On the Workability of Mortar and Concrete Mixtures containing Calcined Clay Blends

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Abstract. Calcined Clays can be used in mortar and concretes as a part of a binder (LC^3) or as a Supplementary Cementing Material (SCM). The aim here is to substitute fly ash as an additive in concrete recipes. A stable mixture between two regionally available clays, burnt together with a certain ratio of 60 : 40 wt.-% at 650-680°C, could be produced. Such Metaclays produced in larger amounts were investigated in different mortar and concrete mixtures. The production indicates an important problem with the workability of the fresh concrete mixtures. That`s why different superplastizers were tested. It could be found that especially a mixture between a PCE- based material and a special additive, developed for loam sands provides very good results. The workability increases from less than 200 mm slump on a value of about 300 mm. The combination of calcined clay materials and special developed superplastizer mixtures allows producing concrete with very different properties. It can be a closed system for the production of durable concrete structures.

Keywords: Calcined clay mixtures, Supplementary cementing material, workability, superplastizers mixtures, precast concrete elements

1 Introduction

The goal for the performed investigations is to substitute fly ash as an additive in concrete recipes. Already in some years, one type of certificated fly ash in Germany will then no longer be available, as the power plant will be closed. Therefore, it is necessary to find substitute materials with same or even better properties. One of them can be Calcined Clay.

Calcined Clay is the main term for a group of substances consisting of thermally treated clay materials. An important representative of this group is metakaolin. The formation of metakaolin, the common material for use as a pozzolanic reactant in cement or concrete structures, is connected to relatively pure raw clays consisted of kaolinite with a content of more than 90%. Because of the calcination process at approx. 750 to 800°C, metakaolin is formed by destruction of the crystal structure of the kaolinite mineral. But also other not so pure clay materials are in the focus of the international research. Here in this paper the name “Metaclay” is used for such materials.

During the last decades many researchers have been dealed with metaclay materials in order to reduce CO_2 emissions and to increase the strength and durability of mortars and concretes [1,2,3]. Already in 1995, 25 years ago, this subject was part of the research work summarized in [4]. Investigations of special mixtures of clay minerals were performed too to improve the pozzolanic properties [5,6]. Exactly this idea was taken up for the research presented here. First results have been described in [7].

In the meantime, a stable mixture between two regionally available clays, burnt together with a certain ratio of 60/40 wt.-% at 650-680°C, could be developed. In cooperation with a regional company the production reaches a technical scale of approx. several 100 kilograms of calcined clay materials. With this amount, also larger formatted concrete samples are available.

What works in the lab does not have to work in the field. The large production indicates an important problem with the workability of the fresh concrete mixtures. This is a problem described in the literature too. Certain "old" and "new" superplastizers were tested and obviously different results were obtained. In [8] a good workability was reached by using Superplastizers based on ligninsulphonate. Other researcher [9] reported on the good effectiveness of PCE-based superplastizers added to calcined clay limestone cement mixtures.

Because of contradictory results by using superplastizers in combination with calcined clay mixtures each calcined clay material requires obviously its special component. That`s why a comprehensive program for testing different superplastizers were performed.

2 Materials used

The investigations were made with four different groups of superplastizers.

- on the basis of PCE from different producers,
- on the basis of ligninsulphonate,
- on the basis of mixtures between both,
- and additionally a special additive, developed for loam containing sands (sand blocker system).

The reference recipes were well-known fly ash containing concrete mixtures. The new mixture should indicate a same or better workability behavior.

The workability was measured very easy by determination of the slump using a so called "Haegermann" table for mortar and a larger spreading table for concrete mixtures. On selected mixtures additionally, the setting behavior was pursued by using the ultrasonic technique. Investigations in the Lab but also investigations in the field (performed in cooperation with the company) were realized. Mortar prisms, and also, concrete samples were produce to find out the best recipes or the most effective SP-materials. **Table 1** summarizes the superplastizers used in the Lab und also in the Field.

Table 1. Superplastizers chosen.

material	SP1	SP2	SP3	SP4	SP5
name	ACE455	334 BV	22 BV	SBS 8005	18 BV
basis	PCE	Na-Lignin-sulphonate	PCE+Lignin-sulphonate	Sand blocker system	Mg-Lignin-sulphonate
effect as	FM	BV	VZ/BV/FM	SB	BV

FM: superplastizers; BV: condenser; VZ: retarder; SB: sand blocker

It is very difficult to get information on the composition of superplastizers used in this project. The manufacturer advertises e.g. with a special developed sand blocker system for layer silicate structure substances, which is very useful for highly clay containing sands. The focus lays also on the use of substances containing ligninsulphonate because of results and advertises from the literature.

To determine the influence of the cement strength two cements with a strength class of 42.5 N/mm^2 and 52.5 N/mm^2 according to the European standard EN 197 were selected. Data of the Calcined Clay material used here as a substitute for fly ash can be taken from [7].

3 Performance

Investigations were performed as well in the Lab (slump experiments) as also in the Field (in cooperation with the company). The last one means, that large concrete samples were produced under real production conditions. **Table 2** contains the recipes for determination of the slump in the Lab. In a first step, the pure substances were tested and the slump were determined. The activity index f was defined with 0.4, equal to fly ash. In a second step, also because of an economic view, mixtures of superplastizers were investigated.

Table 2. Recipes of the laboratory investigations.

Cement type	42.5 / 52.5	42.5 / 52.5	42.5 / 52.5
Volume [L]	0.77	0.77	0.77
Cement [g]	450	450	450
Water [g]	225	250	250
Aggregate	1056	850	850
Fly ash	-	112	-
Calcined clay	-	-	112
w/(z+k*f)	0.5	0.5 (f=0.4)	0.5 (f=0.4)

The dosages of superplastizers used can be taken from **Table 3**. According to the information of the producers the amount varies from SP to SP. Additionally Min-, Med- and Max-values were selected for producing mortar prisms.

Table 3. Dosages of superplastizers.

	min.[wt.%]	min. [g]	med.[wt.%]	med. [g]	max.[wt.%]	max. [g]
MS SBS 8005	0.20	0.90	0.85	3.82	1.50	6.74
MP 18 BV	0.10	0.45	0.50	2.25	0.90	4.04
MP 22 BV	0.20	0.90	1.10	4.94	2.00	8.98
MP 334 BV	0.10	0.45	0.55	2.47	1.00	4.49

Additionally mixtures between different SP`s in all possible ratios (Min-Min, Min-Med, Min-Max) were investigated.
Based on the results in the Lab a large investigation program was performed in cooperation with the practical partner. Recipes are summarized in **Table 4**.

Table 4. Investigation in cooperation with the company.

components	SP [wt.% of cement	Volume	density ϱ	Mass for 1 m³ concrete	Mass for 30 Liter mixture
units		dm³	kg/dm³	kg	kg
sand, 0-2mm		259.70	2.63	683	20.49
gravelsand 2-8		102.67	2.62	269	8.07
gravel 8-16		321.29	2.63	845	25.35
CEM I 52.5 R		90.32	3.1	280	8.4
Fresh water		162.00	1	162	4.86
Fly ash or Calcined Clay		32.41	2.16	70	2.1
ACE 455	0.7	1.81	1.08	1.96	0.0588
MS SBS 8005	0.4	1.02	1.1	1.12	0.0336
Air void		28.78	0	0	0
sum		1000		2312.08	69.39

4 Results

4.1 Slump/Spreading behavior/

Fig. 1 shows the results of the slump of samples produced in laboratory. It can be observed that an effect to improve the workability can be measured with every material. Especially MS SBS 8005 shows a strong increase of the slump, but also the other substances reach the reference mixture with fly ash. In general, the values are a little bit too high because of the high amount of water inside of the mixtures.

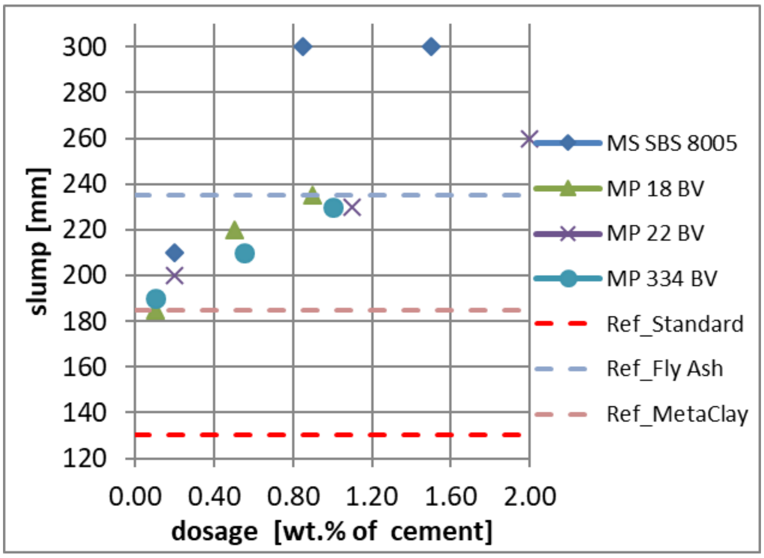

Fig. 1: Slump of samples produced with different superplastizers

Because of the fact that MS SBS 8005 provides very good results, also mixtures between some SP were investigated. The background here is an economical view too because SBS 8005 is very expensive. **Fig. 2** shows the results of these investigations. A minimum concentration of SBS 8005 combined with a middle concentration of MP BV 22 or 334 provides results, which are equal to the reference recipe with fly ash.

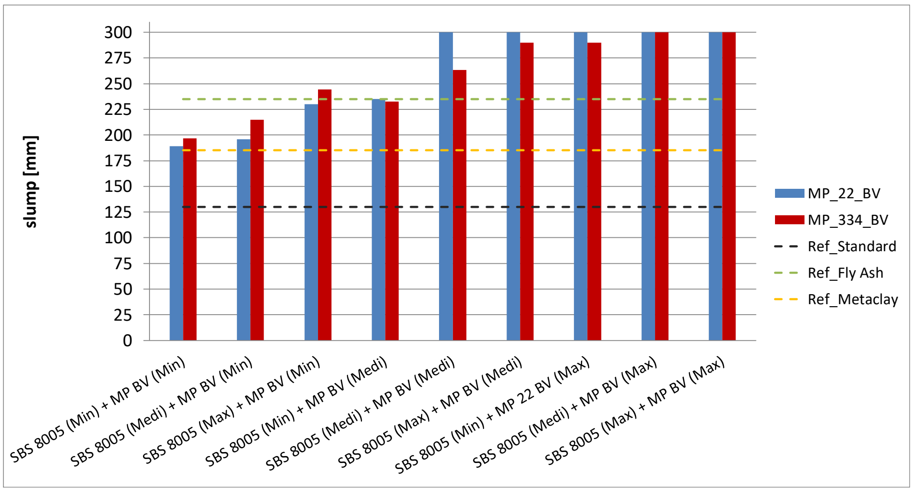

Fig. 2: Slump of samples produced with different superplastizers in mixtures

Therefore the amount of SBS 8005 can be reduced and extended by a cheaper SP substance.

4.2 Dynamical Modulus of Elasticity of mortar samples

Fig. 3 contains data of the evaluation of the dynamical modulus of elasticity of produces mortar samples. The behavior is equal to the reference mixtures and confirm the principal suitability of recipes developed in the laboratory.

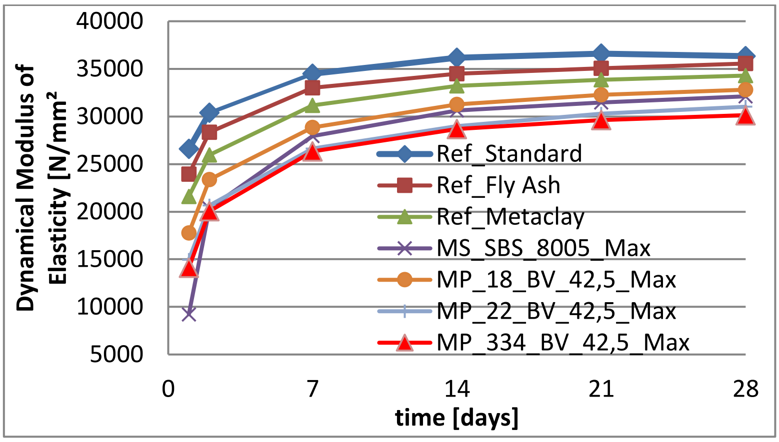

Fig. 3: Dynamical Modulus of Elasticity of mortar samples investigated

4.3 Production of precast concrete samples

Table 5 summarizes experiences of the company when dealing with different superplastizers. SP`s were also used in mixtures based on the results of the laboratory investigations. In total more than 20 different recipes were tested by the company. Three of them were selected producing larger formatted concrete samples. Because of many years of use, the superplastizers ACE 455 was also included in the study program.

Table 5: Recipes for practical use

No.	recipe	superplas-tizer	SP type	dosage wt.-%	slump [cm]	observations
1	**ref fly ash**	**ACE 455**	**FM**	**0.9**	**62**	**good cohesiveness**
2	FDW recipe Metaclay	ACE 455	FM	0.9	50	good cohesiveness
3	FDW recipe Metaclay	MP 334 BV	BV	0.9	34	not suitable, stiff
4	FDW recipe Metaclay	MP 22 BV	VZ/BV/FM	0.9	31	not suitable, stiff
5	FDW recipe Metaclay	SBS 8005	SBS	0.9	52	good cohesiveness
16	**FDW recipe Metaclay**	**ACE 455**	**FM**	**0.7**	**58**	**good cohesiveness**
		SBS 8005	**SBS**	**0.4**		
18	**FDW recipe Metaclay**	**MP 22 BV**	**VZ/BV/FM**	**1.5**	**53**	**very soft, particular frothed**
		SBS 8005	**SBS**	**0.5**		

Concrete samples (see **Fig. 4**) were produced using recipe No. 1, No. 16 and No. 18 because of the best workability and stability values. There are no significant differences in the concrete structure however in the surface quality of the samples. The surface has a great importance for the production of precast elements, that`s why different technologies to smooth the surfaces were applied (with hand, with a plate or an impeller smoother). One half of the plates were produced with, the other without reinforcement.

Fig. 4: Precast elements produced with different recipes

Values of the compressive strength are satisfactory. While recipe No. 1 (reference with fly ash) reaches values of approx. 62-64 N/mm^2 the values of the recipes No 16 and No 18 are a little bit among them and reaches 57 N/mm^2 (No. 16) and 53 N/mm^2 (No. 18). Actually precast elements produced store under the same conditions as the normal produced one to compare the shrinkage and durability behavior.

5 Conclusions

1. A specially developed Calcined Clay mixture between two different clays, burnt at temperature of approx. 650-680°C is suitable for using as SCM in concretes.
2. Because of the Calcined Clay structure, sometimes the workability is a problem for producers of precast concrete elements.
3. Different superplastizers with different compositions and molecule structures were tested, because some information from the literature are contradictorily.
4. The combination of Calcined Clay materials and special developed superplastizers mixtures allows producing concrete with different properties.
5. Results obtained in the Lab cannot transform in a direct way to the conditions in the company, that`s why the recipes from the Lab have to be tested under production conditions.
6. It can be summarized that a substitution of fly ash by Calcined Clay materials using a special mixture of superplastizers is possible and allows producing large formatted precast elements with equal properties.

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