

INFLUENCE OF METAKAOLIN AND RICE HUSK ASH ON TIME-DEPENDENT STRENGTH DEVELOPMENT OF CONCRETE STRENGTH

Klaus Holschemacher*, Lars Hoffmann, Stefan Käseberg, Thi Phuong Nguyen

HTWK Leipzig, University of Applied Sciences, Structural Concrete Institute, Karl-Liebknecht-Str. 132, 04277 Leipzig, Germany

Abstract

Fly ash, ground granulated blast furnace slag and silica fume are often used cementitious materials for concrete production in Germany. Caused by environmental issues and the withdrawal from coal-based energy production, it is expected that fly ash will be widely replaced by other suitable materials when producing concrete in future. In this context, the interest in so far minor applied cementitious materials like metakaolin and rice husk ash is increasing, presently. The paper reports an experimental investigation where different amounts of fly ash, blast furnace slag, silica fume, metakaolin, and rice husk ash were applied in concrete mixes. The research was focused on the influence of the various cementitious materials on the time-dependent concrete compressive strength development. For this, cube compressive strength was measured in concrete age of 1, 3, 7 and 28 days. As a main result it can be stated that silica fume and rice husk ash have comparable influence on the concrete strength. Metakaolin also contributes to the concrete strength development, but the experiments highlighted that it is reducing the workability of fresh concrete, too.

Keywords: cementitious materials, concrete strength, fresh concrete properties, metakaolin, rice husk ash

1. INTRODUCTION

Nowadays, environmental protection issues are gaining importance in all industrial sectors. In construction industry, the production of Portland cement is one of the critical points. The production of one ton Portland cement roughly results in one ton of polluting carbon dioxide (Neville 2005). It is estimated that the manufacturing process of Portland cement is responsible for about 8% of total global carbon dioxide (CO₂) emissions (Andrew 2018). For improvement of this situation there are major efforts to partially or fully replace Portland cement by other appropriate cementitious materials. In this context fly ash (FA) and ground granulated blast furnace slag (GGBS) are most applied substances in Germany up to date. Furthermore, lime stone powder and, for production of high strength concrete, silica fume (SF) are frequently used, too. Caused by the intended withdrawal of coal-based electrical energy production and other changes in industry, it is expected that the disposability of FA will be limited in future. Consequently, the importance of other cementitious materials for the concrete production will increase.

Whereas outside of Germany the application of metakaolin and rice husk ash as component of concrete mixes is well approved, there is only limited experience with these materials inside of the country. Therefore, an experimental study has been performed aiming on the investigation of metakaolin and rice husk ash as cementitious materials and on their influence on the concrete strength.

2. EXPERIMENTAL INVESTIGATION

2.1. Scope of investigation

The aim of the experimental program is the investigation of the influence of various cementitious materials on the concrete strength and strength development over a defined time. For this, besides FA, GGBS, and SF, additionally metakaolin (M) and rice husk ash (RHA) were included in the experimental program. These additives were separate or combined constituents of the concrete mix. Besides concrete strength, fresh concrete properties were studied.

2.2. Applied cementitious materials

The investigated cementitious materials are shown in Figure 1 and their chemical composition is specified in Table 1. Grading curves were measured with laser diffraction particle size analyzer for cementitious materials as well as cement and sieving was conducted in case of sand and gravel. The results are illustrated in Figure 2. A comparison to the grading curve of the Portland cement used in the carried-out experimental program is highlighted as well.

The used aggregate corresponded to grading curve A16/B16.



Fig. 1. Investigated cementitious materials.

Cementitious material	$\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	$\text{CaO} + \text{MgO}$	SiO_2	Other constituents
Fly ash	37%	5%	50%	8%
Ground granulated blast furnace slag	12%	50%	34%	4%
Silica fume	2%	1%	94%	3%
Metakaolin	28%	5%	55%	12%
Rice husk ash	2%	2%	92%	4%

Table 1. Chemical composition.

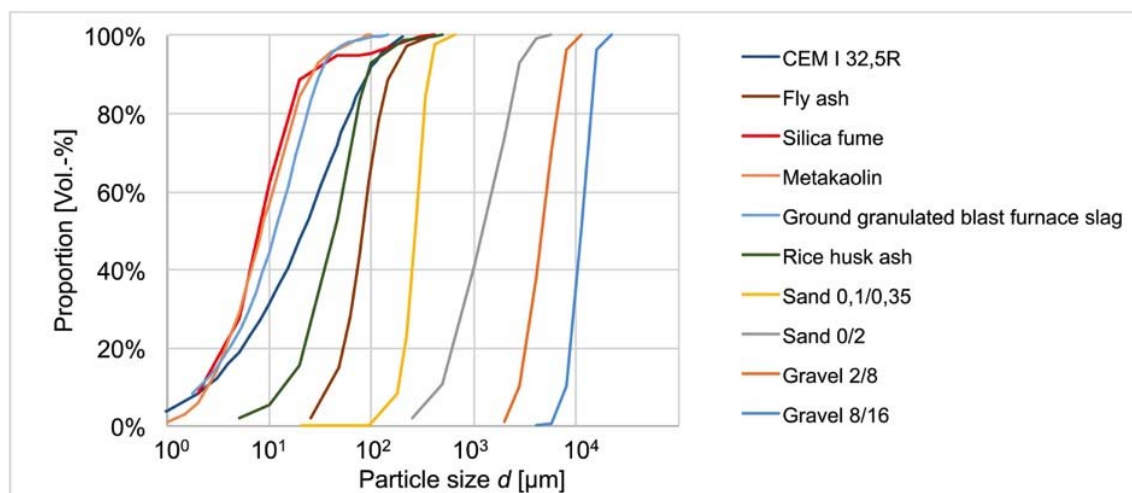


Fig. 2. Grading curves of the investigated cementitious materials.

It is obvious that ground granulated blast furnace slag, metakaolin, and silica fume have a higher fineness than Portland cement. Therefore, besides the pozzolanic reaction, a filler effect in the lower powder range may be expected when using these very fine cementitious materials.

2.3. Test program

In total, 13 different concrete mixes were tested. For all concrete mixes Portland cement CEM I 32.5R was applied as the main binder material. In the reference mix only the Portland cement, but no other cementitious materials were part of the mix composition. In the other 12 investigated concrete mixes Portland cement was partially replaced through fly ash, ground granulated blast furnace slag, silica fume, metakaolin and rice husk ash. The cementitious materials were applied in varying amounts. To get a better understanding for the efficiency of the various cementitious materials they were combined in some of the mixes.

All mixes were designed aiming on an equivalent water-binder ratio of $(w/c)_{eq} = 0.6$ according to European Standard EN 206. Therefore, the Portland cement content varied between 320 kg/m³ (reference mix) and 260 kg/m³ (mixes with two additional cementitious materials). For the calculation of the equivalent water-binder ratio the k-value concept according to EN 206 was applied. The influence of rice husk ash was equated to silica fume because of the similar silicon content. Metakaolin and fly ash were considered in comparable procedure. An overview of all tested concrete mixes is given in Table 2.

Test series	Mix components							
	Cement	F	GGBS	SF	M	RHA	Aggregate	Water
	kg/m ³							
Ref	320	–	–	–	–	–	2338	192
F	280	84	–	–	–	–	2327	188
F+SF	260	78	–	26	–	–	2315	190
F+M	280	42	–	–	42	–	2330	188
F+RHA	260	78	–	–	–	26	2317	190
GGBS	280	–	84	–	–	–	2347	188
GGBS+M	280	–	84	–	28	–	2331	196
GGBS+RHA	260	–	78	–	–	26	2336	190
SF	280	–	–	28	–	–	2338	187
SF+M	280	–	–	26	78	–	2323	190
M	280	–	–	–	84	–	2335	188
M+RHA	260	–	–	–	78	26	2325	190
RHA	280	–	–	–	–	28	2340	187

Table 2. Mix composition.

Metakaolin particles are characterized by flat shape similar to plates. This fact is resulting in a noticeable deterioration of the workability. For balancing this disadvantage, PCE superplasticizer had to be added to all mixes including metakaolin. By this measure, the workability of all mixes was comparable.

3. TEST RESULTS

3.1. Concrete compressive strength

The concrete compressive strength was measured in concrete age of 1, 3, 7, and 28 days respectively using cubes with an edge length of 150 mm. The mean values from 3 cube tests are presented in Table 3.

Test series	Concrete age (days)			
	1	3	7	28
Ref	8.0	18.4	24.8	30.1
F	4.6	16.1	22.6	29.1
F+SF	5.8	15.4	22.1	32.2
F+M	7.7	17.5	26.7	37.8
F+RHA	4.6	15.2	21.1	28.4
GGBS	6.9	19.6	28.4	40.8
GGBS+M	7.8	18.3	29.0	38.8
GGBS+RHA	7.4	17.0	26.2	36.4
SF	6.7	17.0	23.1	34.0
SF+M	8.2	17.3	30.8	40.3
M	8.2	17.8	30.7	41.4
M+RHA	6.0	16.0	29.0	35.0
RHA	7.0	18.0	23.8	34.0

Table 3. Mean values of concrete compression strength.

The test results show that the 1-day compressive strength for most mixes with alternative cementitious materials is lower than those of the reference mix. Only SF+M and M mixes achieved a higher early concrete strength. As to expect the mixes with fly ash (F, F+RHA, F+SF) exhibited the lowest 1-day compressive strength.

In comparison to the 1-day compressive strength, the differences for the 3-day strength of the mixes are lesser. Thereby, the GGBS mix showed the highest strength. Very close are the results for the reference mix and the mixes GGBS+M and RHA. Again, the lowest strength was achieved if a mix comprised fly ash as a constituent.

Regarding the 7-day compressive strength, it is obvious that all mixes obtaining metakaolin (especially the mixes SF+M, M, M+RHA) achieved a considerably high strength if compared to the reference mix. To the contrary, the mixes with fly ash had a lower strength than the reference mix.

In common, the 28-day concrete compressive strength of the most mixes with alternative cementitious materials was higher than the strength of the reference mix. Mixes M, GGBS, and SF+M developed the highest strength.

3.2 Comparison of test results with Eurocode 2 regulations

Eurocode 2 and fib ModelCode 2010 offer an approach for the calculation of the concrete compression strength in dependence of the concrete age.

$$f_{cm}(t) = \beta_{cc}(t) f_{cm} \quad (1)$$

with

$$\beta_{cc}(t) = e^{s \sqrt{28/t}} \quad (2)$$

where:

- $f_{cm}(t)$ mean concrete compressive strength at concrete age t in days,
- f_{cm} mean concrete compressive strength at concrete age of 28 in days,
- β_{cc} function for the description of the development of concrete strength with time,
- t concrete age in days,
- s coefficient dependent on cement type.

The concrete age t must be adjusted if there are larger deviations from the mean temperature of 20 °C. The coefficient s amounts for normal strength concrete as follows:

- 0.38 for cement type 32.5 N (cement class S)
- 0.25 for cement types 32.5 R, 42.5 N (cement class N)
- 0.20 for cement types 42.5 R, 52.5 N, 52.5 R (cement class R).

For comparison of test results with Eurocode 2 regulations, the coefficient s was set in accordance to the applied Portland cement CEM I 32.5R to a value of 0.25. An overview to the strength development of the reference mix and the mixes with one additional cementitious material is presented in Table 4.

The 1-day strength of the reference mix amounted 27% of its 28-day strength and thus was significantly lower than to expect according to Eurocode 2 approach with coefficient $s = 0.25$. There is no better compliance if the factor s is set to a value of 0.38, which is applicable for class S cements. In this case, the ratio of 1-day to 28-days strength according to Eurocode 2 is 0.20 and not more close to the test result. As to expect, all mixes with additional cementitious materials had a slower strength development compared with the reference mix.

Measured 3-days and 7-days strength of the tested mixes differed lesser as their 1-day strengths. After 7 days all mixes with additional cementitious materials had a larger increase than the reference mix. The highest absolute 28-day compressive strength was determined for the mixes M, SF+M, and GGBS. Their strength was about 30% higher as that for the reference mix.

3.3 Comparison of silica fume and rice husk ash

Because of their similar chemical composition, the measured strength values of mixes containing silica fume and rice husk ash are discussed separately, see Figure 3. It is obvious that the measured mean compressive strength development and the 28-days strength of SF and RHA mixes do not differ considerably. This fact might suggest enhancing the k-factor concept valid for silica fume to concrete mixes containing rice husk ash.

Concrete age		Test series						
		Ref	F	SF	GGBS	M	RHA	EC2
1 day	$\frac{f_{cm}(t)}{f_{cm}}$	27%	16%	20%	17%	20%	22%	34%
3 days	$\frac{f_{cm}(t)}{f_{cm}}$	61%	55%	50%	48%	43%	56%	60%
	$\frac{f_{cm}(3 \text{ days}) - f_{cm}(1 \text{ day})}{f_{cm}}$	34%	39%	30%	31%	23%	34%	26%
7 days	$\frac{f_{cm}(t)}{f_{cm}}$	82%	77%	68%	70%	74%	75%	78%
	$\frac{f_{cm}(7 \text{ days}) - f_{cm}(3 \text{ days})}{f_{cm}}$	21%	22%	18%	22%	31%	18%	18%
28 days	f_{cm}	100%	100%	100%	100%	100%	100%	100%
	$\frac{f_{cm} - f_{cm}(7 \text{ days})}{f_{cm}}$	18%	23%	32%	30%	26%	25%	22%

Table 4. Concrete strength development in relation to its 28-days strength.

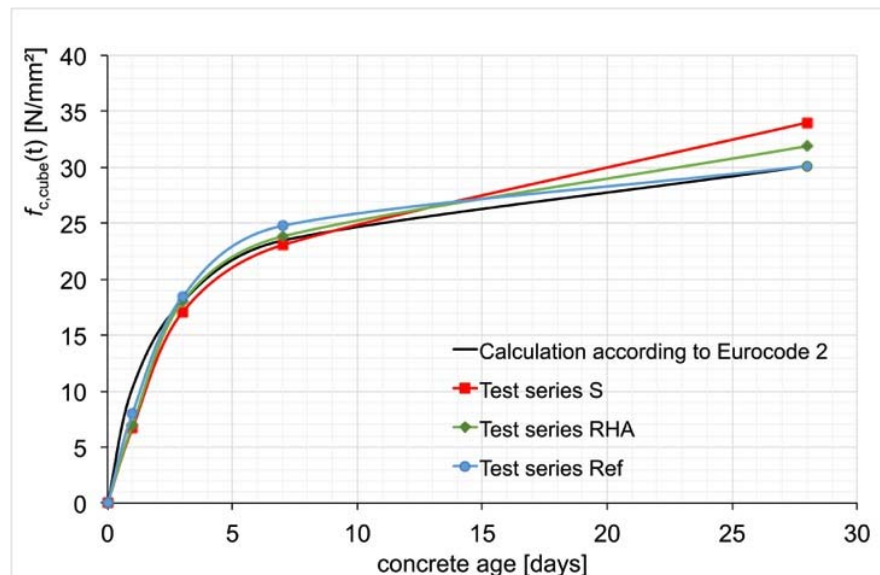


Fig. 3. Concrete strength development of mixes containing SF and RHA.

3.4 Comparison of fly ash, ground granulated blast furnace slag and metakaolin

The M and GGBS mix had a similar strength development, see Figure 4. However, the scattering of the test results of test series F and GGBS was higher than for the reference and the M mix. Within the k-concept, it may be assumed that the effect of metakaolin can be considered in a similar way as for GGBS.

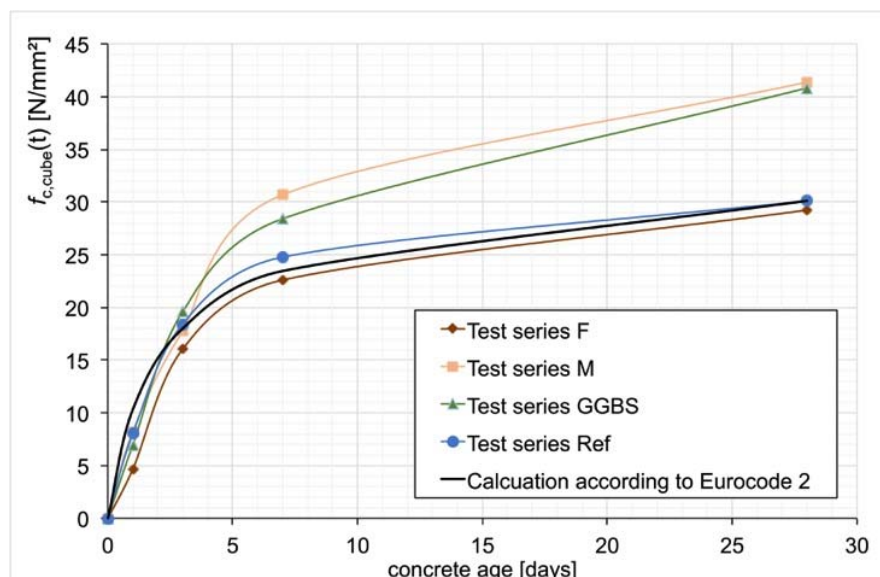


Fig. 4. Concrete strength development of mixes containing F, M, and RHA.

4. SUMMARY AND CONCLUSION

In the described experimental study the influence of various cementitious materials on the concrete compressive strength development was investigated. The results indicate that rice husk ash and metakaolin are suitable materials for replacing fly ash and ground granulated blast furnace slag as cementitious materials. Rice husk ash and silica fume had a comparable effect on the time dependent development of the concrete strength. The addition of metakaolin to concrete mixes resulted in an essential increase of concrete's 28-day strength.

More detailed information on the experimental program is reported in (Hoffmann, Kaeseberg, Holschemacher 2021). The experiments must be continued, especially in the context of concrete durability.

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