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SHORT REPORT

F 960

Combined Applications of Fly Ash and Ground Granulated Blast Furnace Slag as Concrete Additives

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1 AIM OF THE RESEARCH PROJECT

Within this research project basic investigations on the combined use of fly ash (FA) and ground granulated blast furnace slag (GGBFS) in concrete were carried out. On the one hand it should be demonstrated that concretes, which are produced with fly ash and GGBFS as concrete additives, meet the requirements of European Standards /DIN08, DIN05b/. On the other hand they should have comparable fresh and hardened concrete properties as concretes made of blast furnace slag cement and fly ash. Further the influence of raw material fluctuations, caused by the production process, on the fresh and hardened concrete properties should be detected. By the target-oriented use of FA and GGBFS a higher quality of building materials and components was expected. Here the potential of binder optimization should be estimated.

2 REALIZATION OF THE RESEARCH PROJECT

The research project was divided into four phases. In phase 1 several raw materials were characterized. In the second phase of the project it should be demonstrated that mortars containing cement, fly ash and GGBFS have comparable fresh and hardened mortar properties as mortars with slag cement and fly ash. The tests were performed according to /DIN05a/ on CEN standard mortars. In the last phase of the project it was examined whether the results obtained at mortar scale can be transferred to concrete. Another step was the optimization of the granulometric size distribution curve for exploiting the full potential of target-oriented combination of the raw materials with varying fineness.

Furthermore investigations on the influence of fluctuations of the raw materials, which are caused by the production process, on the fresh and hardened properties were conducted. Therefore, within half a year monthly batches of raw materials were taken and mortars of the same composition were produced and compared.

3 SUMMARY OF THE RESULTS

In phase 1 first different raw materials were characterized and commercial products were selected for the second phase. A CEM I 42.5 R, a CEM II/B-S 32.5 R and a CEM III/A 32.5 N were used. Originally proposed Portland cement CEM I 32.5 R, with the same clinker as the other cements, was with the approval of the advisory board removed from the program because it is out of production. For the mortar tests in phase 2 the mixtures were composed with the same clinker and GGBFS proportion to compare it with each other (see table 1, column 7). For example, mixture M X.1.4 consists of 50.0 % by mass of CEM I and 50.0 % by mass of GGBFS and the corresponding CEM II-mixture consists of 76.9% by mass of CEM II/B-S and 23.1% by mass of GGBFS.

Table 1: Mixture compositions of the examined mortars (phase 2)

Designation	Type of cement	Binder composition			w/c_{eq}	$cl/ggbfs_{tot}$		f/(c+ggbfs)
		c	ggbfs	f		aim	actual	
-	-	% by mass of binder			-	-	-	-
1	2	3	4	5	6	7	8	9
M X.1.0	CEM I 42.5 R	100	0	0	0.5	100/0	100/0	0
M X.1.1		75	0	25	0.59			0.33
M X.1.2		65	35	0	0.5	65/35	65/35	0
M X.1.3		48.75	26.25	25	0.59			0.33
M X.1.4		50	50	0	0.5	50/50	50/50	0
M X.1.5		37.5	37.5	25	0.59			0.33
M X.1.6		35	65	0	0.5	35/65	35/65	0
M X.1.7		26.25	48.75	25	0.59			0.33
M X.2.0	CEM II/B-S 32.5 R h_z = 30 % by mass	100	0	0	0.5	65/35	70/30	0
M X.2.1		75	0	25	0.59			0.33
M X.2.2		76.9	23.1	0	0.5	50/50	54/46	0
M X.2.3		57.7	17.3	25	0.59			0.33
M X.2.4		53.8	46.2	0	0.5	35/65	38/62	0
M X.2.5		40.35	34.65	25	0.59			0.33
M X.3.0	CEM III/A 32.5 N h_z = 50 % by mass	100	0	0	0.5	35/65	50/50	0
M X.3.1		75	0	25	0.59			0.33
M 1.2.6	CEM II/B-S 32.5 R h_z = 30 % by mass	92.9	7.1	0	0.5	65/35	65/35	0
M 1.2.7		69.6	5.4	25	0.59			0.33
M 1.3.2	CEM III/A 32.5 N h_z = 50 % by mass	70	30	0	0.5	35/65	35/65	0
M 1.3.3		52.5	22.5	25	0.59			0.33

c cement; ggbfs ground granulated blast furnace slag
f fly ash; $ggbfs_c$ ggbfs in cement
cl clinker; $ggbfs_{tot} = ggbfs + ggbfs_c$; $w/c_{eq} = w/(c+ggbfs+0.4 \cdot f)$

To detect the fluctuations caused by the production process, investigations of each 6 batches of raw materials have been carried out. Overall, a high uniformity of the raw materials was observed. The spread of the fresh and hardened mortar properties of the individual batches was low.

All batches of the CEM II/B-S contained only approx. 30 % by mass of GGBFS instead of 35 % by mass. Therefore for the first batch the reference mixture M X.2.0 was prepared with an addition of GGBFS to achieve a proportion of clinker to GGBFS of 65/35 (M 1.2.6). The CEM III/A contained an effective amount of GGBFS of 50 % by mass instead of 65 % by mass. Again, the reference mixture of the first batch was prepared with the addition of GGBFS to achieve a proportion of clinker to GGBFS of 35/65 (M 1.3.2). These two combinations of CEM II/B-S and CEM III/A with GGBFS have also been considered in combination with fly ash (M 1.2.7 und 1.3.3, table 1).

The results show that mortars containing cement and fly ash plus GGBFS as additives are not completely equivalent to mortars with blast furnace slag cement and fly ash. The fresh mortar properties were comparable. They were in the range of usual standard mortars with slumps between 200 and 240 mm, air void contents between 1.4 und 2.5 % by volume and bulk densities between 2.23 and 2.31 g/cm³. It turned out that in the mixes with CEM I 42.5 R and GGBFS the compressive strength after 28 days was higher than the strength of the reference mixture (see fig. 1). The mixtures containing fly ash had a lower compressive strength than the reference, since the fly ash was fully taken into account.

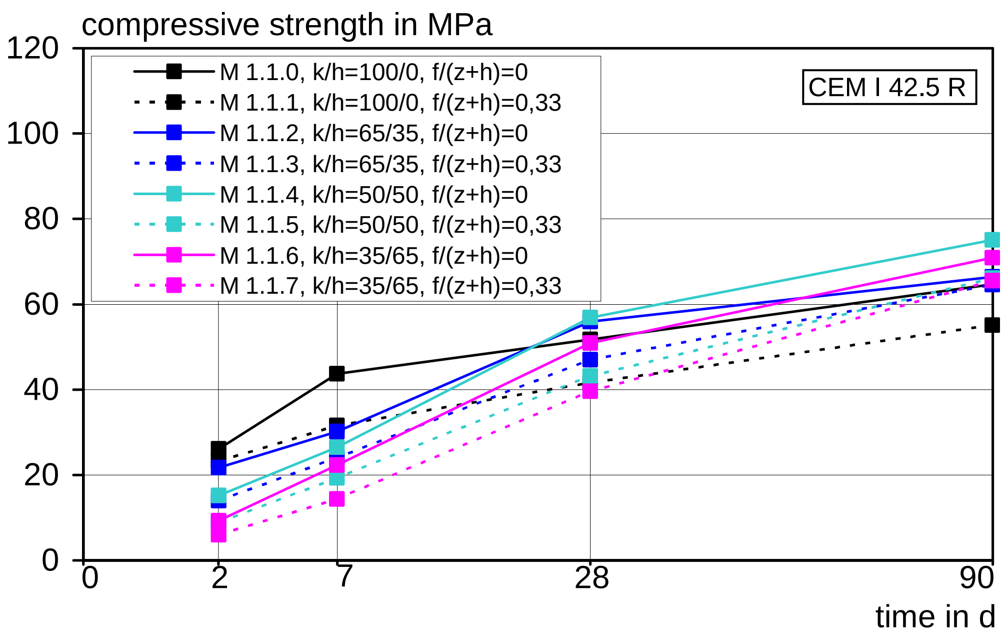
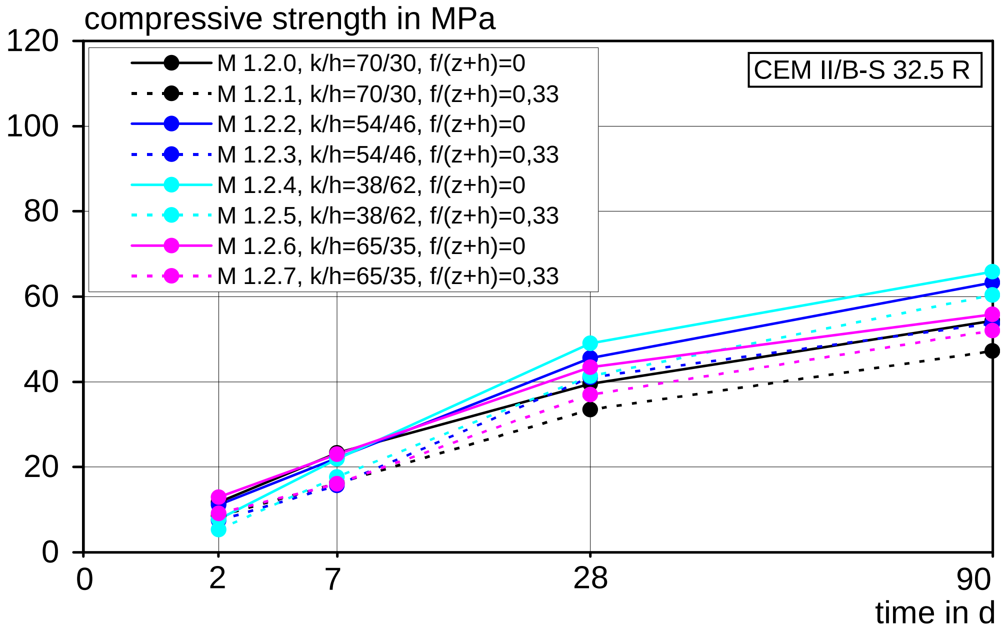


Figure 1: Compressive strength development of mixtures with CEM I of the first batch

However, in the case of CEM II/B-S 32.5 R in combination with GGBFS and fly ash the compressive strength of the reference was reached after 28 days, despite full consideration of the fly ash (see fig. 2). So this binder combination was therefore very good.



<u>Figure 2:</u> Compressive strength development of mixtures with CEM II of the first batch

The mixtures with CEM II showed slightly higher compressive strengths than the mixtures with CEM III. A comparison between the mixtures with CEM I and the other mixtures could not be performed because of the different cement strength classes. The determination of the activity indices and related compressive strengths showed a significant age-dependent reactivity of the concrete additives. Until the age of 28 days the combination of CEM II with fly ash and GGBFS is significantly better than with CEM I (see fig. 3). After 90 days, the related compressive strengths are comparable.

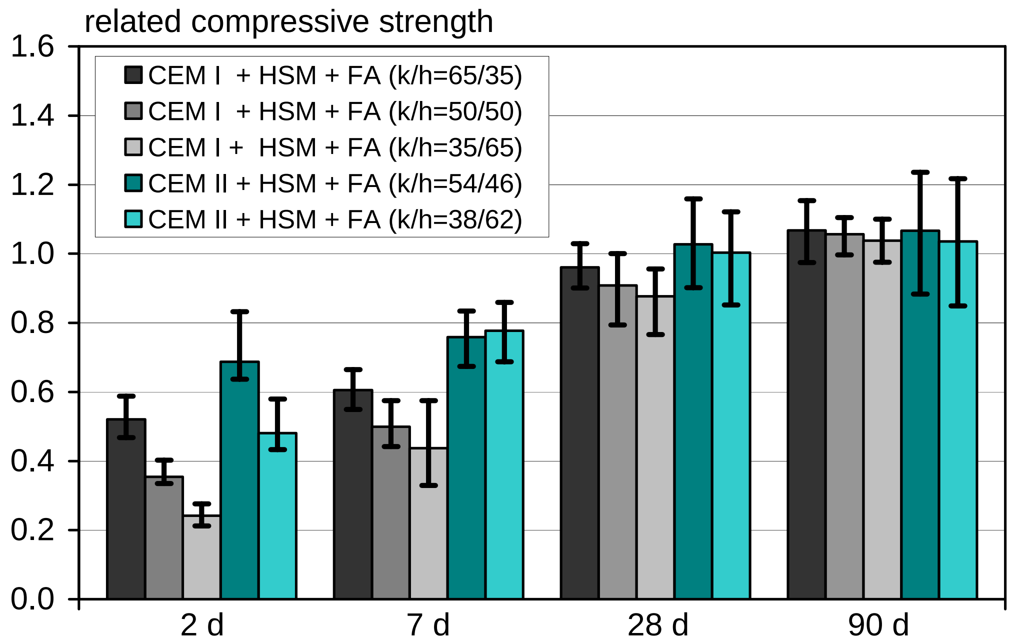


Figure 3: related compressive strengths (including spreading width of the different batches) of the mixtures containing GGBFS and fly ash to the investigated test dates

As expected, the mixtures containing additives carbonated faster than the reference mixes. The carbonation velocities (v_c) of the CEM II and CEM III-mixtures were higher than those of CEM -I mixtures at similar GGBFS contents (see table 2).

Table 2: medium carbonation velocities of mortars for the time period of 14 to 365 days

Desig-nation	Type of cement	$cl/ggbfs_{tot}$	f/(c+ggbfs)	v_c
-	-	-	-	mm/√d
1	2	3	4	5
M X.1.0	CEM I 42.5 R	100/0	0	0.116
M X.1.1			0.33	0.226
M X.1.2		65/35	0	0.188
M X.1.3			0.33	0.317
M X.1.4		50/50	0	0.207
M X.1.5			0.33	0.400
M X.1.6		35/65	0	0.274
M X.1.7			0.33	0.486
M X.2.0	CEM II/B-S 32.5 R h_z = 30 % by mass	70/30	0	0.291
M X.2.1			0.33	0.498
M X.2.2		54/46	0	0.296
M X.2.3			0.33	0.493
M X.2.4		38/62	0	0.334
M X.2.5			0.33	0.516
M X.3.0	CEM III/A 32.5 N h_z = 50 % by mass	50/50	0	0.365
M X.3.1			0.33	0.581
M 1.2.6	CEM II/B-S 32.5 R h_z = 30 % by mass	65/35	0	0.316
M 1.2.7			0.33	0.533
M 1.3.2	CEM III/A 32.5 N h_z = 50 % by mass	35/65	0	0.376
M 1.3.3			0.33	0.535

In phase 3 granulometric optimizations were performed to reach better fresh and hardened mortar properties. Partially lower water demands are achieved, which, however, did not lead to an increase in compressive strength of the optimized mixes. Generally, it must be stated that the granulometric optimizations in this project were not effective. It needs further basic research in this field.

Finally, in phase 4, it was checked whether the results of phase 2 can be transferred to the concrete scale. In the mix design the k-values k_{GGBFS} = 1.0 and k_{FA} = 0.4 were assumed. Among the concretes with CEM I the reference mixture showed the highest compressive strength, because the assumed effectiveness of the concrete additives was overestimated.

For the mixture, which contained only GGBFS, the GGBFS had a k-value of 0.77 after 28 days and 0.89 after 90 days. Since there was no mixture, which contained only fly ash, a single k-value for the fly ash could not be determined. The combined k-value ($k_{GGBFS + FA}$) was at both testing times about 0.55 for the mixture with CEM I. If the fly ash had had a k-value of 0.4, the combined k-value would have been 0.62 after 28 days and 0.69 after 90 days. Using CEM II, the additive-containing concrete mixtures showed an equal or higher compressive strength compared to the reference mixture at the age of 28 days. The k-value for the GGBFS was k_{GGBFS} = 1.0 after 28 days and 1.15 after 90 days. The combined k-value was 0.83 after 28 days and 0.88 after 90 days. With a k-value of the fly ash of 0.4 the combined k-value would have been 0.76 after 28 days and 0.85 after 90 days. That means this combination was very good also in the concrete scale. The additive-containing mixtures had the highest carbonation velocities. As in the mortar scale the carbonation depth was higher in the mixtures with CEM II than in the mixtures with CEM I. Mostly, the carbonation velocity of the mortar is higher than that of the concrete, which was in the range of usual concretes. The permeability of the additive-containing mixtures was lower than that of the reference mixes as expected.

The present results of the strength development of the tested binder combinations indicate that concrete additives interact better with certain cements than with others because of their chemical or physical properties. The exact correlations should be investigated in more detail. It is also unclear how the packing density and chemical effects overlap and maybe compensate each other. Further, it is unclear whether and how GGBFS and fly ash temporally interact in their reactivity. Therefore, there is need of further research.

4 LITERATURE

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