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INFLUENCE OF MIXING TECHNOLOGY ON FRESH CONCRETE PROPERTIES OF HPFRCC

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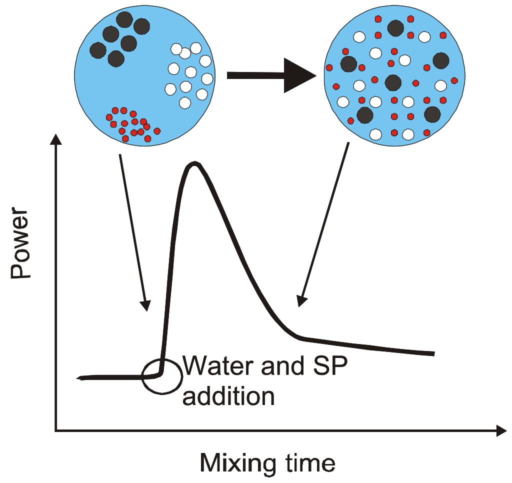
Abstract

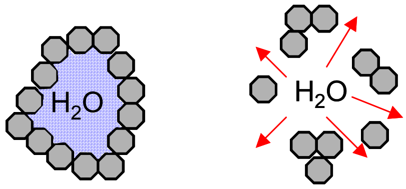
A main issue of a wider application for HPFRCC is a reliable transfer of production processes from laboratory into practice considering the specific boundary conditions in conventional plants for ready mixed concrete or prefabrication. Within a research project the influence of mixing technology on the fresh concrete properties of HPFRCC was investigated. Therefore, the effect of mixing period, intensity and order, including breaks was observed in order to find out how these parameters affect in general the fresh HPFRCC. During the mixing process the temperature of mixtures, engine speed, engine output, energy consumption etc. were recorded and graphed constantly. The measurements were carried out in the laboratory. It was shown that the HPFRCC mixtures could be produced methodically and reproducibly which is essential for the acceptance of these "high-tech" materials in practice.

1. INTRODUCTION

Mixing concrete is a complex procedure and can be subdivided into two parts. Within the first, the so-called distributive mixing, the attitudes of mix particles are changed by low shear velocities. At second, the so-called dispersive mixing, agglomerations of mix particles are solubilized by high shear velocities. In fig. 1 these effects are shown theoretically for a HPFRCC with a very flowable consistency (self compacting HPFRCC) (use of superplasticizer, SP) (see fig. 1).

In comparison to normal concrete HPRFCC can be described as a 6-material system consisting of cement, additives and additions, water, aggregates and of course fibres. Due to the concrete composition the packing density of HPFRCC is essentially higher than for NC. Therefore, mixing parameters such as particle size, distribution and shape, differences in density as well as their surface roughness is of main importance. A "*visual mixing*" which is common for normal concrete seems not reasonable for HPFRCC concerning high energy and time requirements. In order that the mix particles can change their attitude kinetic energy has to be supplied. Depending on the consistency and viscosity respectively a power entry and electric consumption can be observed for the mixture. If the power entry could be journalized and controlled statements for the concrete viscosity are possible. That means at the same time information on an optimized energy entry and an ideal mixing time is adjustable.





Effects of distributive and dispersive mixing:

- Filling the voids among coarser particles and fibres with finer particles
- Filling the voids among all solid particles with water
- Release of water enclosed in agglomerates
- Dispersion and homogenization of fibres

Figure 1: Distributive and dispersive mixing

HPFRCC is a high performance material whose efficiency is described by its fresh and hardened properties. These can be only utilized sufficiently if the rheology of the fresh concrete offers optimal characteristics. In general, HPFRCC can be described as a system of viscous mortar or paste, disperse fibres and/or coarse aggregates. Experiences with HPFRCC show that for a usable concrete recipe the desired properties in the fresh state are generated by frequently long mixing. A total mixing time of 5 to 6 minutes isn't uncommon. The mixing period is defined as the duration of stirring of the raw materials entirely filled in the mixer till the beginning of the discharge period.

In fig. 2 the theoretical mixing order according [1] is shown. But this mixing order makes only sense for a classical approach where the raw materials are dosed at the beginning of mixing. If multi-leveled mixing processes are applied this definition of mixing time seems to be not appropriate.

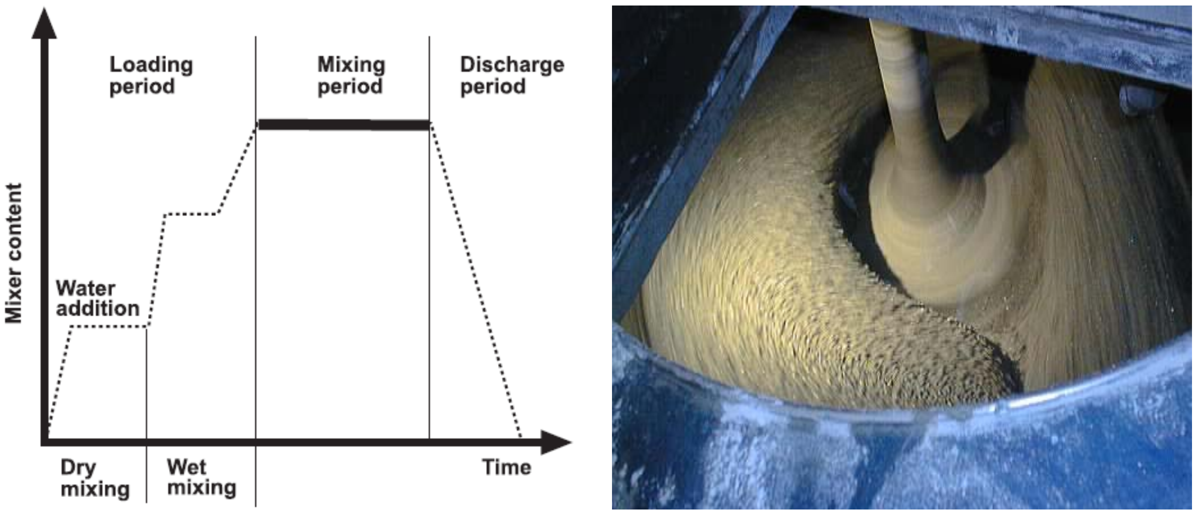


Figure 2: Mixing procedure according [1]

It is well known, that the performance of HPFRCC is highly influenced by its microstructure and the transition between matrix, aggregates and fibres. According to Ferraris [2] besides composition and curing especially the mixing conditions during production affect the microstructure. The mixture performance is a quantity of homogeneity and thus a quality criteria. A bad mixing performance for HPFRCC leads to uncontrollable defects, e.g. fibre clusters. At present it is unexplained if the longer mixing time for HPFRCC depends more on the concrete composition or rather on the production process, especially the mixing parameters, such as order, intensity and period. The question is if a uniformity of the concrete is achievable for each type of mixer only by an increase of mixing time or if a change of mixing parameters and order of raw materials addition respectively influence the mixing time positively.

An additional evaluation of HPFRCC in the fresh state can be carried out by rheological measures. The rheological properties of HPFRCC are particularly determined by the concrete composition and the characteristics of raw materials. In a homogenous HPFRCC only a few agglomerates of powder components and fibres remain. The achievable dispersion rate depends on the function of the mixer and the mixing regime, e.g. the mixing order, the mixing period, mixing intensity etc.

Different models for the description of rheological properties of concrete are known. These models are based on two aspects. On the one hand both the yield point and viscosity decrease with rising dispersion rate of fine particles. On the other hand a varying shear rate can be observed. The fresh concrete will be mixed first with a rising and then with a declining shear rate (see left graph of fig. 3). In the right graph of fig. 3 the ascending branch isn't identical with the descending function within the shear-stress/shear-rate-diagram. The area of hysteresis loop between these two curves depends on the dispersion rate of the fine particles and the fibres. The area becomes smaller for a higher dispersion rate.

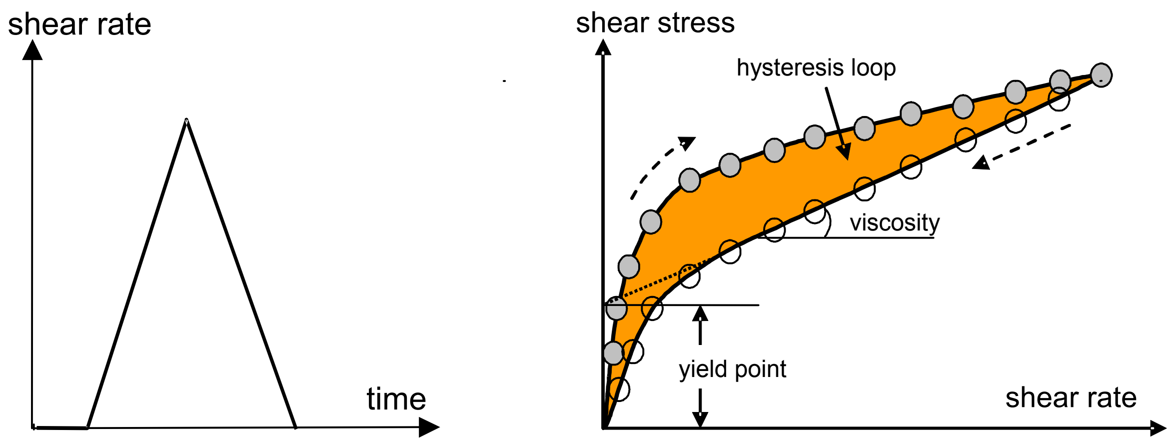


Figure 3: Hysteresis loop of a rheological curve

In order to investigate the above mentioned influences a research work was launched. Therefore, a typical HPFRCC mixture with a ultra high strength, almost self compacting consistency and a fibre mix was tested. For all experiments the concrete was kept constant.

Besides the slump low and funnel time according to the Japanese SCC experiences the concrete temperature during mixing, its bulk density and the air content have been measured. The following chapter gives some explanations on the mix procedure and summarizes the gained results.

2. INVESTIGATION ON MIXING TECHNOLOGY ON FRESH HPFRCC

For this investigation a so-called Eirich mixer was used (see fig. 4). With this intensive mixer different steps of mixing are possible. One main advantage of such a mixer is that because of constant data recording (temperature of mix, control mode for mixer tools, engine speed, engine output, energy consumption, programmable mixing course etc.) a traceability of the whole mixing process is possible which can be used to compare different concrete mixtures.

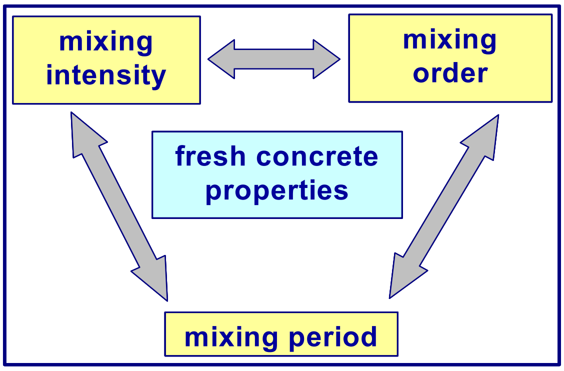


Figure 4: Eirich intensive mixer

The concrete consists of the subsequent ingredients: Portland Cement CEM I 42,5 R-HS with high sulphate resistance (665 kg/m³), undensified silica fume (200 kg/m³), quartz powder with a average size of 5.5 µm (285 kg/m³), and quartz sand (0.3 to 0.8 mm) (1001 kg/m³). No coarse aggregates were put in the mix. In order to achieve a nearly self compacting consistency a superplasticizer on polycarboxlyte base was utilized (53.2 kg/m³).

Altogether two types fibres were used (fibre mix). The short fibres had a diameter of 0.18 mm and a length of 6 mm (156 kg/m³). For the long ones (diameter: 0.38 mm, length: 30 mm) 78 kg/m³ have been applied. The strength of concrete was in all cases 150 ± 5 N/mm² (28d, water curing) with a water-cement-ratio of 0.24.

The following tables 1 to 3 summarize the tests carried out in this research work.

Table 1: Influence of mixing intensity

No.	mixing parameter							
	mixing order		mixing intensity				mixing period	
	step	description	plate		tack			
1	1	dry mixing	1,1	m/s	3,9	m/s	60	s
	2	water + 100% superplasticizer	1,1	m/s	3,9	m/s	240	s
					total period		5	min
2	1	dry mixing	1,1	m/s	6,5	m/s	60	s
	2	water + 100% superplasticizer	1,1	m/s	6,5	m/s	240	s
					total period		5	min
3	1	dry mixing	1,1	m/s	9,0	m/s	60	s
	2	water + 100% superplasticizer	1,1	m/s	9,0	m/s	240	s
					total period		5	min
4	1	dry mixing	1,1	m/s	12,9	m/s	60	s
	2	water + 100% superplasticizer	1,1	m/s	12,9	m/s	240	s
					total period		5	min
5	1	dry mixing	1,1	m/s	18,0	m/s	60	s
	2	water + 100% superplasticizer	1,1	m/s	18,0	m/s	240	s
					total period		5	min
6	1	dry mixing	1,1	m/s	25,8	m/s	60	s
	2	water + 100% superplasticizer	1,1	m/s	25,8	m/s	240	s
					total period		5	min

fresh concrete properties										
No.	slump flow		funnel time		air content		bulk density		temperature	
1	660	mm	8,94	s	4,50	vol-%	2,39	kg/dm³	19	° C
2	670	mm	7,6	s	4,60	vol-%	2,43	kg/dm³	20	° C
3	720	mm	6,87	s	3,95	vol-%	2,43	kg/dm³	26	° C
4	705	mm	7,28	s	4,05	vol-%	2,42	kg/dm³	28	° C
5	675	mm	8,28	s	3,95	vol-%	2,44	kg/dm³	33	° C
6	740	mm	4,72	s	3,30	vol-%	2,44	kg/dm³	35	° C

Table 2: Influence of mixing period

No.	mixing parameter							
	mixing order		mixing intensity				mixing period	
	step	description	plate		tack			
7	1	dry mixing	1,1	m/s	3,9	m/s	60	s
	2	water + 100% superplasticizer	1,1	m/s	3,9	m/s	120	s
					total period		3	min
8	1	dry mixing	1,1	m/s	3,9	m/s	60	s
	2	water + 100% superplasticizer	1,1	m/s	3,9	m/s	180	s
					total period		4	min
9	1	dry mixing	1,1	m/s	3,9	m/s	60	s
	2	water + 100% superplasticizer	1,1	m/s	3,9	m/s	240	s
					total period		5	min
10	1	dry mixing	1,1	m/s	3,9	m/s	60	s
	2	water + 100% superplasticizer	1,1	m/s	3,9	m/s	360	s
					total period		7	min

fresh concrete properties										
No.	slump flow		funnel time		air content		bulk density		temperature	
7	660	mm	9,91	s	5,10	vol-%	2,40	kg/dm³	19	° C
8	710	mm	7,66	s	4,40	vol-%	2,42	kg/dm³	20	° C
9	720	mm	6,87	s	3,95	vol-%	2,43	kg/dm³	26	° C
10	725	mm	7,53	s	4,40	vol-%	2,43	kg/dm³	26	° C

Table 3: Influence of mixing order

No.	mixing paramter							
	mixing order		mixing intensity				mixing period	
	step	description	plate		tack			
11	1	dry mixing	1,1	m/s	9,0	m/s	60	s
	2	water	1,1	m/s	9,0	m/s	90	s
	3	superplasticizer	1,1	m/s	9,0	m/s	150	s
					total period		5	min
12	1	dry mixing	1,1	m/s	9,0	m/s	60	s
	2	water	1,1	m/s	9,0	m/s	90	s
	3	superplasticizer	1,1	m/s	9,0	m/s	150	s
					total period		5	min
13	1	dry mixing	1,1	m/s	9,0	m/s	60	s
	2	water + 33% superplasticizer	1,1	m/s	9,0	m/s	90	s
	3	66 % superplasticizer	1,1	m/s	9,0	m/s	150	s
					total period		5	min
14	1	dry mixing	1,1	m/s	9,0	m/s	60	s
	2	water + 66% superplasticizer	1,1	m/s	9,0	m/s	90	s
	3	33 % superplasticizer	1,1	m/s	9,0	m/s	150	s
					total period		5	min
15	1	dry mixing	1,1	m/s	9,0	m/s	60	s
	2	water + 100% superplasticizer	1,1	m/s	9,0	m/s	240	s
					total period		5	min

fresh concrete properties										
No.	slump flow		funnel time		air content		bulk density		temperature	
11	730	mm	4,66	s	3,00	vol-%	2,33	kg/dm³	26	° C
12	765	mm	5,37	s	3,60	vol-%	2,43	kg/dm³	27	° C
13	725	mm	5,85	s	3,90	vol-%	2,43	kg/dm³	26	° C
14	720	mm	6,47	s	4,00	vol-%	2,43	kg/dm³	26	° C
15	715	mm	7,16	s	4,00	vol-%	2,42	kg/dm³	27	° C

3. CONCLUSIONS

Within a research project the influence of mixing technology on fresh HPFRCC was investigated. For a typical HPFRCC with a fibre mix varying mixing parameters, such as mixing time, intensity and sequences, including breaks were observed. The concrete composition and the conditions before and during mixing were kept constant in order to investigate only the effect of mixing. To verify these effects the slump flow and the funnel time were measured. The gained results indicate that the mixing processes has an emphatic influence on the obtainable HPFRCC properties in the fresh state.

Additionally tests have to be made to determine the compressive and flexural tensile strength. This investigation would be a next step to evaluate the influence of mixing technology on the hardened properties of HPFRCC.

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