Concrete Plant International
www.cpi-worldwide.com

June 2012 3

SPECIAL PRINT | CONCRETE TECHNOLOGY

Influence of mixing on the fresh and hardened concrete characteristics

SPECIAL PRINT
CPI 12/03

Ultra High Performance Concrete (UHPC)

Influence of mixing on the fresh and hardened concrete characteristics

Ultra high performance concrete (UHPC) differs from ordinary concrete by its composition and its characteristics. It exhibits a considerably higher powder content with usually a smaller maximum grain diameter, very low water/cement or water/binder ratios and a considerably higher superplasticiser content. UHPC can achieve compressive strengths of over 200 N/mm² and flexural strengths of over 20 N/mm². Due to its dense microstructure it is virtually impermeable to water, chemically aggressive substances and chlorides.

Peter Lieblang, Fachhochschule Köln, Germany
Daniel Ringwelski, Tillman B. V. Construction Chemicals, The Netherlands

A long-proved recipe [1] was slightly modified for the tests performed here. The composition is shown in the table below.

Table 1: UHPC recipe

Concrete composition (1.0 m³)			
Materials name	Mass [kg/m³]	Gross density [kg/dm³]	Volume [dm³/m³]
CEM I 52,5 R-HS/NA	832,0	3,10	268,4
Water	166,0	1,00	166,0
Quartz powder	199,0	2,65	75,1
Microsilica	128,0	2,35	54,5
Air void	0,0	0,00	40,0
Liquefier (PCE)	35,0	1,10	31,8
Basalt sand 0/2	1056,1	2,90	364,2
Total	2416,1	—	1000,00

In principle there are no differences between the production of UHPC and that of normal concrete. However, great importance is attached to the mixing process, because the complete wetting of the very large specific surface area and the disintegration of the admixture increase the required mixing energy in comparison with normal concretes.

Mixing technology

Mixing means nothing other than placing a system consisting of many particles in a state of the greatest possible disorder. Different types of mixer are used for this purpose in the manufacture of concrete. Commonest are the variants designated according to DIN 459-1 as pan mixer, ring pan mixer and trough mixer. With these types the actual mixing process takes place by means of fast relative movements between the mixture and the mixing tool. Due to the design, relative movements take place at the same time between the mixture and the mixing vessel. Intensive mixers on the other hand have an inclined mixing vessel, wall-floor scrapers and eccentrically arranged agitators. Unlike the aforementioned mixer types, in the intensive mixer the mixture is transported upwards by static friction in the inclined mixing pan and falls back down again by the force of gravity. This coarse mixing process is additionally assisted by the scraper and feeds the mixture to the mixing tool. The fine mixing is accomplished by the agitator immersed in the mixture. As a result, material streams develop with a high difference in speed between the mixture and the mixing tool, without the occurrence of significant friction losses between the mixture and the mixing vessel. This circumstance is important when the power consumption of the mixer is increased, because the total energy that is input can be split up into two portions as products of power and time. These are on the one hand the work expended in order to overcome the 'internal friction', i.e. for the actual mixing of the raw materials, and on the other the work required to overcome the 'external friction', i.e. the loss between the mixture and the wall of the vessel. Types of mixer in which a pronounced relative displacement occurs between mixture and vessel wall exhibit a non-linear correlation between the applied power and the mixing effect. On the other hand an increased power consumption in the case of intensive mixers with agitator and driven mixing vessel leads directly to an increase in the mixing effect due to the practically non-existent exterior friction, so that an approximately linear correlation between the power consumption and the applied mixing energy into the mixture can be assumed.
The maximum capacity of the laboratory mixer used here is 75 l or 120 kg (figure 1). The mixing process can be performed using both concurrent and countercurrent flow. A star-type agitator (figure 2) and a pin-type agitator (figure 3) are available as mixing tools. In addition, the controller enables the recording of all relevant parameters, i.e. speed of rotation, power input and mixture temperature.

Laboratory researches

Different mixing times and power levels were investigated in preliminary tests. In doing so the goal was pursued of adhering to practicable mixing times. In particular, the total mixing time should not significantly exceed a value of six minutes, because in the case of long mixing times the beginning hydration processes also affect the fresh concrete characteristics. Two different mixing tools were used for the tests (see figs. 2 and 3). In addition the mixing time and power consumption were varied. In order to examine the effect of the mixing parameters a total of 16 mixtures each with three batches was manufactured.
All mixtures were weighed with an accuracy to the gram in order to exclude variances due to dosing inaccuracies. From the preliminary tests it was known that, in order to adhere to a fresh concrete temperature of approx. 20 °C, all solid raw materials had to be tempered to a constant 5 °C. No investigation was carried out into how the temperature rise during mixing is distributed between friction heat development and hydration heat development.
The mixing regime always followed the same pattern and encompassed the following steps:

Figure 1: laboratory mixer

Figure 2: star agitator

Figure 3: pin agitator

- pour in the solid raw materials in the so-called mixer home position (mixing vessel 20 % power consumption, agitator 5 % power consumption),
- dry mixing until the specified target value is reached (either mixing time or energy input),
- manual addition of water and superplasticiser (as far as possible within a fixed time),
- wet mixing until the specified target value is reached (either time or energy input) and
- emptying.

The power consumption, the mixing time and the amount of mixing energy input are functionally correlated in the type of mixer employed if the composition of the mixture is not varied.

$$P = \frac{dE}{dt}$$

The amount of mixing energy that is input can be determined by integration of the power consumption over time and can be interpreted graphically as the area under the power curve if the losses due to 'external friction' are negligibly small.

$$E = \int_t P \cdot dt$$

A defined amount of mixing energy can be input in a short time with a high mixer power or in a correspondingly longer mixing time if the power is lower. This correlation is also shown by the mixing logs, which are illustrated below in fig. 4 for mixtures 7 and 9. The total mixing energy is input in mixture 7 (batch 3) with the pin-type agitator at a peak power of 6.34 kW (agitator and container drive) within 548 s and in mixture 9 (batch 3) with the star-type agitator at a peak power of 4.37 kW within 663 s. It can be seen that the pin-type agitator is the more effective of the two mixing tools, because the power consumption of the mixer is higher and the mixing time shorter. The amount of mixing energy input is equivalent to the area under the respective power curve and was determined by numerical integration in both cases as precisely 0.516 kW/H.
The mixing parameters are illustrated in Table 2 below.

Results

Fresh concrete properties

The sequence of the fresh concrete test takes place in a defined order. The times quoted here are referenced to the emptying of the mixer as the zero time.

Prof. Dr.-Ing. Peter Lieblang was born in 1969 and studied civil engineering at the RWTH Aachen, gaining a degree in 1994 and a doctorate in 2000 with a thesis on a topic from material mechanics. He has worked since 1995 as a freelance civil engineer and since 2000 for the Bundesverband der deutschen Zementindustrie (Federal Association of the German Cement Industry) in Cologne, Stuttgart and Berlin. He was Professor of Building Materials Sciences and head of the building materials laboratories at the University of Bochum from 2006 to 2010. Since 2009 he has also been managing partner of the Institut für Beton- und Fertigteilbau (Institute of Concrete and Precast Construction, annexed to the University of Bochum) and since October 2010 he has been Professor of Building Physics and Building Materials as well as head of the building materials laboratory at the University of Applied Sciences of Cologne. peter.lieblang@fh-koeln.de

Dipl.-Ing. (FH), M.Sc. Daniel Ringwelski was born in 1980 and studied civil engineering ('Structural Civil Engineering') at the University of Bochum (graduation in 2008) and studied civil engineering ('Sustainable Building') likewise at the University of Bochum (Master of Science in 2010). From 2007 to 2009 he worked in the design department at Berding Beton – large pipes and jacking pipes; from 2009 to 2010 he worked in a freelance capacity in the field of concrete technology/building materials technology and over the same period was a research associate at the University of Bochum in the Institute of Building Physics, Building Materials and Construction. Since October 2010 he has been laboratory head and technical manager in the research and development department at Tillman B.V. - Construction Chemicals.
d-ringwelski@tillman.nl

- Consistency after approx. 1 min,
- Fresh concrete temperature after approx. 2 min,
- Air void content after approx. 10 min,
- Manufacture of the test cubes after approx. 15 min.

The test results are illustrated in Table 3 below.

A comparison of the mixtures shows that the slump flow and the amount of mixing energy input exhibit an approximately linear correlation with a fixed recipe. This correlation, determined with the aid of a regression, is drawn in as a straight line in fig. 5.

Hardened concrete properties

Compressive strength

The effect of the mixing tool, mixing time and mixing speeds on the compressive strength was investigated. The compressive strength was determined on cubes with an edge length of 10 cm at the ages of 2, 7, 14 and 28 days following normal storage. A detailed illustration of all strength values is dispensed with at this point. Overall it can be said that the choice of mixing tool has practically no effect on the strength or development of strength. The variance in

the 28-day strength is no greater than 7 %. The strength tends to increase with a longer mixing time. However, the observed increase in the compressive strength was maximally 11 % and thus lies within the range of normal variance.
With the pin-type agitator an increase in the 2-day or 14-day strengths respectively is determined with increasing power consumption. It is 11.0 % for the 2-day strengths and 5.6 % for the 14-day strengths. These values mark the maximum differences between the lowest and highest power consumption. For the other strength developments the tendency is even less pronounced.
The test results are illustrated in Table 4 below.

Summary and outlook

In this study the effect of mixing on the fresh and hardened concrete properties of UHPC was investigated. Attention was thereby mainly paid to the fresh concrete temperature, slump flow and compressive strength. The investigations show a linear correlation between the amount of mixing energy that is applied and the slump flow. Hence it is possible, using an intensive mixer, to adjust the consistency of a UHPC recipe with the aid of the amount of mixing energy that is applied. The mixing tool or mixing time employed is of minor importance. The interactions between power consumption, mixing time, fresh concrete temperature and consistency have not yet been investigated. There is still need for explanation here. In addition, the results obtained so far give rise to the assumption that the mixing process is of no great importance for the strength or strength development of UHPC. However, this assumption must be confirmed by further tests.

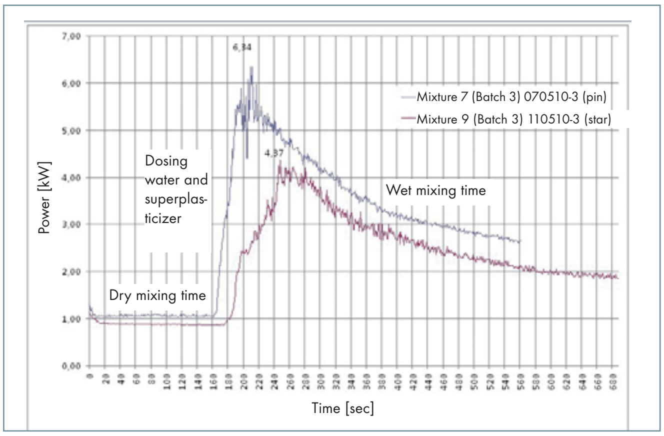

Figure 4: power consumption over time for mixtures 7 (batch 3) and 9 (batch 3)

Table 2: summary – average values of the individual batches

Mixtures	Tool	Speed (~ Power) [m/s]	Criterion	Time [sec]	Energy [kWh]
1	Pin	5,3/0,7	Time	375	0,403
2	Pin	2,6/0,4	Time	374	0,247
3	Pin	7,9/1,1	Time	378	0,581
4	Star	5,3/0,7	Time	373	0,309
5	Star	2,6/0,4	Time	371	0,178
6	Star	7,9/1,1	Time	374	0,454
7	Pin	5,3/0,7	Energy	512	0,521
8	Pin	7,9/1,1	Energy	195	0,355
9	Star	5,3/0,7	Energy	528	0,523
10	Star	7,9/1,1	Energy	258	0,349
11	Star	5,3/0,7	Energy	502	0,399
12	Star	7,9/1,1	Energy	188	0,272
13	Pin	5,3/0,7	Energy	407	0,417
14	Pin	7,9/1,1	Energy	148	0,284
15	Pin	5,3/0,7	Time	702	0,671
16	Star	5,3/0,7	Time	702	0,534

References

[1] Schmidt et al.: Brückenfamilie aus Ultrahochfestem Beton in Niestetal und Kassel, Beton- und Stahlbetonbau 101 (2006), Heft 3

[2] DIN 459–1: Mischer für Beton und Mörtel. Teil 1: Begriffe, Leistungsermittlung, Größen. Ausgabe November 1995. Berlin: Beuth Verlag. 1995

[3] O. Mazanek und D. Lowke: Reduzierung der Mischzeit von ultrahochfesten Betonen durch Optimierung der Betonzusammensetzung. Betonwerk International, 2009 (Heft 2). S. 58 – 63

[4] F. Dehn, M. Orgass: Einfluss unterschiedlichster Mischparameter auf die Frischbetoneigenschaften von ultrahochfestem Faserbeton, Betonwerk International, 2007 (Heft 4). S. 44 – 52

[5] D. Ringwelski: Einfluss der Mischparameter eines Intensivmischers auf die Frisch- und Festbetoneigenschaften von ultrahochfestem Beton, Master-Thesis (unveröffentlicht), 2010

Table 3: summary – average values of the individual batches (fresh concrete)

Mixture	Tool	Speed [m/s]	Criterion	Time [sec]	Energy [kWh]	Temperature [°C]	Gross density [kg/dm³]	LP [%]	Slump-flow [mm]
1	Pin	5,3/0,7	Time	375	0,403	22,0	2,470	4,4	620
2	Pin	2,6/0,4	Time	374	0,247	19,4	2,480	4,8	530
3	Pin	7,9/1,1	Time	378	0,581	24,0	2,520	4,4	630
4	Star	5,3/0,7	Time	373	0,309	21,0	2,470	4,6	580
5	Star	2,6/0,4	Time	371	0,178	17,6	2,470	4,4	430
6	Star	7,9/1,1	Time	374	0,454	21,6	2,500	4,1	630
7	Pin	5,3/0,7	Energy	512	0,521	23,5	2,510	4,0	640
8	Pin	7,9/1,1	Energy	195	0,355	21,4	2,460	4,4	570
9	Star	5,3/0,7	Energy	528	0,523	21,8	2,500	4,1	630
10	Star	7,9/1,1	Energy	258	0,349	20,5	2,470	4,5	520
11	Star	5,3/0,7	Energy	502	0,399	21,7	2,490	4,5	620
12	Star	7,9/1,1	Energy	188	0,272	20,2	2,450	4,9	520
13	Pin	5,3/0,7	Energy	407	0,417	23,4	2,480	4,4	640
14	Pin	7,9/1,1	Energy	148	0,284	20,2	2,450	4,5	520
15	Pin	5,3/0,7	Time	702	0,671	25,7	2,500	3,6	750
16	Star	5,3/0,7	Time	702	0,534	23,7	2,490	4,0	710

Table 4: summary – average values of the individual batches (hardened concrete)

Mixture	Tool	Speed	Criterion	Time	Energy	Concrete compressive strength			
		[m/s]		[sec]	[kWh]	2d [N/mm²]	7d [N/mm²]	14d [N/mm²]	28d [N/mm²]
1	Pin	5,3/0,7	Time	375	0,403	85,6	125,1	143,9	152,7
2	Pin	2,6/0,4	Time	374	0,247	84,3	126,6	138,5	158,5
3	Pin	7,9/1,1	Time	378	0,581	93,6	127,7	146,2	156,6
4	Star	5,3/0,7	Time	373	0,309	90,5	122,6	133,3	144,2
5	Star	2,6/0,4	Time	371	0,178	85,6	127,3	139,2	149,7
6	Star	7,9/1,1	Time	374	0,454	86,0	128,5	143,6	154,3
7	Pin	5,3/0,7	Energy	512	0,521	90,7	126,2	141,4	159,6
8	Pin	7,9/1,1	Energy	195	0,355	84,4	123,5	139,0	149,4
9	Star	5,3/0,7	Energy	528	0,523	92,5	131,8	144,3	163,3
10	Star	7,9/1,1	Energy	258	0,349	86,1	121,0	132,0	k. A.
11	Star	5,3/0,7	Energy	502	0,399	90,8	130,2	k. A.	153,6
12	Star	7,9/1,1	Energy	188	0,272	89,8	121,0	135,9	146,3
13	Pin	5,3/0,7	Energy	407	0,417	93,7	129,4	144,0	149,7
14	Pin	7,9/1,1	Energy	148	0,284	79,0	122,1	139,5	k. A.
15	Pin	5,3/0,7	Time	702	0,671	90,4	130,3	144,7	k. A.
16	Star	5,3/0,7	Time	702	0,534	83,9	125,4	140,9	160,2

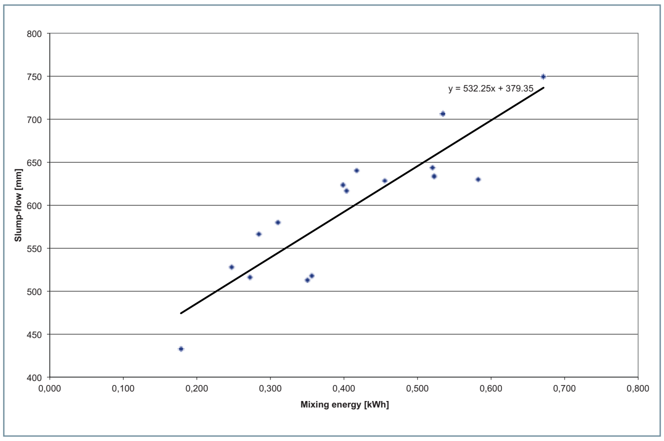

Figure 5: correlation between amount of mixing energy input and slump flow (test results and straight regression line)