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The FBC ash as a hydraulic ingredient of hydraulic lime

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Abstract

This work is focused on the possibilities of utilization of ashes from fluidized bed combustion, i.e. FBC ashes, for the manufacturing of hydraulic lime. Alternative hydraulic binders are becoming very popular in the present due to requirements on reducing CO_2 emissions. FBC ash is an easily available, though not easily usable raw material. Because it has several hydraulic characteristics, it can create a hydraulic binder together with lime. Mixtures of hydrated lime and FBC ash from filters and from a bed were prepared in this work. The main criterion was the hydraulic modulus. The physico-mechanical properties were observed and were compared with the reference sample, which was hydraulic lime from industrial production. The prepared hydraulic limes achieved similar parameters as commercially manufactured hydraulic limes or lower strength class cements.

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Keywords: FBC Ash; hydraulic lime; ettringite.

1. Introduction

Increased emphasis has been put on the use of secondary materials in all industries recently. In the building industry, these substances are used in the production of tiles, fillers, but also in the production of binders. In the case of binders they are used as a substitution for primary raw materials. A large number of the different authors are currently focused on the utilization and processing of various kinds of secondary materials in [1-4]. One of the interesting and important materials is fly ash from fluidized bed combustion (FBC Ash). Mineralogically this material consists of quartz, amorphous aluminosilicate phases, insoluble anhydrite and calcium oxide. Because of the mineralogical composition and mainly due to the formation of ettringite during hydration this material has some hydraulic properties. But its

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direct use as a binder is highly risky mainly due to considerable thermodynamic instability of ettringite. However, it can be assumed that both of the basic properties of FBC ash, i.e. hydraulic properties and volumetric expansion, could be advantageously used in the preparation of hydraulic limes. FBC ash might improve the strength and volume stability of lime while maintaining good plasticity too [5]. Hydraulic limes are well defined in EN 459-1 [6]. Based on the hydraulic lime definition in this standard, the preparation of hydraulic lime based on FBC ash seems to be possible. The only problem may be the content of SO_3. The standard allows producing lime containing up to 3 % SO_3. However, the SO_3 content can be increased up to 7 % while meeting test volume stability.

2. Material and methods

A total of eight samples of hydraulic limes were prepared in this work. Four samples based on FBC ash from the bed part of a furnace and four samples based on FBC ash from the filter part of a furnace were prepared. FBC ash has been produced by the power plant Tisova, for chemical composition, see Table 1.

Table 1. Chemical composition of the FBC Ashes Tisova.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	Others
Filter FBC ash	42.70	19.22	4.64	17.78	9.20	6.44
Bed FBC ash	36.68	18.70	7.22	20.80	8.62	7.95

First, granulometry was determined for FBC ash from the filter by the sieve test. The residues on the sieves 0.125; 0.09 and 0.063 mm were measured. The FBC ash from the bed had to be ground in a laboratory ball mill OM BRIO 20 to approximately the same residue on the 0.09 mm sieve. The hydraulic lime samples were created by mixing FBC ash and hydrated lime CL 90 S from the lime plant Vitosov. The mutual mixing ratio between the FBC ash and hydrated lime was first determined for hydraulic modulus of MH = 1.7 and 3. These values correspond to the upper limit of the hydraulic modulus which determines strongly hydraulic limes. The FBC ash and lime ratios were calculated for both the selected hydraulic modules. Subsequently these ratios have been rounded to a technically acceptable value. For these rounded dose ratios, the degree of the lime saturation factor according to Kühl and hydraulic modules were re-calculated. The dose ratios and calculated values of the hydraulic modules and lime saturation factor are presented in Table 2.

Table 2. The dose ratio of the FBC ash and hydrated lime.

Parameter	**M_H = 1.7**		**M_H = 3.0**	
	Filter FBC ash	Bed FBC ash	Filter FBC ash	Bed FBC ash
Sample	F1.7	L1.7	F3.0	L3.0
FBC ash : lime ratio	1:1.25	1:1.25	1:2.5	1:2.5
Content of the FBC ash [%]	44.5	44.5	28.5	28.5
Content of the lime [%]	55.5	55.5	71.5	71.5
Hydraulic modulus M_H	1.95	2.15	3.14	2.90
Lime saturation factor	1.06	0.93	1.46	1.30

The vertical laboratory homogenizer was used for homogenizing all the samples. Homogenization was carried out for 1 hour at about 20 kg. The technological properties have been determined for all the samples. At first, the residues on sieves 0.125; 0.09 and 0.063 mm were measured for all prepared mixtures. Next, the water/cement ratio, initial and final setting time according to CSN EN 196-3 [7] were determined. The prisms with dimensions of 20 × 20 × 100 mm were manufactured to determine the compressive strength. The samples were stored in two different conditions; wet and dry. In the wet conditions the relative humidity was higher than 90% and the temperature was 21°C. In the dry conditions the temperature was also 21 °C but the relative humidity has been only 40 %. The compressive strength was determined at times 1, 3, 7, 14, 28 and 56 days.

Due to the higher content of SO_3 in the mixtures, the samples were subjected to determination of soundness by the modified soundness test according to EN 459-2 article 5.3.2.3 [8]. Test specimens were placed in the same environments as the samples for determination of compressive strength. Expansion was assessed visually in accordance with the procedure specified in the standard. However, the test was extended onto the assessment of the shrinkage. The change in two perpendicular diameters of the testing lime cake before and after hardening was evaluated. Based on the technological tests results of the hydraulic limes which have been described above, the second step was done. The mixing ratio between FBC ash and hydrated lime was redistributed in favor of FBC ash, and the mixtures with an increased proportion of FBC ash were designed and prepared. The dose ratios and calculated values of the hydraulic modules and lime saturation factor are presented in Table 3.

Table 3. The dose ratio of the FBC ash and hydrated lime - additionally designed ratios.

Parameter	**M_H = 1.0**		**M_H = 1.3**	
	Filter FBC ash	Bed FBC ash	Filter FBC ash	Bed FBC ash
Sample	F1.0	L1.0	F1.3	L1.3
FBC ash : lime ratio	1 : 0.625	1 : 0.625	1 : 0.83	1 : 0.83
Content of the FBC ash [%]	61.5	61.5	54.5	54.5
Content of the lime [%]	38.5	38.5	45.5	45.5
Hydraulic modulus M_H	1.02	0.94	1.26	1.17
Lime saturation factor	0.64	0.55	0.78	0.69

The procedure of designing and testing the new mixtures was the same as in the previous case.

The same technological tests were carried out on the reference samples besides the newly designed hydraulic lime samples. The commercial hydraulic lime HL-5 (sample HV) and hydrated lime CL-90 -S Vitosov (Sample VV) were chosen as a reference.

3. Results and discussion

The results of the granulometry tests of the input materials are summarized in Table 4.

Table 4. Granulometry of the input materials.

Monitored property	Hydrated lime (VV)	Filter FBC ash	Bed FBC ash (milled)
Residue on sieve [%]			
0.125 mm	0.0%	0.0%	0.0%
0.09 mm	4.2%	2.1%	3.3%
0.063 mm	8.1%	5.2%	11.0%

The residue on the sieve of 0.09 mm was chosen as the benchmark. For this size of sieve, the same values of the residue on sieve were achieved for both tested ashes. However, it is apparent that the FBC ash from the bed showed a significantly higher proportion of particles larger than 0.063 mm than the sample from the filter.

The results of the granulometric analysis of the homogenized mixtures and reference materials are shown in Tables 5 and 6.

Table 5. Granulometry of the hydraulic lime based on filter FBC ash.

Monitored property	HV	VV	F3.0	F1.7	F1.3	F1.0
Residue on sieve [%]						
0.125 mm	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.09 mm	2.2%	4.2%	3.6%	3.3%	3.1%	2.9%
0.063 mm	4.2%	8.1%	7.3%	6.8%	6.5%	6.2%

Table 6. Granulometry of the hydraulic lime based on bed FBC ash.

Monitored property	HV	VV	L3.0	L1.7	L1.3	L1.0
Residue on sieve [%]						
0.125 mm	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.09 mm	2.2%	4.2%	3.9%	3.8%	3.8%	3.6%
0.063 mm	4.2%	8.1%	9.5%	10.2%	10.8%	11.1%

The results correspond to the input material properties. The samples based on FBC ash from the bed contained fewer fine particles than the samples based on filter ash. This phenomenon then influenced the results of physical and mechanical tests.

The values of water cement ratio of the samples with ash from bed were significantly lower than in the case of the samples based on filter FBC ash, see Table 7 and 8.

Table 7. Water/cement ratio and setting time of the Filter FBC ash based lime.

Monitored property	HV	VV	F3.0	F1.7	F1.3	F1.0
Water/cement ratio	0.58	0.95	0.72	0.71	0.81	0.86
Initial setting time [h:min]	1:35	46:00	1:40	1:30	1:30	1:45
Final setting time [h:min]	8:30	72:00	18:30	7:30	13:15	9:30

Table 8. Water/cement ratio and setting time of the Bed FBC ash based lime.

Monitored property	HV	VV	L3.0	L1.7	L1.3	L1.0
Water/cement ratio	0.58	0.95	0.67	0.60	0.66	0.62
Initial setting time [h:min]	1:35	46:00	2:30	2:20	3:30	5:45
Final setting time [h:min]	8:30	72:00	20:00	18:30	18:45	17:45

No correlation relation among the samples with different mixing ratio of the two basic components and their water/cement ratio has been found. The reason was probably the fact that samples with higher content of hydrated lime than ash behaved more like lime than cement and the testing method seemed to be inappropriate in this case, because the method prescribed in the standard for determining water cement ratio of hydraulic limes by Vicat apparatus is designed for cement and materials similar to cement. The second negative effect was the strong thixotropic behavior of the samples.

Likewise, the Vicat apparatus was not suitable for the setting time determination of the samples with predominant content of lime. Therefore it can be said that the closest setting time to the reference hydraulic lime HL5 was achieved by sample F1.7 which is based on filter FBC ash. A positive finding was that none of the tested mixtures exceeded setting time of 20 hours.

The results of physical and mechanical tests of both types of mixtures in the two different environments are presented in Tables 9 to 12.

Table 9. Technological properties, Filter FBC ash, dry conditions.

Monitored property	HV	VV	F3.0	F1.7	F1.3	F1.0
Soundness						
expansion after 28 days	passed	passed	passed	passed	passed	passed
shrinkage after 28 days[%]	5.3	7.2	3.0	3.2	3.1	3.0
Compressive strength [MPa]						
1 day	1.5	0.0	0.6	0.9	0.5	0.5
3 days	2.9	0.6	1.1	1.2	1.4	1.3
7 days	3.8	0.7	1.3	2.2	1.6	1.6
14 days	5.5	1.0	1.9	3.0	2.2	2.0

28 days	5.8	2.1	2.1	3.6	2.5	2.4
56 days	6.3	2.9	2.7	4.7	3.3	3.8

Table 10. Technological properties, Filter FBC ash, wet conditions.

The monitored property	HV	VV	F3.0	F1.7	F1.3	F1.0
Soundness						
expansion after 28 days	passed	-	passed	passed	passed	passed
shrinkage after 28 days[%]	2.3	-	1.4	1.5	1.1	0.9
Compressive strength [MPa]						
1 day	1.6	-	0.7	0.8	0.5	0.5
3 days	2.5	-	1.1	1.4	1.0	1.5
7 days	4.1	-	2.1	4.5	3.1	3.9
14 days	7.0	-	3.2	7.2	4.4	6.4
28 days	10.9	-	5.2	11.3	6.8	9.0
56 days	15.4	-	6.2	11.5	9.8	12.6

Table 11. Technological properties, Bed FBC ash, dry conditions.

The monitored property	HV	VV	L3.0	L1.7	L1.3	L1.0
Soundness						
expansion after 28 days	passed	passed	passed	passed	passed	passed
shrinkage after 28 days[%]	5.3	7.2	3.8	3.6	3.8	3.8
Compressive strength [MPa]						
1 day	1.5	0.0	0.7	0.8	0.4	0.4
3 days	2.9	0.6	1.3	1.3	0.9	0.8
7 days	3.8	0.7	1.6	1.7	1.9	1.5
14 days	5.5	1.0	2.2	2.7	2.4	3.0
28 days	5.8	2.1	2.5	3.0	2.8	3.5
56 days	6.3	2.9	2.9	3.4	3.3	4.6

Table 12. Technological properties, Bed FBC ash, wet conditions.

The monitored property	HV	VV	L3.0	L1.7	L1.3	L1.0
Soundness						
expansion after 28 days	passed	-	passed	passed	passed	passed
shrinkage after 28 days[%]	2.3	-	1.4	0.8	0.6	0.4
Compressive strength [MPa]						
1 day	1.6	-	0.7	0.8	0.5	0.4
3 days	2.5	-	1.0	1.3	1.0	1.0
7 days	4.1	-	1.6	2.7	2.1	2.5
14 days	7.0	-	3.7	5.5	4.0	5.0
28 days	10.9	-	6.0	11.5	9.5	11.5
56 days	15.4	-	9.9	16.8	18.3	19.7

As regards compressive strength, the samples based on filter FBC ash achieved slightly higher initial value, both in dry and in wet conditions than the samples with ash from the bed. However, after 28 days of hydration, the situation was rather opposite. The compressive strength of the samples with FBC ash from the bed was slightly higher compared to the samples manufactured from filter ash. This difference was more pronounced after 56 days of hydration. All the performed tests also showed that all the prepared mixtures behaved more like hydraulic binder than non-hydraulic binder. Because the compressive strength of the samples stored in wet conditions achieved five times higher values compared to the samples stored in dry conditions. Regarding the influence of dosage ratio of FBC ash and hydrated lime in the mixtures it can be said that the lowest strength was always exhibited by F3.0 sample, i.e. a sample with the lowest content of FBC ash from the filter. With gradual increase of the ash content in the sample, an abrupt increase of the compressive strengths was recorded for the dosage ratio of 1: 1.25. The observed increase in strength was negligible when increasing amounts of the ash above the previously mentioned ratio. From the standpoint of the compressive strength, the sample L1.0 seemed to be most appropriate, because after 56 days of hydration in wet conditions it achieved a strength of about 20 MPa. The question of its volume changes is considered as a serious usability parameter of the FBC ash for the preparation of hydraulic binders. Therefore, the soundness test was performed for all the samples. The results can be positively evaluated in terms of the applicability of the tested hydraulic limes. It was found that samples did not show expansion, but on the contrary, low shrinkage, which has been much lower than for the reference sample of hydrated lime VV and even lower than in the case of the sample of reference hydraulic lime HL5. The considerable shrinkage of hydrated lime and, on the other hand, considerable expansion of FBC ash positively compensated the volume changes of the tested hydraulic limes.

3. Conclusion

In conclusion we can say that the FBC ash would be a suitable raw material for the production of hydraulic lime. Despite the higher SO_3 content in the prepared mixtures, the samples have not showed any expansion. Compared to the reference, the shrinkage of the samples has been reduced in both tested environments, i.e. in wet and in dry conditions. The FBC ash from the bed seemed to be more advantageous in terms of physical and mechanical properties. The samples prepared from this kind of ash achieved final compressive strength of a similar level as the reference lime HL5. However, there is the question of its treatment by grinding. The grinding is a relatively energy-intensive process. Therefore FBC ash from the filter can be considered preferable. The mechanical strength was slightly lower and shrinkage was slightly higher than in the case of FBC ash from the bed, but without any need to refine the ash before use. The final physical and mechanical properties of the binder based on filter FBC ash were sufficient for the HL5 class of hydraulic lime. All the experimental work confirmed the usability of the FBC ashes for the preparation of hydraulic limes. However, it will be necessary to focus on the thermodynamic stability of these binders and consequently on their long-term durability.

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