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Road Concrete Containing Coal Ashes of Thermal Power Stations Located in Krasnoyarsk

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Abstract. The paper reports on outcomes of research into a road concrete containing coal ash powders of thermal power stations located in Krasnoyarsk. The study was focused on characteristics of a fly ash, and ash taken in an ash-disposal area of Krasnoyarsk Thermal Power Station 1, as well as ash of Beryozovskaya GRES. To compare characteristics a standard limestone powder was used. Physical and mechanical characteristics, chemical and mineral compositions of these powders were analyzed. Mineral powders differed in a concentration of free calcium oxide (CaOfr.). Samples of a fine-grained road concrete were composed and prepared using materials above. Physical and mechanical properties of formed road concrete samples were tested. A coefficient K was introduced to assess the relation between key characteristics of a road concrete mix and concentration of free calcium oxide, furthermore, it considers a percentage of CaOfr. in ash (m) and percentage of this ash in a road concrete (n), i.e. K= m·n. It has been established a coefficient K ranging 0 to 32 CaOfr. has no significant effect on characteristics of a road concrete mix. A fly ash and ash taken in an ash-disposal area of Krasnoyarsk thermal power station are recommended for the use in industry as a mineral powder in a road concrete mix. Additionally, ash taken in an ash-disposal area is to be dried and grinded, a maximal content of a fly ash in a road concrete mix is estimated to be 4% provided that a concentration of CaOfr. is less than 8%.

Introduction

To date, the demand for road-building materials has been increasing due to booming road construction in regions of Siberia and Far East. A shortage of such materials slows down dramatically construction works and makes them more cost intensive. The only way to accelerate construction works and reduce their cost price is to use local road construction materials, as well as industrial wastes and by-products [1-4]. Moreover, wastes are hazardous for the environment and their recycling requires considerable financial resources [5-7]. Nowadays, ash of thermal power stations is broadly used in construction [8-14].

Road building companies have been facing a significant mineral powder gap to produce road concrete mixes. Therefore, break stone and sand without mineral powders are frequently used for road concrete layers of automobile roadbeds. However, a mineral powder is well known to be important for characteristics of a road concrete mix. It is a granulometric additive to structure bitumen and form an asphalt-binding substance, which dominates density, strength, heat resistance and durability of a road concrete mix. It has been revealed powders produced via fine grinding of limestone, limestone rock and dolomites meet exactly the technical requirements. Unfortunately, there has been no centralized supply of reliable mineral powders in Krasnoyarsk Krai so far. According to specification of road concrete mixes industrial wastes can be used as mineral powders [15], but a concentration of free calcium oxide in them can't exceed 3%.

There is a lot of data in literature on the use of ashes taken in thermal power stations as a component of a road concrete mix [16-21], although authors have different attitudes to their influence on properties of road concrete.

This work aims to find out the effect of $CaO_{fr.}$ in ashes produced in Krasnoyarsk on characteristics of road concrete materials.

Materials and Methods

For the study we used the following raw materials:

1. Break stone – a coarse filler of a road concrete, produced via grinding of gravel to extract in an open mine "Peschanka", Krasnoyarsk.
2. Sand – sieving residue produced when grinding in an open mine "Peschanka". A size modulus of a sieving residue $M_s = 4.11$.
3. For the purpose of research we analyzed: a fly ash produced in Krasnoyarsk Thermal Power Station 1 (Sample 1); ash taken in an ash-disposal area of Krasnoyarsk Thermal Power Station 1 (Sample 2); a fly ash of Beryozovskaya GRES (Samples 3 and 4); limestone powder grinded in laboratory (Sample 5). Physical and mechanical characteristics of powders vs. requirements are given in Table 1.

Table 1. Physical and mechanical characteristics of powder wastes

Criterion	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Standard
1. Porosity in volume, %	42.37	18.48	26.8[illegible]	39.[illegible]	26.60	Max. 45
2. Water resistance coefficient of powder + bitumen samples	0.98	0.87	0.58	0.56	1.0	Min. 0.6
3. Bitumen content coefficient, g	63.21	66.17	[illegible]	71.07	38.82	Max. 100
4. Content by mass of water dissolvable compounds, %	2.35	2.2[illegible]	8.5	7.9	2.7	Max. 1
5. Loss by roasting, wt. %	1.02	13.57	0.57	6.46	38.47	Max. 20

As seen in the table, powder wastes meet all requirements, except ashes of Beryozovskaya GRES with a water resistance coefficient slightly below the required one. The content of water dissolvable compounds is abnormal in all wastes. Chemical compound of wastes was explored in X-ray analysis (Figures 1-5); their chemical composition is given in Table 2.

Table 2. Chemical composition of powders

Sample	Percentage of oxides							
	$CaO_{fr.}$	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	SO_3	Loss by roasting
1	[illegible]29	31.02	6.48	9.78	7.78	39.7	0.96	1.02
2	0.18	19.91	4.33	7.14	7.55	43.6	0.52	13.57
3	[illegible]	43.14	6.06	8.12	11.34	20.87	4.77	0.57
4	24.6	43.37	7.6	8.17	10.34	15.1	3.43	6.46
5	-	48.13	1.87	2.94	1.81	5.48	0.96	38.47

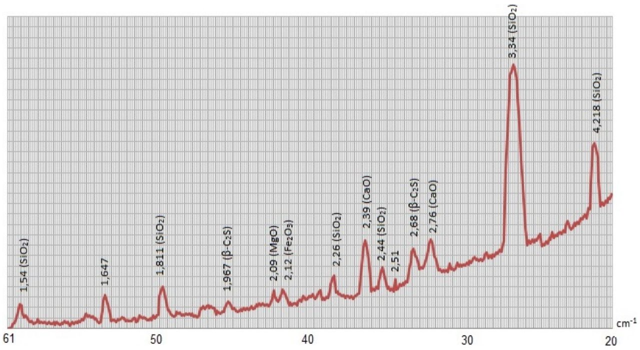

Figure 1. Diffraction pattern of a fly ash (Sample 1)

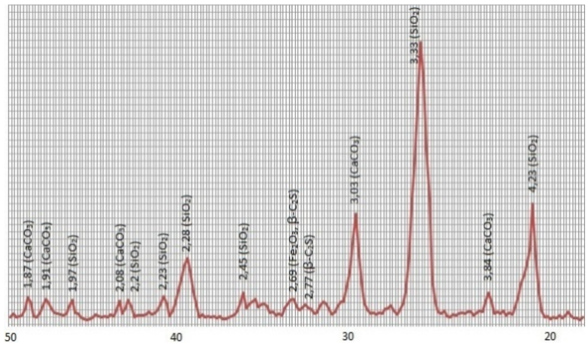

Figure 2. Diffraction pattern of ash taken in an ash-disposal (Sample 2).

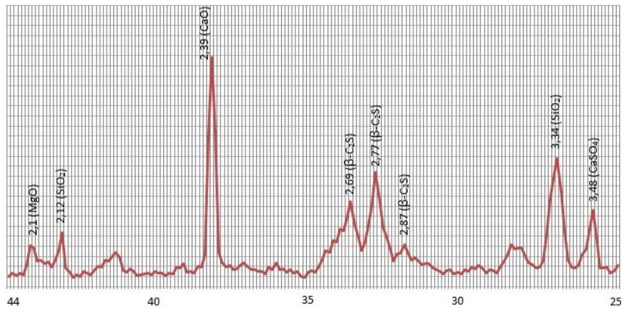

Figure 3. Diffraction pattern of a fly ash (Sample 3)

Figure 4. Diffraction pattern of a fly ash (Sample 4)

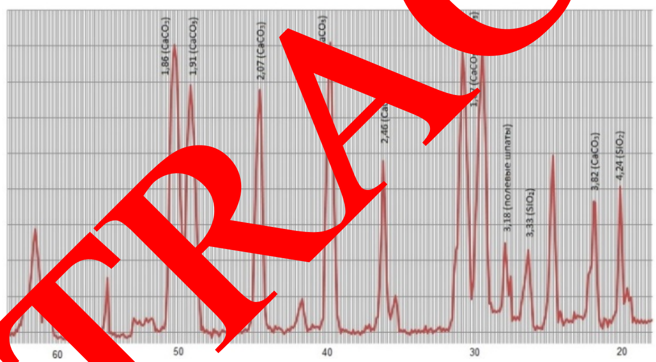

Figure 5. Diffraction pattern of a limestone powder (Sample 5)

The table shows that ashes of Beryozovskaya GRES contain a high amount of free calcium oxide, whereas it is not found in ash taken in an ash-disposal and in a limestone powder, its concentration in a fly ash produced in Thermal Power Station 1 is reasonable.

4. Bitumen. A road bitumen BND 90/130 (Achinsk Oil Processing Plant) was used to mix a road concrete material.

Results

A road concrete composition a was determined according to an appropriate ratio of components, this ratio is to provide a necessary density of the mineral base alongside with a required amount of bitumen and to mix a concrete material with specified technical characteristics.

Compositions of a fine-grained road concrete (Type B) used in the upper layer of roadbeds were found on the base of materials above. A mineral component of a road concrete was calculated with the help of limiting curves for dense-graded mixes.

As a result of composing road concrete mixes below were obtained (Table 3).

Table 3. Compounds of road concrete mixes

Components	Component percentage in a mix, %				
	A road concrete mix				
	1	2	3	4	5
Break stone	42.5	35.82	35	42.5	42.5
Sieving residue	46.9	51.18	55.9	46.63	46.63
Mineral powder	10.6	13	9.1	10.87	10.87
Bitumen	6.0	7	6.5	7	7

Hot road concrete mixes were prepared on the base of compositions above and samples were formed. Principal physical and mechanical characteristics of samples obtained were tested. Physical and mechanical characteristics of road concrete compositions under study were compared with standards for the second climatic zone and a high-grade road concrete material (Table 4).

Table 4. Physical and mechanical characteristics of a road concrete

Criteria	Mix					Standard
	1	2	3	4	5	
1. Ultimate compression strength, MPa, at temperatures:						
20°C,	4.82	4.46	4.55	[illegible]	[illegible]	Min. 2.5
50°C,	1.27	1.30	1.41	1.70	[illegible]	1.1
0°C	8.98	9.56	9.70	9.87	9.75	Max. 11
2. Water resistance coefficient	1.25	1.34	[illegible]	1.0	0.9	Min. 0.9
3. Water resistance coefficient in long-termed water saturation	1.1	[illegible]	0.79	0.8	0.86	Min. 0.85
4. Water absorption in vacuum in volume, %	2.9	3.0	2.22	2.9	1.99	-
5. Long-termed water absorption in volume, %	3.7	5.62	6.0	7.2	3.1	-

A coefficient K taking into consideration a percentage of $CaO_{fr.}$ in a certain industrial waste (m) and a percentage of this waste in a road concrete mix (n), i.e. K=m·n was introduced for deeper analysis of main road concrete characteristics vs. a concentration of $CaO_{fr.}$ in ashes. Table 5 provides the data on K in various road concrete compositions.

Discussion

The study has found the relevance of $CaO_{fr.}$ for the properties of a road concrete. A compression strength at 20°C of an ash-containing road concrete is slightly lower than that of a material with a limestone mineral powder (composition), being far higher than requirements indeed.

Table 5. Coefficient of $CaO_{fr.}$ in wastes

Road concrete	Concentration of CaO_{fr} in a waste, %	Concentration of a waste in road concrete, %	Coefficient K
1	7.29	10.6	77.27
2	0.18	13	2.34
3	21	9.1	191.1
4	24.6	10.87	267.42
5	2.94	10.87	31.95
6	0	10.87	0

Furthermore, the strength increases gradually for higher CaO_{fr} in a mix (ranging to K=32), and it falls at moderate rates for coefficients above K=32. At 50 °C strength of all ash-containing composites was higher than a specified one. The strength of ash-containing composites at 0 °C doesn't depend much on a concentration of $CaO_{fr.}$ in a mix, being similar to a limestone-based road concrete material and complying with the standards.

A water resistance coefficient of an ash-containing road concrete mix is better than that of a limestone-containing material. Interestingly, this coefficient rises for higher concentration of $CaO_{fr.}$, however, up to a value of K=32, with further gradual decrease. Probably, $CaO_{fr.}$ has a binding effect on a road concrete structure. In long-time water saturation $CaO_{fr.}$ has a weakening effect on the strength of a road concrete mix, and compositions 3 and 4 with higher $CaO_{fr.}$ concentration don't meet the State Standard specifications. Water absorption of ash-containing composites is higher than of limestone-based ones, being though above the required.

So, a coefficient K of CaO_{fr} ranging 0 to 32 hardly influences characteristics of a road concrete mix, improving even some of them (water resistance in vacuum).

In terms of laboratory experiments a grinded and dried ash taken in an ash-disposal area of Krasnoyarsk Thermal Power Station 1 is recommended for the use in industry, as well as a fly ash of the same thermal power station unless its maximal concentration in a road concrete mix is below 4 %. A fly ash produced in Beryozovskaya GRES can't be used as a mineral powder in a road concrete mix because of a high CaO_{fr} concentration.

Conclusion

1. Compositions of a fine-grained hot road concrete were analyzed; a fly ash produced in Krasnoyarsk Thermal Power Station 1, ash taken in an ash-disposal of Krasnoyarsk Thermal Power Station 1, and ash produced in Beryozovskaya GRES were used as mineral fillers. A limestone mineral powder was accepted as a standard one. Mineral powders differed in a concentration of $CaO_{fr.}$
2. The study found the influence of $CaO_{fr.}$ on characteristics of a road concrete mix. At temperatures of 20 and 50°C the strength of an ash-containing road concrete mix is a little lower that that of limestone-containing samples but much better than that of a standard mineral powder. At 0°C compositions based on ashes of Krasnoyarsk Thermal Power Station have a worse strength than in limestone-based compositions, so their potential of deformation is higher at temperatures below zero.
3. A coefficient of water resistance in vacuum of all ash-containing road concrete mixes is better than in a limestone-containing material. The reason, probably, is a binding effect of $CaO_{fr.}$ on the structure of a road concrete mix.
4. $CaO_{fr.}$ affects significantly a coefficient of water resistance under long-time water saturation. However, compositions containing a fly ash and ash taken in an ash-disposal area of Krasnoyarsk Thermal Power Station meet the requirements to this parameter.
5. Assessing long-time water absorption, porosity of a fly ash produced in Beryozovskaya GRES and ash taken in an ash-disposal area is higher than in limestone-based compositions because of a higher $CaO_{fr.}$ concentration.
6. A coefficient K, being a product of CaO_{fr} .percentage in a waste and a percentage of this waste in a road concrete mix was introduced to determine how main characteristics to be studied depend on $CaO_{fr.}$ concentration in powder wastes. The work has established a coefficient K ranging 0 to 32 $CaO_{fr.}$ has no significant effect on characteristics of a road concrete mix.
7. A fly ash and ash taken in an ash-disposal area of Krasnoyarsk Thermal Power Station 1 are recommended for the use in industry as a mineral powder of a road concrete mix. Additionally, ash taken in an ash-disposal area is to be dried and grinded, a maximal content of a fly ash in a road concrete mix is 4% unless a concentration of $CaO_{fr.}$ in it is above 8%.

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