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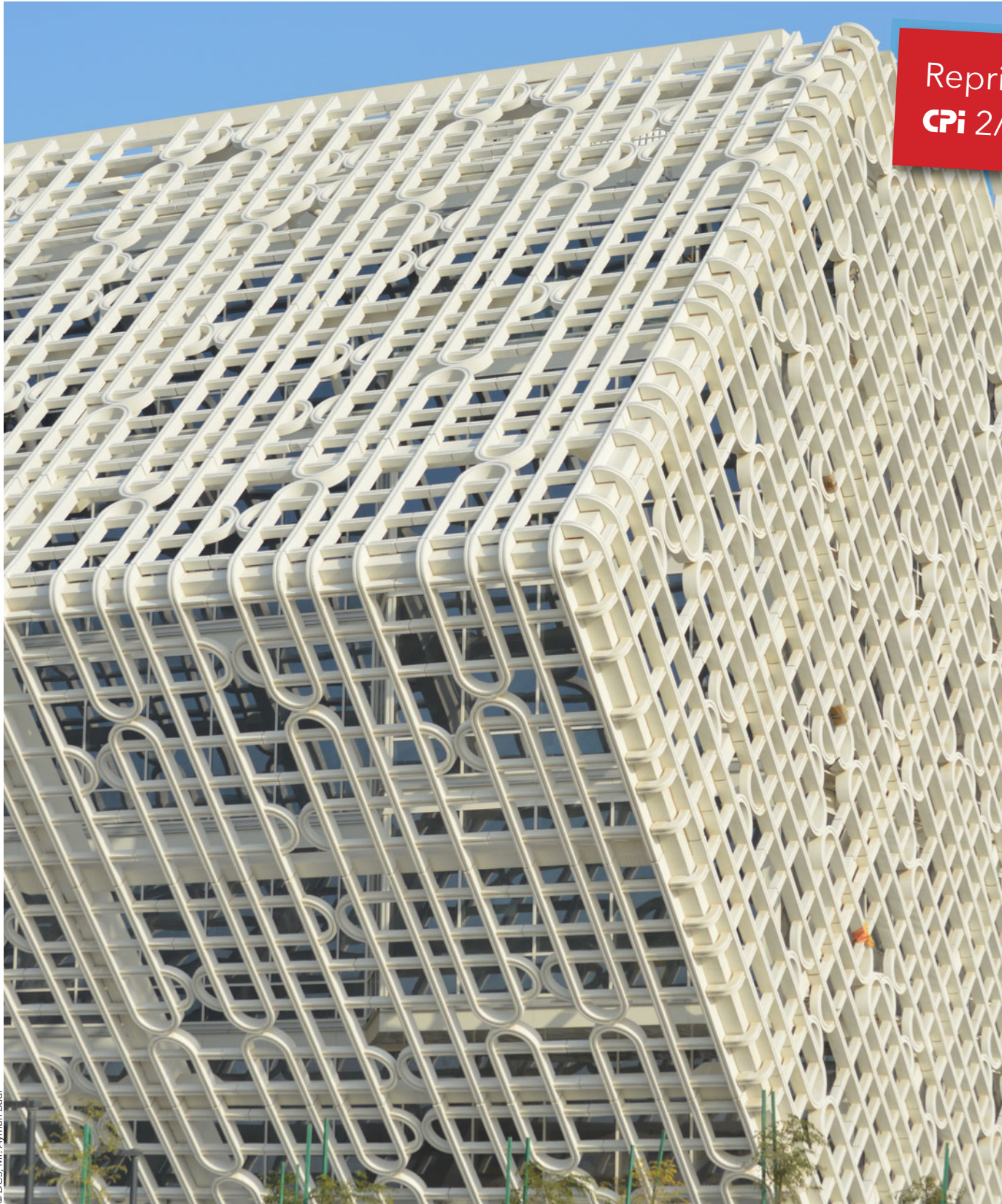
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A Babylonian confusion of languages
and simple solutions in practice



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A Babylonian confusion of languages and simple solutions in practice

■ Thomas Deuse, Stefan Hainer, Frank Parker, Thomas Sievert, Dyckerhoff GmbH, Wiesbaden, Germany

Theologians consider building the Tower of Babel to be mankind’s attempt to become equal with God. Because of this self-exaltation, God brings the construction works to a standstill without bloodshed by causing a confusion of languages, which forces the project to be abandoned due to the insurmountable difficulties in communication [1]. The differing designations used for high performance concretes are in some ways reminiscent of this historical construction project. Yet, one can still hope for a better ending in this case. Although everything is supposed to become simpler from a European perspective, there are in fact quite a number of names for a densely packed cement paste matrix based on cement and diverse ultra-fine (pozzolanic) materials with or without fibres ...

Following on from a simplified and bold description of important correlations, this article will demonstrate possibilities with modern cement technology gained from positive experience over many years with applications using high performance and ultra high performance concrete (HPC and UHPC). The

paper will also present the perspectives in line with the German standard-compliant view of ultra high strength concrete according to the new UHPC guideline intended to be published by the German Committee for Structural Concrete. Simple implementation with standard cements in conjunction with common aggregates and existing concrete mixing technology is particularly promising in this respect. It offers the prospect of considerable economic and environmental advantages when compared with conventional formulations with, amongst other things, additions such as silica fume.

At an international level, the following terms are employed for these special concretes (without claiming to be exhaustive):

- UHPC “Ultra high performance concrete”
- UHSC “Ultra high strength concrete”
- UHPFRC “Ultra high performance fibre reinforced concrete”
- DFRCC “Ductile fibre reinforced cementitious composite”

Table 1: Dyckerhoff High Performance Construction Materials

Dyckerhoff Product	Type			Composition						System	
	Cement acc. to EN 197-1	Binder compound	High Performance Concrete	Grey cement	White cement	Mineral filler	Aggregates	Steel fibers	Water + admixture	Mikrodur technology	Nanodur technology
Variodur 30	x			x						x	
Variodur 40	x			x						x	
Variodur 50	x			x						x	
Flowstone grey		x		x		x				x	
Flowstone white		x			x	x				x	
Nanodur Compound 5941 grey		x		x		x				x	x
Nanodur Compound 5941 grey		x			x	x				x	x
Xposal 105			x	x			x	x	x	x	

- SHCC "Strain hardening cementitious composite"
- ECC "Engineered cementitious composite"
- UHP-HFRC "Ultra high performance hybrid fibre reinforced concrete"
- HPFRCC "High performance fibre reinforced cementitious composites"
- RPC "Reactive powder concrete"
- UHFB "Ultra hochfester Beton" (Germany)
- UHFB "Ultra-Hochleistungs-Faserbeton" (Switzerland)
- UHLB "Ultra Hochleistungsbeton" (Germany)
- BFUP "Béton fibré à ultra-hautes performances" (France)
- BPR "Béton de Poudres Réactives" (France) [2].

In Germany, it is particularly difficult to differentiate between the English "Ultra High Performance Concrete" (UHPC) and the German "Ultra-Hochfester Beton" (UHFB). The German Wiki concrete, however, rightly states: "The term 'High Performance Concrete' is intended to highlight the fact that, for many applications, durability criteria are more important than, or equally important to, strength. There is generally no difference between high strength concrete and high performance concrete from a viewpoint of concrete technology" [3].

High Performance Concrete

Dense packing and cement hydration

Roughly simplified, classic high performance concretes are composed of standard cements (mostly with low alumina ratio) in combination with silica fumes, aggregates with graded particle sizes and, if required, micro steel fibres. An additional dense microstructure is created by the pozzolanic reaction between the calcium hydroxide formed during cement hydration and the silica fumes. As the entire system is based on very fine-graded raw materials, the cement paste matrix is substantially denser than the micro-structure in ordinary concrete and thus also stronger and more durable. This principle of dense packing has been improved at numerous universities and technical research facilities over many years: commencing with the dry raw materials, including reinforcing with various types of fibres and accelerating the cement reaction by means of heat treatment. Extremely complex systems have been created to such an extent that it has become incomprehensible to the user. These ideas are basically going into the right direction but cement hydration is a dynamic system. By adding water, the optimised dense packing of the dry raw materials is significantly changed within a short period of time by the growth of individual clinker phases. After the dormant period, the column or strip shaped crystals formed during the first hydration period develop into a matrix composed of CSH fibre bundles or CSH plate-shaped structures, plate-shaped calcium hydroxide, and needle-shaped ettringite crystals [4]. Ultra fine materials, such as silica fume, fly ash, blast furnace slag and fine limestone powder, in combination with cement cause a substantially changed microstructure at the early hydration stage [5].

In summary, it can be said that the microstructure of the hardened cement paste is formed by a wide variety of parameters. A dense packing optimised in a dry state does not necessarily have to be the best one for the crystal structures developed

during cement hydration in conjunction with admixtures and ultra fine materials.

Water/cement ratio and PCE superplasticiser

(Ultra) high performance of a precast construction element means exceptional properties and durability. Alongside dense packing, it is well known that the most important parameter is the w/c ratio, which can be adjusted to the lowest level possible with the aid of suitable PCE superplasticisers. However, it is also of great importance to know which flow properties are required in production for the specific application. Whilst shear thickening (dilatant) flow behaviour is suitable for self-compacting concrete in the precast element industry, it is rather shear thinning (thixotropic) behaviour that is advantageous for vibrated in-situ concrete. Rheological properties and consequently workability are important aspects of "(ultra) high performance".

Production

UHPC has been an object of research for more than 20 years and yet, up to now, its implementation in practice has shown little consideration for the existing state of technical systems within the concrete industry. Ready-to-use mixes tried and tested throughout the world do indeed require little extra silo and dosing capacities but do not generally work without high performance mixers. A few companies have specialised in this particular field but there is no sign of a wide application of classic high performance concretes based on Portland cement and fine-graded pozzolans.

However, there have nonetheless been well-proven, high performance concretes based on modern cement technology available for more than 15 years. These will be presented in this article using examples of applications. Table 1 gives an overview of various tried and tested varieties.

Binder compound premixes for self-compacting concretes

Flowstone HPC in precast element production facilities

The concrete industry needs robust mix designs and not just the highest technical performance. Dyckerhoff forged ahead with pioneer work in the case of Flowstone to develop a binder compound premix for HPC based on Mikrodur® technology with normal and ultra fine cement components optimised in size plus fine quartz sand. This premix has been successfully utilised for years in artistic and architectural concrete with suitable admixtures, aggregates and pigments tailored for the purpose. With water-cement ratios considerably less than 0.4, durable concretes can be configured accurately with compressive strengths higher than 100 MPa and flexural strengths in the range up to 15 MPa. The latter are actually more important, as it mostly concerns filigree construction elements – such as façade panels –, which are subjected to bending rather than pressure. Since its launch on the market more than 15 years ago, Flowstone has proven itself in the following areas of application:

Examples for the application of Flowstone

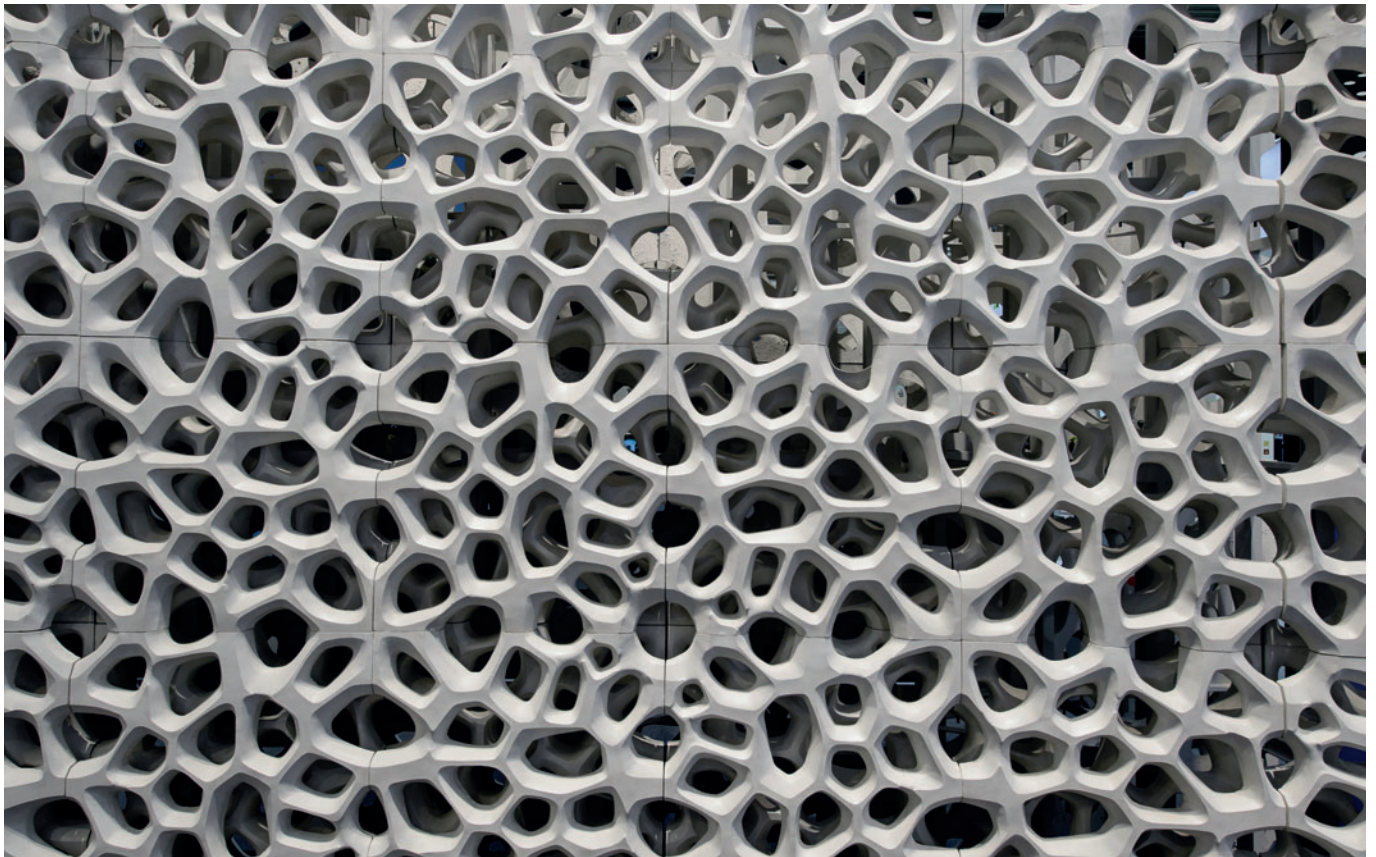


Fig. 1: Honeycomb wall Frankfurt (Flowstone)



Fig. 2: Wehrhahn Underground Line Düsseldorf (Flowstone) (Picture: Joerg Hempel)

- High-quality cast stone slabs for indoor and outdoor areas
- Large format slabs and angled staircases
- Concrete products with very high resistance to frost/de-icing agents
- Non-reinforced cast stone façades
- Concrete furniture for indoor and outdoor areas
- Coping stones, pillars and balustrades
- Window benches and special elements.

Nanodur® UHPC in precast production facilities and as in-situ concrete

Nanodur Compound 5941 is a binder premix made from 59 % standard and ultra fine components controlled by synthetic silica and 41 % fine quartz sand. Robust, very simple basic mix designs with air-dried sand 0/2 mm and chippings 2/5 mm as a coarse grained variant or those just with sand 0/2 mm as a fine particle mixture enable UHPC to be manufactured in ordinary concrete mixers.

With special aggregates, a modulus of elasticity of 80,000 MPa can be attained - corresponding to that of aluminium. Besides suitable PCE based super-plasticisers, the use of approx. 8 l/m³ shrinkage reducing admixture is recommended in order to minimise restraint forces during hardening and alterations in the shape of the finished construction element.

Nanodur for machine beds and tool frames (precast production facility)

One of the most significant fields of application for UHPC in Europe and China today is in manufacture of machine beds and tool frames [6].

Their geometry is sometimes very complex. Wood and plastic moulds are often utilised with self-compacting UHPC to prevent troublesome compaction work in steel formwork (as required with polymer concrete). Besides easy processing, UHPC possesses advantages particularly with regard to vibration damping when compared with metallic materials such as grey cast iron or welded steel structures. Tool machines are becoming increasingly faster and their precision in processing depends to a great extent on the smooth running of the machine bed. Of course, this effects the operational life of the tools and, in this case, UHPC provides a 10 - 20 % longer service life compared to welded steel structures.

Nanodur for special elements in the construction industry (precast production facility)

As the Nanodur Compound 5941 binder premix is not standardised, its utilisation is restricted to special construction elements in the building industry in Germany. It started at the BAU 2011 in Munich with a demonstration stairway as a folded structure with steps of merely 29 mm in thickness that

Table 2: Nanodur Standard Mixes

Examples of mix design		Coarse mix E80	Coarse mix E45	Fine mix
Nanodur Compound 5941 grey	[kg/m ³]	1,050	1,050	1,050
Pit sand 0/2 mm (air-dry)	[kg/m ³]	-	430	1,150
Chippings 2/5 mm (air-dry)	[kg/m ³]	-	880	-
Durigid 1/3 mm	[kg/m ³]	1,193	-	-
Durigid 3/6 mm	[kg/m ³]	430	-	-
Micro steel fibres 020/10	[kg/m ³]	-	60	-
PCE-superplasticiser	[kg/m ³]	17	15	18
Water	[kg/m ³]	149	158	168

Mechanical values after 28 days specimen storage under water at 20°C

Flexural strength*	[MPa]	23	20	18
Prism compressive strength*	[MPa]	180	150	130
Cylinder compressive strength**	[MPa]	150	130	120
Modulus of elasticity**	[MPa]	80,000	50,000	45,000

* Prism 4 cm x 4 cm x 16 cm | ** Cylinder d = 15 cm, h = 30 cm



Fig. 3: Robot cell (Picture: FPT Robotik GmbH & Co. KG)

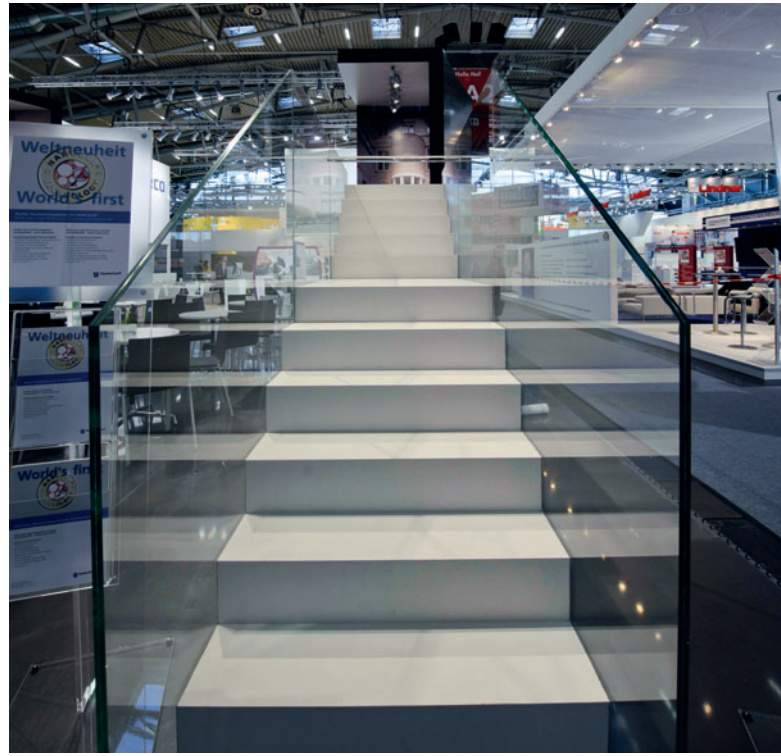


Fig. 4: Demonstration stairway

were glued between two sheets of laminated safety glass 20 mm thick. A load test at the Technical University of Dresden gave a load-bearing capacity of about 2 tonnes per step. The fine particle mix reinforced with 75 kg/m³ micro steel fibres held the load up to 3 mm deflection. It also exhibited a good working capacity and ductile behaviour without conventional reinforcing steel [7].

Parabolic troughs are employed in solar thermal power plants for generating energy by bundling the incident sun rays. Most of the collectors are designed as a steel framework. An interdisciplinary consortium made up of representatives from the fields of industry and science under the leadership of the German Aerospace Centre developed a giant demonstration unit for research purposes made from high performance concrete and based on an idea from the Technical University of Kaiserslautern and the Ruhr-University Bochum. Glued-on sheet metal mirrors made of aluminium serve as reflectors for the two 12 m long and 6 m wide UHPC parabolic troughs produced at the Stanecker precast concrete production facility in Borchon. The supports and mechanical assembly in the form of gearwheel and sickles for tracking the sun were produced by TU Kaiserslautern itself using a UHPC coarse particle mix based on Nanodur Compound 5941 [8].

Modular structures made from individual UHPC elements glued to each other to construct a two-storey shrimp farming facility 35 m in length and 5 m wide were implemented in cooperation with the Drössler construction company in Siegen and Green Aqua Farming, Grevesmühlen. The elements have a wall thickness of only 6 cm and were produced without reinforcement using a coarse particle mix with Nanodur Com-



Fig. 5: Parabolic mirror

pound 5941. Once they had been assembled together, the joints were sealed with an epoxy resin adhesive in conjunction with UHPC cover plates. A hydraulic mortar approved for drinking water was utilised for waterproofing the joints between the cover plates and pool elements [9].

The Walsenbridge in Oberstdorf is part of the Stillach flood protection system; the bridge parapet forms a prolongation of a protective embankment against high water. An intentional back-up of water is caused by the small flow cross sec-



Fig. 6: Shrimp farming facility



Fig. 7: Walserbridge (Picture: Rainer Retzlaff)



Fig. 8: Building envelope in Qatar (Picture: Ayman Badr)

tion in the bridge area when the river floods. For this reason, the new bridge parapet had to be manufactured as an enclosed unit. The parapet needed to be particularly tough due to the expected impact of drift wood as well as de-icing salt attack. For economic reasons, only the outer shell was produced as a precast UHPC element using Nanodur Compound 5941 at the Bayer concrete production facility in Munderkingen [10].

In Qatar, a filigree building envelope was constructed from UHPC elements with 6 m in length on average. Doha

Cladding Solutions developed a mix design with Nanodur Compound 5941 in combination with special aggregates exhibiting a cube compressive strength of between 170 and 180 MPa and a flexural strength of almost 25 MPa after 56 days.

Nanodur for structural strengthening (in-situ concrete)

A pilot project initiated by Graz University of Technology in Austria successfully tested the practicability of strengthening



Fig. 9: Bridge strengthening (Picture: TU Graz)

the concrete of bridges with UHPC. 40 m³ UHPC with Nanodur Compound 5941 were prepared in a ready-mix concrete production facility and installed as in-situ concrete. The objective was to enhance the load-bearing capacity with concurrent waterproofing as a replacement for the bituminous surface. The grading curve had to be optimised with a gradient of up to 4.5 % for the installation. Compressive strengths of 146 MPa after 28 days and 172 MPa after 98 days were measured on cubes with 100 mm edge lengths. In the 4 point test on beams 150 x 150 x 700 mm³, the flexural strength was 11.5 MPa - the modulus of elasticity reached 52,000 MPa [11].

As these examples show, the Flowstone and Nanodur Compound 5941 binder premixes have shown their practical suitability in the various fields of application over several years. Research work in sponsored projects has demonstrated the potential optimisation possibilities in cement production facilities [12]. However, since it concerns mixed products principally made from cement constituents and kiln-dried, quality-monitored aggregates, its utilisation in Germany in the area of construction is not possible without very time-consuming and expensive approvals. Approval in individual cases can only be obtained in relation to a project and the costs for a general building authority approval are totally disproportionate to the eventual proceeds. Currently, only niche applications are remaining for this kind of construction that, although more expensive in manufacture, is more advantageous due to its longer service life.

It is a completely different matter when high strength concretes are manufactured based on standard cements. The desired objective of dense packing can be adjusted without silica fume using Dyckerhoff Mikrodur Technology by means of ultra fine cement components with graded particles. This means that e.g. concretes of strength class C90/105 can be implemented easily in The Netherlands and in Germany with approval on an individual case basis.



Fig. 10: Ewijk Bridge (Picture: Bart van Hoeck)

Variodur® standard cements for HPC, UHPC

Actually, compressive strength is just a general basis for assessing the application in bridge strengthening. Its flexural strength and modulus of elasticity in conjunction with steel bar or steel fibre reinforcing have to ensure that the loads can be transferred. A very dense microstructure is essential in order to encounter the stresses in road bridges caused by changes in temperature as well as resistance to frost and de-icing salt. In The Netherlands, high performance concretes have frequently been successfully utilised - both special mixes based on standard cement and silica fume, and Dyckerhoff premium cements with Mikrodur Technology as the sole binder in ready-mix concrete. This meant that a comparatively high performance was possible during concrete paving.

Bridge strengthening with Xposal® 105 HPC ready-mix concrete based on Variodur 30 CEM II/B S 52.5 R standard cement

The old bridge over the river Waal (also called the Ewijk Bridge) was constructed in 1976. It was one of the steel bridges in The Netherlands no longer capable of coping with current traffic loads before its renovation. Strengthening the load-bearing slab by means of a surface layer made from reinforced high strength concrete (C90/105) is a method that has already been employed many times in The Netherlands. This measure reduces stresses in the load-bearing slab by 80 % in comparison with an asphalt top layer, thus enhancing a bridge's service life substantially. The composition of this high strength concrete was developed by Dyckerhoff Basal together with the Wilhelm Dyckerhoff Institut. The result - Xposal 105 - features a tough, high strength concrete of the C90/105 compressive strength class based on Variodur 30 CEM II/B S 52.5 R standard cement. The concrete was supplied by the Dyckerhoff Basal facility in Arnhem. A total of approx. 2,400 m³ Xposal 105 was supplied during 20 concreting days in a time period from June to December 2018; concret-

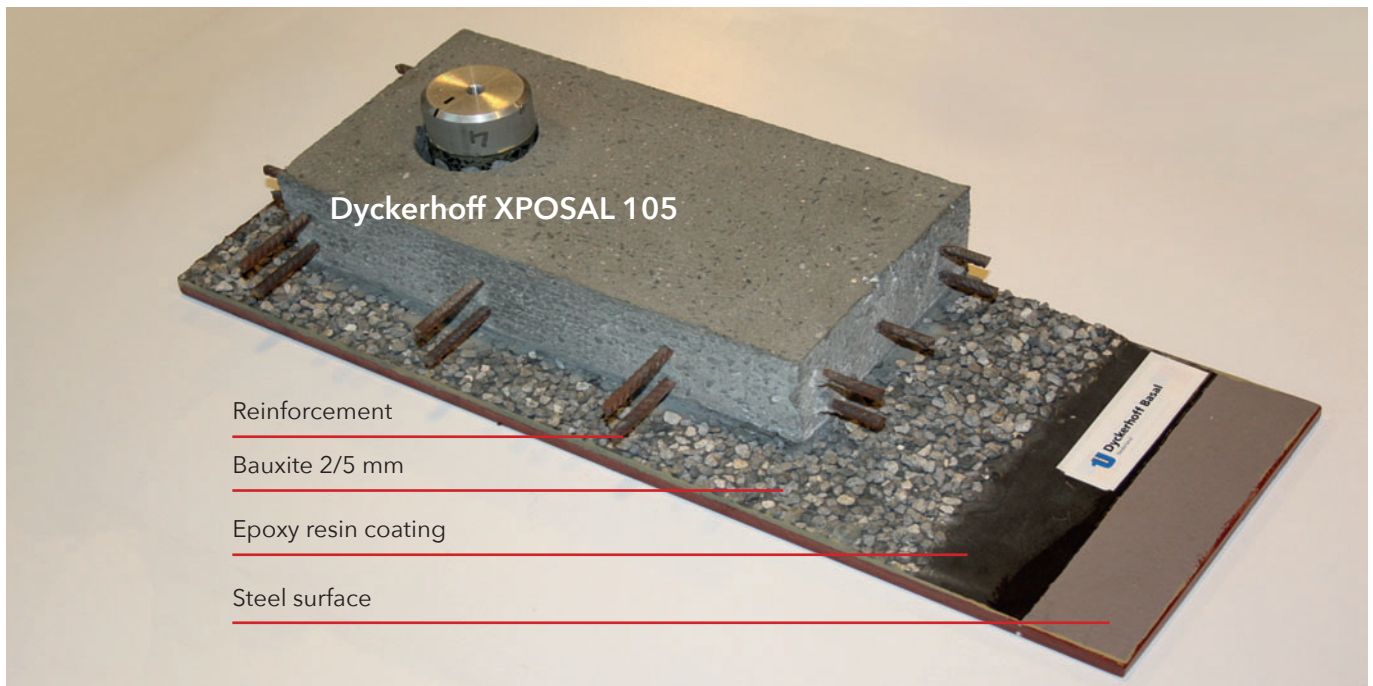


Fig. 11: Design

ing was also carried out twice at night. To install this 8 cm thick concrete layer, the contracting consortium (Strukton and Ballast Nedam) developed a special paving machine, which places great demands on the concrete’s uniformity. This paving machine can create very strong bonding between concrete and steel up to a width of 12 metres with great compaction energy. Its speed of 20 cm per minute enabled the layering of 100 m of bridge covering to be completed in one day. A bonding agent made of bauxite and epoxy resin was applied to generate optimum adhesion at the steel surface. Conventional steel reinforcement and 75 kg/m³ steel fibres were utilised that were added with a new dosing system in the concrete production facility [13].

UHPC coarse particle mix without silica fume with Variodur 40 CEM III/A 52.5 R standard cement

This CEM III/A 52.5 R premium cement has shown its suitability in various concretes with high requirements on durability, e.g. in concrete pipes in the context of renaturation of the Emischer river [14] or in precast railway platform elements for British Rail [15]. It was therefore a natural step to carry out preliminary trials with this cement to attain strength classes above C130/145. The aim was to create a simple concrete mix without any specially graded fractions in the binding compound or in the aggregate. The highest strengths were attained (Tab. 4) in numerous tests with the sand 0/2 mm and

Table 3: Mix design

Requirements for the Concrete

Strength / Exposure Class	C90/105 / XF4
Slump flow	F3/ F4: 450-500 mm
Workability time	≥ 2 hours
Air content	≤ 2.0 %
Density	≤ 2,500 kg/m ³ (±5 %)
Flexural strength	10 MPa (±15 %)
Modulus of elasticity	50,000 MPa (±10 %)
Autogenous shrinkage	≤ 3.0 ‰
Resistance to frost /de-icing salt	≤ 100 g/m ²
Chloride migration	≤ 2.0 * 10 ⁻¹² m ² /sec
Coarse aggregate 2/5	Resistant to alkali-silica reaction
Steel fibres (L = 12.5 mm, ø = 4 mm)	≥ 75 kg/m ³ (homogeneously distributed)

chippings 2/5 mm aggregates already tried and tested in Nanodur UHPC and mixed in a ratio of 30 : 70. The influence of cement content and w/c ratio on compressive strength on the one hand and the dosage of a special PCE superplasticiser on the other are illustrated in the following (Figs. 12 and 13).

The optimum for good workability and compressive strength > 150 MPa is to be found at about 700 kg/m³ Variodur 40 CEM III/A 52.5 R without supplementary reactive substances, such as silica fume.

Despite its low w/c ratio of 0.20, good workability (flow spread 430 mm) is achieved by means of a special PCE superplasticiser. However, high dosages of this superplasticiser delay the strength development - represented in this case by the tem-

perature profile at a young age (compare Fig. 14). This coarse particle mix design at a dosage of 2.4 M.-% of the cement weight and a low w/c ratio would only be suitable to a limited extent for precast elements, since its strength only amounted to about 15 MPa after 24 hours. However, by increasing the w/c ratio to 0.22 and with an accompanying reduction in PCE dosage to 1.6 M.-%, significant strength development already occurs after 16 hours and just on 40 MPa were attained after 20 hours.

Final strength is reduced by approx. 5-10 % by an increased w/c ratio. The utilisation of VARIODUR® 40 CEM III/A 52.5 R standard cement as sole binder - of itself economically advantageous - also lowers the carbon footprint of the concrete by about 30 % in comparison with UHPC coarse particle mix designs reported in the literature, based on Portland cement and silica fume.

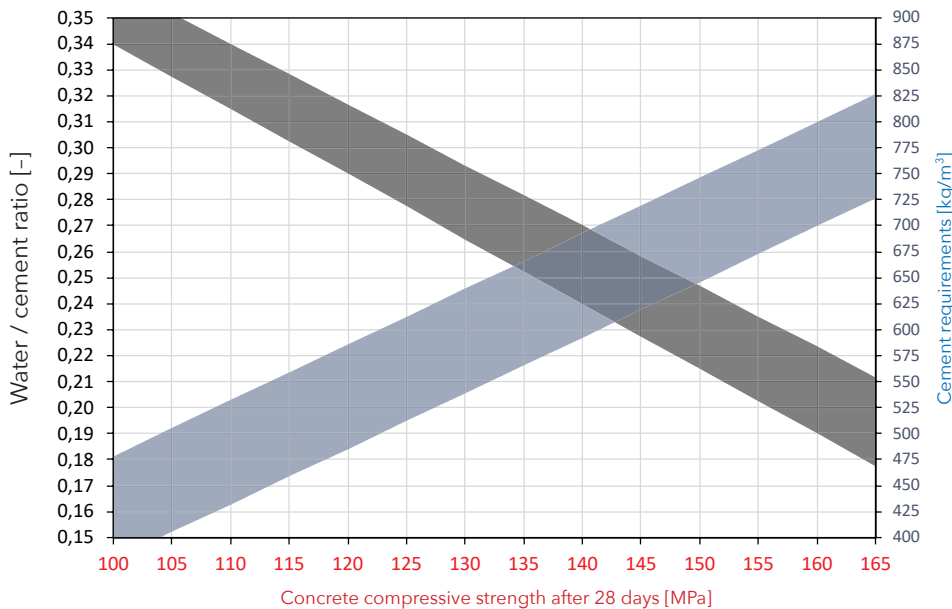


Fig. 12:
Cement content vs. w/c ratio

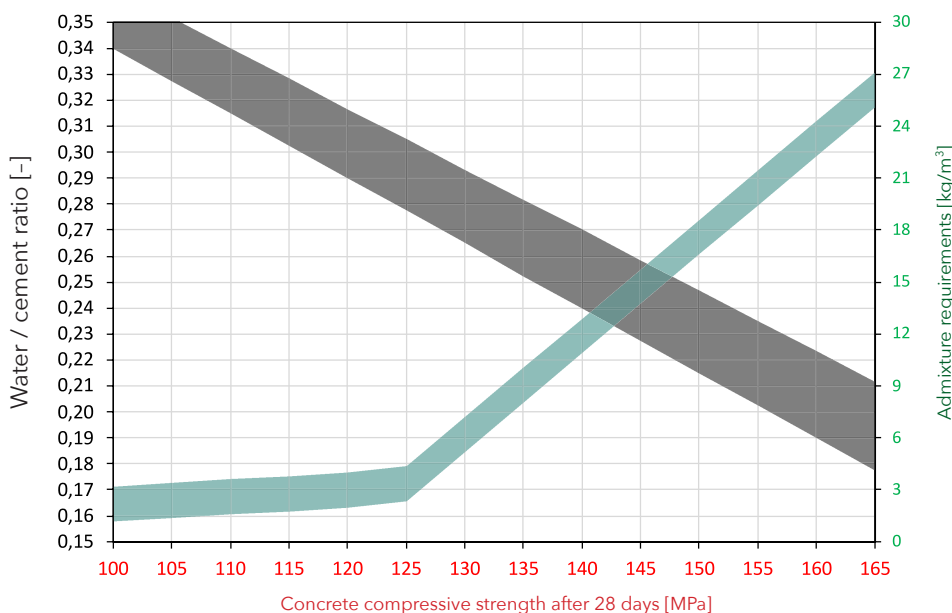


Fig. 13:
Admixture content vs. w/c ratio

Temperature profile in the concrete

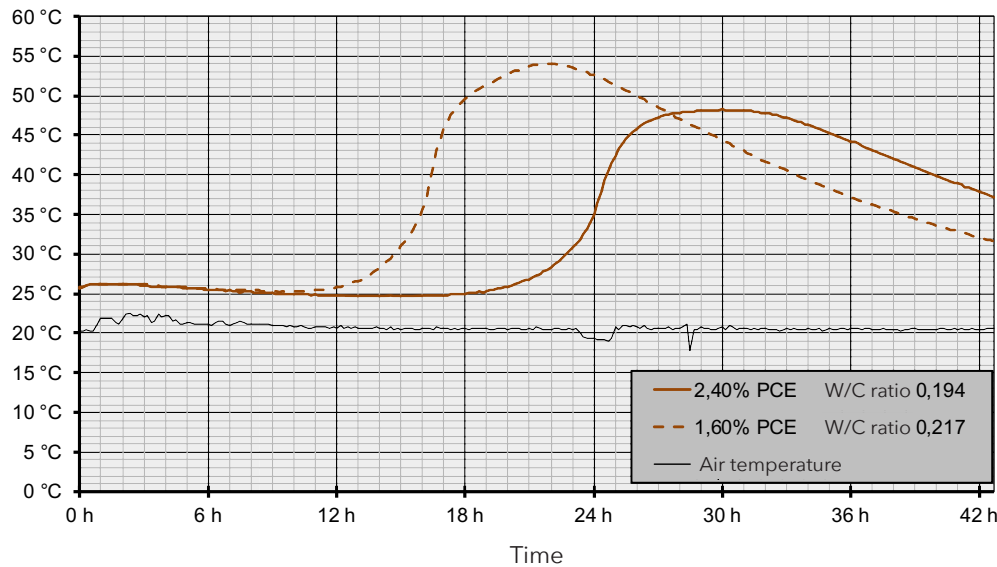


Fig. 14:
Temperature curve

UHPC coarse particle mix without silica fume with micro steel fibres and Variodur 40 CEM III/A 52.5 R standard cement

Fine particle UHPC layers with a high proportion of micro steel fibres are being increasingly utilised in reinforcing infrastructure buildings, such as in Switzerland [16]. Specially graded aggregates with a particle size < 1 mm ensure dense packing in combination with silica fume [17]. Usually, many special components have to be dosed along with the admixtures in a concrete production facility - which can hardly be achieved with existing silos and weighing systems. As a consequence, components are often added manually - certainly feasible in pilot projects giving thoughtful consideration to occupational safety stipulations - but difficult to implement as

a permanent economic solution. Conventional UHPC mixes mostly contain about 50 % binder made up of Portland cement and silica fume. At the usual very low w/c ratios, only parts of them react hydraulically - more than 60 % cement and more than 20 % silica fume remain as unreacted "high quality aggregates" in the densely packed matrix [18].

A fine particle UHPC (Tab. 4) was produced only with Variodur 40 CEM III/A 52.5 R, fine quartz sand, micro steel fibres and the special PCE for low w/c ratios with the purpose of simplifying the above-mentioned compositions. C130/145 concrete can be varied according to the application planned with fibre content from 200 - 250 kg/m³, w/c ratios from 0.20 to 0.24 and cement fractions from 42 - 49 % in relation to the dry mix.



Fig. 15: Coarse particle mix design



Fig. 16: Fine particle mix design

Table 4: Standard Mixes

UHPC recipes with high performance		Coarse particle		Fine particle
VARIODUR 40 CEM III/A 52,5 R	kg/m ³	700	900	900
UHPC Additive CEM III/C 52,5 N	kg/m ³	-	-	80
Fine quartz sand 0.063/0.25 mm	kg/m ³	-	1,230	1,150
Rhine sand 0/2 mm	kg/m ³	480	-	-
High-grade basalt chippings 2/5 mm	kg/m ³	1,300	-	-
Micro steel fibres	kg/m ³	-	200	200
PCE for low w/c ratios	kg/m ³	17	25	22
Water (incl. water from PCE)	kg/m ³	136	196	196
w/c ratio	-	0.20	0.22	0.20
Flow spread	mm	430	450	510
Hardened Concrete Properties 28 days				
Cube compressive strength	MPa	162	157	173
Cylinder compressive strength	MPa	158	145	157
Modulus of elasticity	MPa	55,600	43,900	46,800
Flexural strength	MPa	-	22.0	22.3

UHPC fine particle mix with a standard cement combination of Variodur 40 CEM III/A 52.5 R and UHPC additive CEM III/C 52.5 N

UHPC mixes rich in fibres are stable in gradient and well able to be processed when compacted with pavers for upgrading the strength of bridges. High ductility due to good force transmission to the micro steel fibres, which need to be very densely embedded, is especially important with thin reinforcements. The UHPC additive, an ultra fine cement compliant with standards such as CEM III/C 52.5 N, can additionally

compact the microstructure with fine particles ($d_{95} < 9,5 \mu\text{m}$). At 80 kg/m³ to the expense of fine quartz sand, the water amount in the standard fine particle mix remained constant with just on 200 kg/m³, i.e. the w/c value declined from 0.22 to 0.20. As a consequence, the compressive strength rose by about 10 %; the flow spread increased from 460 to 510 mm by reducing the PCE quantity from 25 to 22 kg/m³. The shift into the finer area of the particle size distribution is visible with laser granulometry when comparing Variodur 40 alone and with the addition of the UHPC additive (Fig. 17).

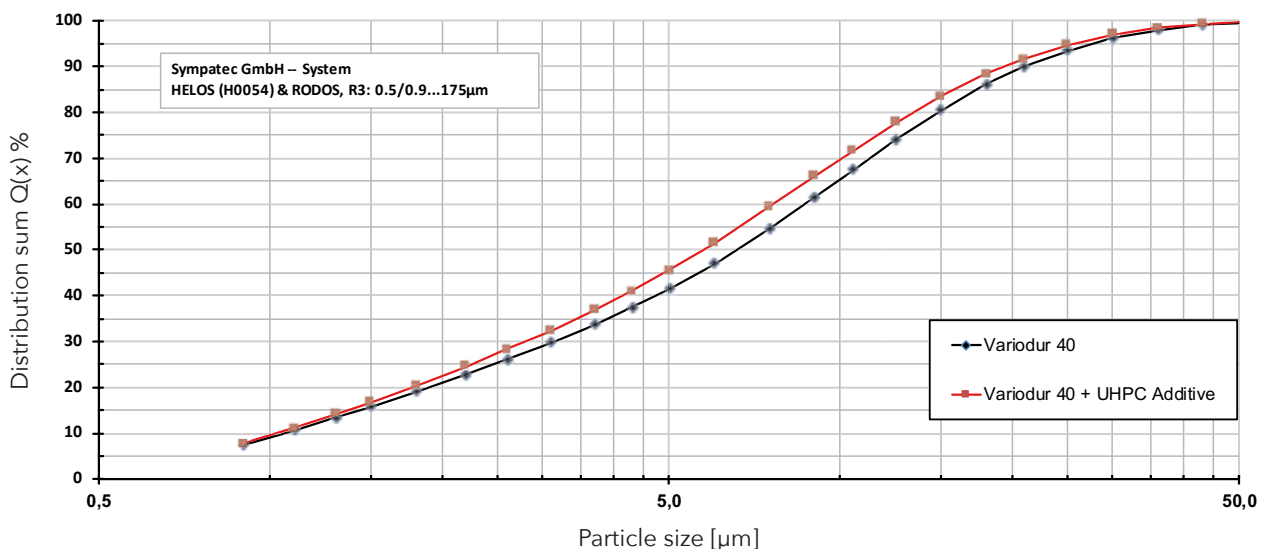


Fig. 17: Laser granulometry



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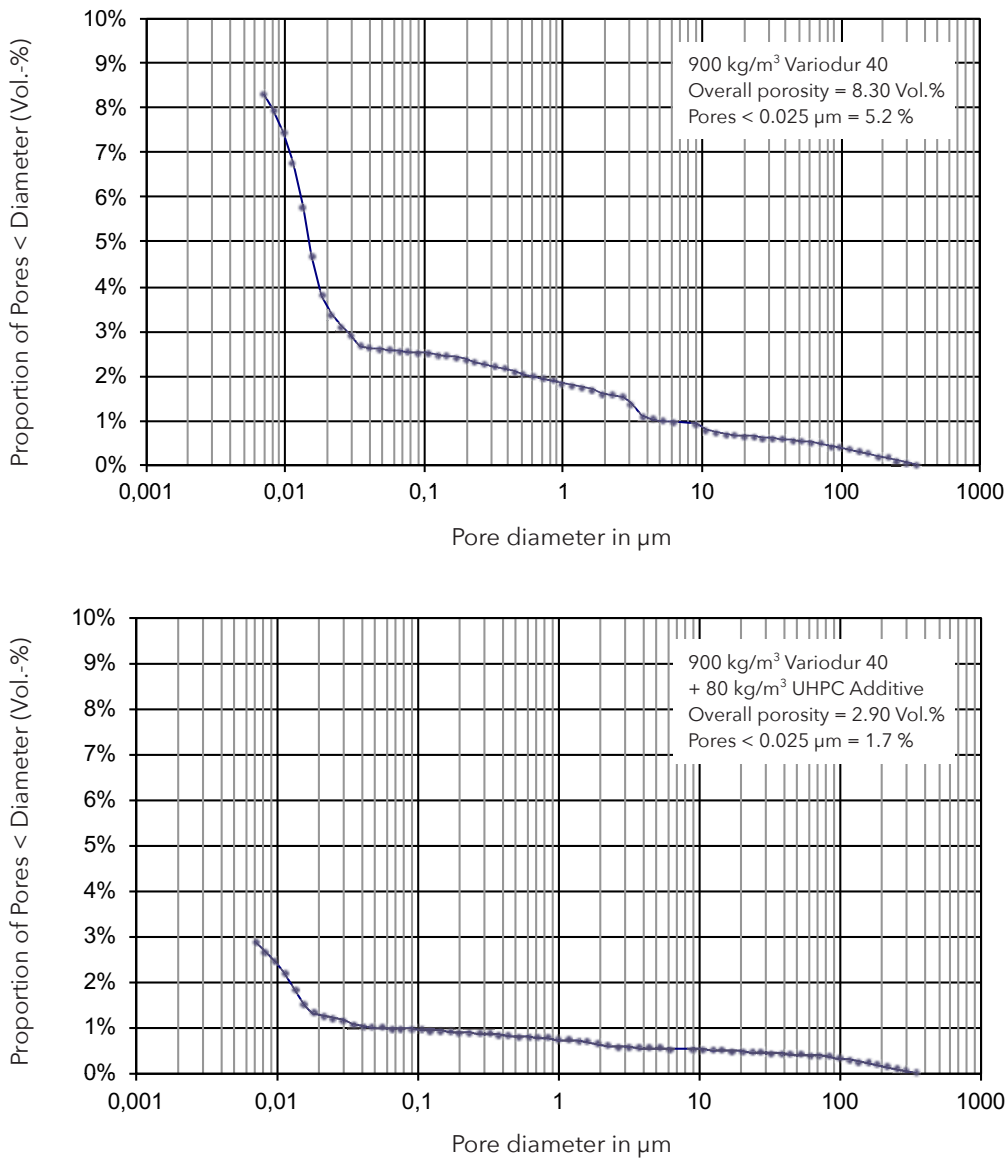


Fig. 18: Alteration in the cumulative distribution of pores by adding 80 kg/m³ UHPC additive

Mercury intrusion porosimetry shows a substantial reduction in overall porosity from 8.3 to 2.9 Vol.-% as well as a decrease in pores < 0.025 µm from 5.2 to 1.7 %. Central post-cracking tensile strength increased as a result of the UHPC additive as regards flexural behaviour.

A C130/145 can only be produced for requirements in Germany with the simple version made from Variodur 40 CEM III/A 52.5 R standard cement, fine quartz sand 0.063/0.25 mm, PCE for low w/c values and 200 kg/m³ micro steel fibres.

With higher requirements as regards ductility, the concrete mix can be further optimised by the addition of the UHPC additive (standard compliant as CEM III/C 52.5 N), e.g. to fulfil the requirements for ultra high performance fibre concrete according to the SIA 2052 leaflet of the Swiss Society of Engineers and Architects.

Basically, all the mix designs given in this article represent concepts for the targeted development of UHPC and are based on specific project requirements from projects, taking into account the respective raw material situation of the user. In the case of the standard coarse particle mix, this has already been successfully implemented in practice.

Summary and conclusion

The dense microstructure of high performance concretes substantially improves both compressive and flexural strengths, increases resistance to chemical and mechanical attacks and, as a result, leads to better functional characteristics and enhanced durability. The solutions based on cutting-edge cement technology that have been presented in this article have no need of pozzolanic additions, such as silica fume, and can be implemented with common aggregates and normal concrete mixing technology.

- Flowstone: Binder premix for self-compacting HPC - High Performance Concrete as artificial stone in a precast production facility
- Nanodur: Binder premix for self-compacting UHPC - Ultra High Performance Concrete for special construction elements and mechanical engineering in a precast production facility

This more expensive manufacturing method, when compared with normal concrete, usually pays for itself in just a few years in connection with a significant reduction in cross section. Applications with these binder premixes being tried and tested over many years will also in future only be possible with an approval on an individual basis or general building authority approval in Germany. As the possibilities for their use are very limited, the high costs for the previously mentioned approvals are out of proportion to the proceeds.

- Variodur: Standard cement for manufacturing HPC and UHSC without silica fume in a precast production facility and as in-situ concrete, as well as maintenance and strengthening of construction elements.
- UHPC Additive: Standard compliant ultra fine cement for the granulometric optimisation of HPC and UHSC mixes

In order to use the interesting results of publicly funded projects [12], Dyckerhoff is continually searching for new ways of manufacturing high performance concretes using few simple, standardised components. It is now possible, using a special PCE superplasticiser for low w/c ratios, to successfully combine the utilisation of standard cements based on Mikrodur Technology that have been tried and tested over many years with the experience gained from UHPC projects. It was helpful to simplify the mix designs and not to integrate every new, supposedly suitable raw material into the already complicated compositions.

The use of ordinary standard cement without reactive additives, such as silica fume, reduces the effort needed for building authority licensing procedures. Enhanced requirements can be achieved by using a standardised UHPC additive as control component.

This means that there is a practical solution for all applications using mixes that are simple to implement. The acceptance of high performance concretes should be accelerated in practice by this means and the number of terms described at the beginning should in future be reduced.

The environmental advantage of high performance concretes is generally a reduction in CO₂ thanks to the lower masses of more slender construction elements. The economically most interesting alternative Variodur 40 CEM III/A 52.5 R standard cement as the sole binder exhibits only about 60 % of CO₂ emissions compared to the usual UHPC mixes with combinations of Portland cement and silica fume. In addition, this also increases the ecological benefit. ■

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FURTHER INFORMATION



Dyckerhoff GmbH, Product Marketing
 Postbox 2247
 65012 Wiesbaden, Germany
 T +49 611 676 1181
marketing@dyckerhoff.com
www.dyckerhoff.com