy metal content in the bottom ash eluates enables its use in composites of various types, even when the bottom ash is applied in high percentage (e.g., composites for road construction have the bottom ash percentage in excess of 90 %).

The gamma spectrometric testing of bottom ash from TENT B and B TEKO (*Regulation on the control of goods at import, export and transit*, Official Gazette RS no. 44/11) was conducted in order to check radioactivity levels of the bottom ash. The results obtained for both bottom ashes are far below the limits of contamination, and the radionuclide content is low, so that both types of bottom ash can freely be used in building construction for interior and exterior applications, as well as in civil engineering.

Mineralogical analysis results show that quartz (86.4 %) and hematite (11.8 %) were predominantly detected in the bottom ash sample from TENT B, while dominant minerals in the bottom ash sample from TEKO B are albite (71.6 %), quartz (13.5 %), lime (6.8 %) and cristobalite (6.7 %). The percentage was given according to the overall crystal phase present in the bottom ash. The sample from TEKO B had a greater amount of the amorphous phase probably originating from the degraded clay phase, which is a characteristic feature of silicate ashes.

The particle size analysis revealed that bottom ash samples were considerably larger than the fly ash from the same thermal power plants. The particle size was in the range of 0,09mm to 8,0mm. The majority fraction's share of the bottom ash grains from TENT B was up to 1.0mm (80 % of all grains), while in the case of the bottom ash from TEKO B the distribution was more even (40 % of grains were smaller than 1mm, and 60 % were larger than 1mm). Particle size distribution of bottom ashes is given in Figure 1.

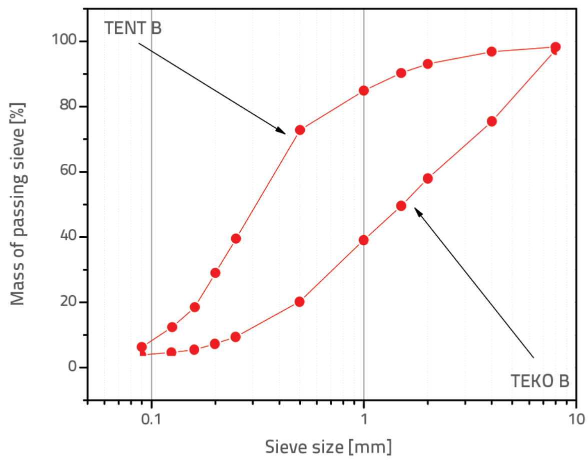


Figure 1. Particle size analysis of a bottom ash sample from TENT B and TEKO B

The physical and mechanical testing of bottom ash was conducted using methods specified in SRPS B.C1.018. The bulk density of bottom ash samples was 2.24g/cm^3 for TENT B and 2.42g/cm^3 for TEKO B. Pozzolanic activity determined on milled samples showed relatively low values of 6.1 and 4.6 MPa. Pozzolanic activity shows the possibility that silicon dioxide and aluminium oxide contained in the bottom ash will react with available calcium and/or magnesium from the hydrated products of Portland cement, i.e. lime (Table 2).

Table 2. Physical and mechanical properties of bottom ash from TENT B and TEKO B silos

	TENT B	TEKO B
Fineness of grind - sieve residue (milled sample) [%]		
0.2 mm 0.09 mm 0.063 mm 0.043 mm	0.0 1.0 3.0 9.0	0.0 0.0 3.2 11.5
Bulk density [g/cm^3]	2.24	2.42
Specific surface [cm^2/g]	4130	5110
Pozzolanic activity [MPa] - flexural strength - compressive strength	 2.2 6.1	 2.0 4.6

After the tests specified in standards were completed, it was revealed that bottom ashes from TENT B and TEKO B not only show good properties with regard to their use, but that they also meet most of the criteria set for fly ash.

2.2. Concrete mixtures

The testing of concrete with the bottom ash originating from the two thermal power plants TENT B and TEKO B was performed in order to investigate the possibilities of bottom ash application in prefabricated concrete products. The replacement of the fine fraction of aggregates 0/4 mm by 4 % 8 %, 12 % and 16 % of bottom ash was performed in both cases. The quantity of cement was 340 kg/m³, the maximum aggregate grain size was D_{max}=16 mm, and the consistency class by slump test was S3 (measured 5 minutes after the water was added). The aggregate mixture designed according to SRPS U.M1.057 is shown in Figure 2.

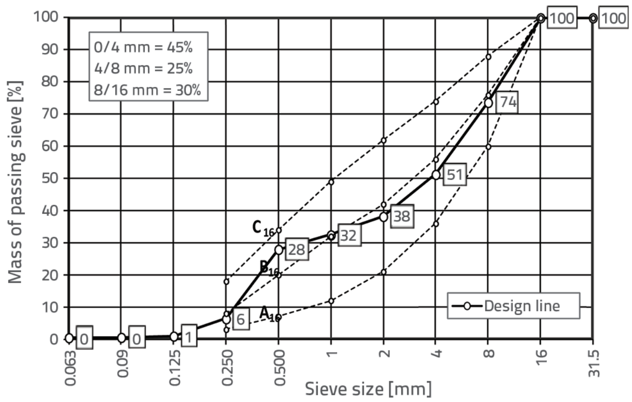


Figure 2. Aggregate mixture

The following materials were used in the testing:
- Cement – CEM I 42.5 R BFC Lafarge (Table 3)
- Aggregate - river, washed, separated, fractions 0/4, 4/8, 8/16, from the Danube
- Admixture - superplasticiser 0.65 % "Dinamon LZF 35" and air entraining agent 0.45 % "Mapeair LP 400", "MAPEI-Betontechnik GmbH", Austria
- Water - from the city water supply (tap water)
- Bottom ash - from the TPP "Nikola Tesla" B, Obrenovac (TENT B), and from the thermal power plant Kostolac B (TEKO B).

Concrete compositions are given in Table 4, and tested properties are presented in Table 5.

Table 3. Properties of cement

Chemical composition [%]	
SiO_2	21.05
Al_2O_3	4.73
Fe_2O_3	2.20
CaO	63.45
MgO	3.00
SO_3	3.20
S^{2-}	0.05
Na_2O	0.27
K_2O	0.52
MnO	0.075
L.O.I.	1.15
I.R.	0.62
$F.C_aO$	0.67
Physical properties of cement	
Specific gravity [kg/m³]	3130
Initial setting time [min]	160
Final setting time [min]	210
Specific surface (Blain) [cm²/g]	4010
Compressive strength of cement [MPa]	
2 days	33.8
7 days	44.8
28 days	54.4

Table 4. Concrete compositions

Concrete series		**Cement** [kg/m³]	**Bottom ash** [kg/m³]	**Aggregate fraction 0/4 mm**	**Admixture** [%]	
					superplasticiser	**air entraining agent**
Reference concrete		330	0	808.0	0.65	0.45
Bottom ash TENT B	4 %	330	32.3	775.7	0.65	0.45
	8 %	330	64.6	743.4	0.65	0.45
	12 %	330	97.0	711.0	0.65	0.45
	16 %	330	129.3	678.7	0.65	0.45
Bottom ash TEKO B	4 %	330	32.3	775.7	0.65	0.45
	8 %	330	64.6	743.4	0.65	0.45
	12 %	330	97.0	711.0	0.65	0.45
	16 %	330	129.3	678.7	0.65	0.45
Aggregat e = 1795 kg/m³, w/c = 0.448						

Table 5. Tested properties

Tested properties	Standard	Number of specimens
Fresh concrete		
Consistency	SRPS ISO 4109	1 sample in series
Bulk density	SRPS ISO 6276	1 sample in series
Entrained air content	SRPS ISO 4848	1 sample in series
Hardened concrete		
Bulk density	SRPS ISO 6275	3 samples of each age
Compressive strength	SRPS ISO 4012	3 samples of each age
Water penetration under pressure	SRPS U.M1.015	3 samples in 1 series
Frost resistance	SRPS U.M1.016	15 samples in 1 series
Resistance of concrete surface to frost and de-icing salts	SRPS U.M1.055	3 samples in 1 series

Table 6. The results of the testing of fresh concrete properties

Concrete series		Bulk density [kg/m³]	Consistency Δh [mm]	Air content [%]
Reference concrete		2280	160	4.5
Bottom ash TENT B	4 %	2279	140	4.9
	8 %	2280	135	4.7
	12 %	2284	150	5.0
	16 %	2268	150	5.8
Bottom ash TEKO B	4 %	2310	105	4.0
	8 %	2315	100	4.1
	12 %	2302	115	4.5
	16 %	2300	110	4.6

Table 7. Hardened concrete test results

Concrete series		Bulk density [kg/m³]	Compressive strength [N/mm²]	Depth of water penetration [mm]	Frost resistance	Resistance to frost and de-icing salts (degree of damage)
		28 days				
Reference concrete		2280	49.9	15	M-200	0
Bottom ash TENT B	4 %	2280	46.9	25	M-200	0
	8 %	2280	46.8	25	M-200	0
	12 %	2280	42.8	25	M-200	0
	16 %	2270	41.8	25	M-200	0
Bottom ash TEKO B	4 %	2310	48.6	15	M-200	0
	8 %	2320	48.4	10	M-200	0
	12 %	2300	47.7	20	M-200	0
	16 %	2300	47.0	20	M-200	0

3. Results and discussion

The results of the testing of fresh concrete properties are shown in Table 6 and hardened in Table 7.
Note: According to SRPS EN 206-1:2011, the recommended value for minimum air content is 4 % for exposure classes XF1 to XF4 (influence on freezing/thawing).

The water-cement ratio for all concretes was W/C=0.448, and the air content was greater than 4.0 %. Taking into account specific characteristics affecting durability of concrete, the testing involving the minimum amount of cement, water-cement ratio, and air content for exposure class XF 4 to freezing and thawing, was conducted in accordance with SRPS EN 206-1:2011 (environmental conditions which include a high water saturation with de-icing salts, for example, on slabs for roads and bridges.

According to this regulation, the strength class C 30/37 must also be achieved. The results obtained show that this objective has been attained. All tested samples complied with the resistance to frost class M-200.

There were no significant changes on the surface of all specimens tested for frost and de-icing salts after 30 cycles of freezing and thawing.

The changes in the compressive strength of concrete at the ages of 3, 7 and 28 days are shown in Figure 3.

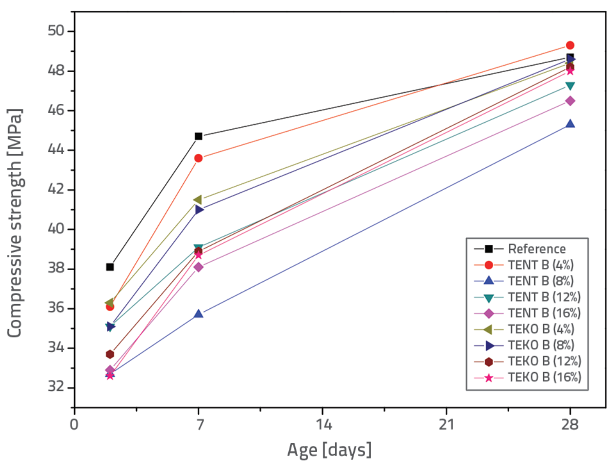


Figure 3. Compressive strength of concrete after 3, 7, and 28 days

Compressive strength results show that this strength tends to decrease with an increase in the percentage of replacement of a part of the fine fraction of aggregates by bottom ash in both cases.

The evaluation criteria are not determined in the standard according to which the pressurized water penetration depth was tested. The water penetration depth amounted to 25 mm for bottom ash TENT B, while it ranged from 10 mm to 20 mm for bottom ash TEKO B.

All samples tested for frost action met the criteria of SRPS U.M1.015 for conditioned resistance to frost action M-200.

All samples tested for resistance to frost and de-icing salts are resistant according to SRPS U.M1.055, the degree of damage being 0 (zero) - without flaking.

4. Conclusions

After completion of testing, it was concluded that the bottom ashes from thermal power plants TENT B and TEKO B can be used as a partial replacement of fine aggregate fractions in concrete. The following specific conclusions were made:

- the compressive strength results tend to decrease with an increase in the percentage of partial replacement of fine aggregate with bottom ash in both cases; individual results comply with MB 40 (C 30/37) requirements
- standard according to which the depth of water penetration under pressure was tested does not determine the criteria for evaluation; based on experience, it can be stated that test results are satisfactory
- all samples tested for frost action meet the criteria set in SRPS U.M1.015 for conditioned resistance to frost action M-200
- all samples tested for resistance to frost and de-icing salts are resistant according to criteria given in SRPS U.M1.055 (30 cycles), the degree of damage 0 (zero)-without flaking.

Since the results meet criteria of the regulations applicable for concrete, the use of the tested material in construction industry is considered justified. The bottom ash from TPP furnaces used in such a way ceases to be a by-product and gains a new value. From the ecological standpoint, this means reducing landfill areas, and thus reducing the risk of polluting and contaminating the environment, while also curbing consumption of non-renewable natural mineral resources.

Saving natural resources is an essential factor both in terms of economy and in terms of contribution to sustainable development.

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