Investigation on the microstructure of ultra high performance concrete

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Introduction

Ultra-high performance concrete (UHPC) is characterised by compressive strengths above 150 MPa and an outstanding durability. These properties are achieved by optimisation of the mixture composition, the mixing procedure as well as the curing conditions of the concrete. Heat curing as well as the use of vacuum mixers may contribute to the high strength. The very high brittleness of UHPC can be compensated by the addition of steel or polymer fibres.

UHPC is produced using a very low water/cement ratio of 0.25 or smaller in combination with adding of polycarboxylate ether based superplasticisers. Furthermore, finest cements with contents of 500 kg/m³, defined selections of coarse and fine aggregates with a maximum grain size between 0.5 and 8 mm and fine pozzolanic (silica fume, fly ash) and inert additives (quartz filler) are used.

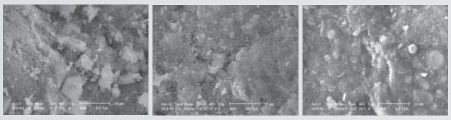
In doing so, the aim is to obtain a very high packing density of the cement paste matrix and the aggregate/paste interface while a very homogeneous microstructure with a high calcium silicate hydrate (CSH) portion is formed.

In the case of optimal mixing and curing conditions, UHPC contains almost no pores and microcracks. Therefore, studies of porosity and pore structure are very important to characterise UHPC materials in connection with the mixture optimisation. Here, the experimental results for UHPC are presented in comparison with those of high-strength concrete (100 MPa) and normal-strength concrete (35 MPa), respectively.

Concrete

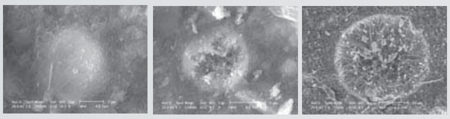
Parameter		Normal strength concrete	High strength concrete	Ultra high performance concrete
Compressive strength	(MPa)	37	109	224
Curing		under water, 20 °C (6 d) 20 °C, 65 % r.h.	under water 20 °C (6 d) 20 °C, 65 % r.h.	under water, 20 °C (3 d) heat treatment, 250 °C (2 d)
Composition				
Cement type / content	(kg/m³)	CEM I 32.5 R / 310	CEM I 42.5 R / 500	CEM I 52.5 R / 500
Silica fume	(kg/m³)	--	50	116
Fly ash	(kg/m³)	--	--	123
Quartz filler	(kg/m³)	--	--	82
w/c		0.60	0.24	0.28
w/b		0.60	0.22	0.23
Superplasticizer	(%)	--	4.5	2.8
Aggregates max. grain size / content	(mm) / (kg/m³)	32 / 1827	16 / 1672	2 / 1340

Results



NSC HSC UHPC

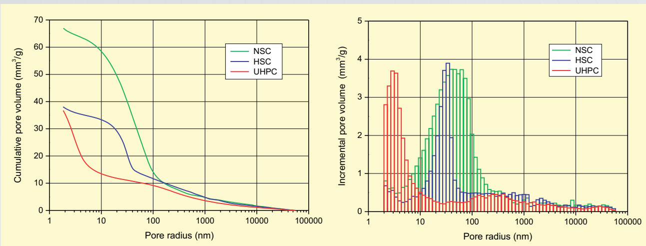
ESEM images of the cement paste matrix of normal-strength concrete (NSC), high-strength concrete (HSC), and ultra-high performance concrete (UHPC)



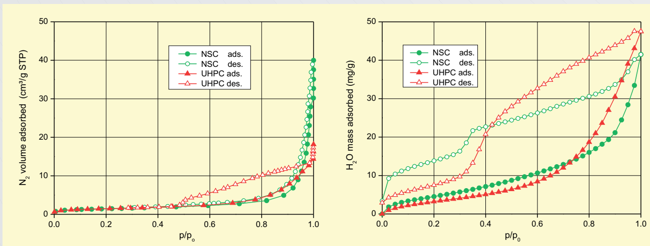
Reacted fly ash particles Air void with needle-like CSH

ESEM images of the cement paste matrix of ultra-high performance concrete (UHPC)

Method		Density & Bulk density	Mercury intrusion porosimetry				N_2 sorption	H_2O_{vapour} sorption
Parameter		Total porosity (%)	Total pore volume (mm³/g)	Capillary pore volume (%)	Gel pore volume (%)	Average pore radius (nm)	BET surface area (m²/g)	Max. adsorbed water (mg/g)
Concrete	NSC	16.9	67.0	66.2	32.7	54.1	5.0	41.5
	HPC	11.4	38.1	66.7	31.6	29.8	2.9	37.9
	UHPC	8.8	36.6	29.5	68.9	3.0	5.3	47.5



Pore volume distributions from mercury porosimetry measurements



Isotherms from nitrogen and water vapour sorption experiments

Conclusions

- In contrast to ordinary concrete and high-strength concrete, UHPC features a more uniform and denser microstructure associated with notably smaller porosity.
- In UHPC, the total pore volume and the fraction of capillary pores are reduced, but the fraction of gel pores is increased and the maximum of the pore volume distribution is shifted to lower pore radii.
- After heat treatment of UHPC, a considerable amount of fly ash particles are already participating in the hydration reactions in early ages of concrete. The thereby released aluminium and potassium ions spread in the whole cementitious matrix by migration. Up to 30 µm long needle-like reaction products of Al- and K-rich calcium silicate hydrates are formed in large air voids.
- The triangular form of the hysteresis loops both of the nitrogen and water isotherms indicate that also a platelike morphology of the CSH phase may be present.
- In general, the BET specific surface area (SSA) decreases with rising concrete strength. However, here the UHPC exhibts the largest SSA because all accessible pores are free of water. In addition, the reacted fly ash particles and other pozzolanic additives as well as the needle-like reaction products in the air voids may also contribute to the BET area.

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