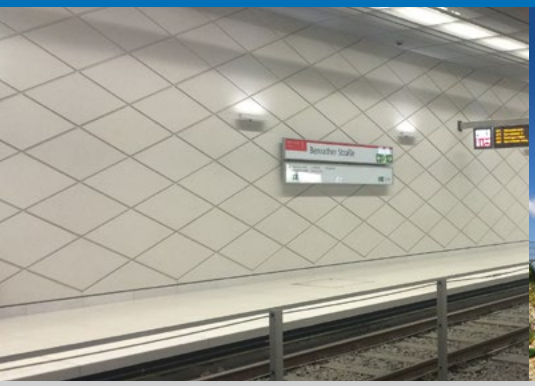
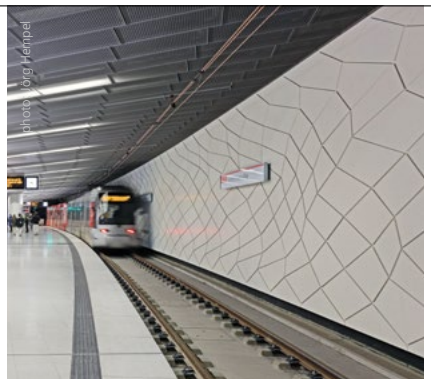
Dyckerhoff

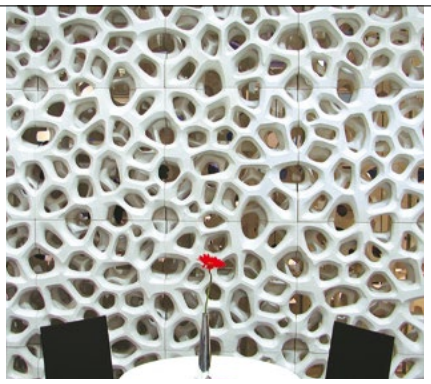
Dyckerhoff BUILDING MATERIALS
for high performance concrete



High Performance Concrete (HPC) for Artificial Stone and Precast Elements
with Dyckerhoff FLOWSTONE®



Wehrhahn Underground Line, Düsseldorf



Honeycomb wall

FLOWSTONE

Application:	concrete elements
Compaction:	self-compacting
Production:	prefabrication
Type of binder:	premix of cement and mineral flour
Color:	white and gray

Short description

Introduction

"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." (www.beton.wiki)

Common abbreviations:

HPC
High **p**erformance **c**oncrete

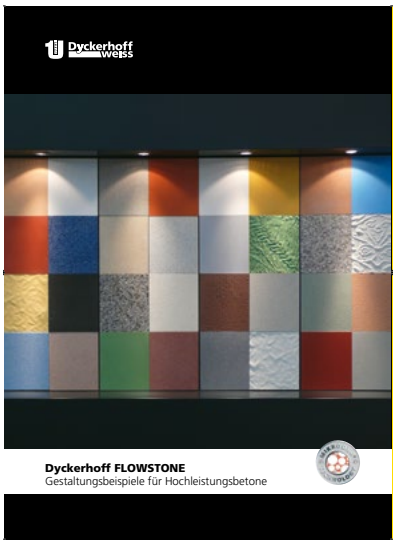
UHPC
Ultra **h**igh **p**erformance **c**oncrete

UHPFRC
Ultra **h**igh **p**erformance **f**iber **r**einforced **c**oncrete

Binder premix for self-compacting concrete in precast plants

The concrete industry needs robust formulations and not just the highest technical performance. In the case of FLOWSTONE, Dyckerhoff forged ahead with pioneer work to develop a binder compound premix for HPC based on MIKRODUR® technology with normal and ultrafine cement components optimized in size plus quartz fines. This premix has been successfully utilized for years in architectural concrete with suitable admixtures, aggregates and pigments recommended for the purpose. With w/c ratios considerably < 0.4, durable concretes can be configured accurately with compressive strengths > 100 MPa and flexural strengths in the range up to 15 MPa. The latter are, in fact, more important, as it mostly concerns filigree construction elements – such as façade panels – which are more stressed in terms of bending than pressure.

Since its launch on the market more than 15 years ago, FLOWSTONE has proven itself in the following **areas of application**:
– 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
– Artificial stone façades
– Concrete furniture for indoor and outdoor areas
– Coping stones, pillars and balustrades
– Window benches and special elements
– Precast elements



Ultra High Performance Concrete (UHPC) for Machinery Industry
with Dyckerhoff NANODUR® Compound 5941

NANODUR

Application:	machinery industry
Compaction:	self-compacting
Production:	precast plant
Type of binder:	premix of cement and mineral flour
Color:	white and gray

Short description

Machine bed with NANODUR

Binder premix for self-compacting concrete in precast plants

Machine beds and tool frames

One of the most significant fields of application for UHPC is the manufacture of machine beds and tool frames. Their geometry is sometimes very complex. Wood and plastic moulds are often utilized 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 to metallic materials such as gray cast iron or welded steel structures.

NANODUR Compound 5941 is a binder premix made from 59 % standard and ultrafine components actuated by synthetic silica and 41 % fine quartz sand. Robust, very simple basic formulations with air-dried sand 0/2 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 simple concrete mixers.

With special aggregates, a module of elasticity of 80,000 MPa can be attained, corresponding to that of aluminum. Besides suitable PCE (poly-carboxylate ether) based superplasticizers, the use of approx. 8 l/m³ shrinkage reducing admixture is recommended in order to minimize restraint forces during hardening and alterations in the shape of the finished construction element.

Robot cell

Examples of mix design		Coarse mix E80	Coarse mix E45	Fine mix
NANODUR Compound 5941 gray	[kg/m³]	1,050	1,050	1,050
Pit sand 0/2 mm (air-dry)	[kg/m³]	-	430	1,150
Chippings 2/5 mm (air-dry)	[kg/m³]	-	880	-
Durigid 1/3 mm	[kg/m³]	1,193	-	-
Durigid 3/6 mm	[kg/m³]	430	-	-
Micro steel fibers 020/10	[kg/m³]	-	60	-
PCE superplasticizer	[kg/m³]	17	15	18
Water	[kg/m³]	149	158	168
Mechanical values after 28-day storage of the test specimen under water at 20 °C				
3-point flexural strength*	[MPa]	23	20	18
Prism compressive strength*	[MPa]	180	150	130
Cylinder compressive strength**	[MPa]	150	130	120
Young's modulus**	[MPa]	80,000	50,000	45,000

* prism 4 cm x 4 cm x 16 cm
** cylinder d = 15 cm, h = 30 cm

Ultra High Performance Concrete (UHPC) in Construction Industry
with Dyckerhoff NANODUR® Compound 5941

Parabolic mirror

Shrimp farming facility

NANODUR	
Application:	special construction elements
Compaction:	self-compacting
Production:	precast plant and ready-mixed concrete
Type of binder:	premix of cement and mineral flour
Color:	gray and white

Short description

Binder premix for self-compacting concrete in precast plant and for ready-mixed concrete

NANODUR Compound 5941

The not standardized binder premix is technically suitable even in construction industry where several projects with large-sized façade panels (3 m long and 4 cm thick) without any reinforcement showed the economic efficiency compared to natural stone panels.

Parabolic troughs

For research purposes an interdisciplinary consortium developed a giant demonstrator made from HPC based on an idea of the Technical University of Kaiserslautern. Glued-on sheet metal mirrors made of aluminum serve as reflectors for the two 12 m long and 56 m wide parabolic troughs. The supports and mechanical assembly in the form of gearwheel and sickles for tracking the sun were also produced using the UHPC coarse particle mix.

Shrimp farming

Modular structures made from individual UHPC elements glued to each other to create a two-story shrimp breeding facility 35 m in length and 5 m wide were implemented at a shrimp farm in Grevesmühlen. The elements have a wall thickness of only 6 cm and were produced without reinforcement using the coarse particle mix. Once they had been assembled together, the joints were sealed with epoxy resin adhesive in conjunction with UHPC cover plates. A hydraulic mortar approved for drinking water was utilized for waterproofing the joints between the cover plates and pool elements.

Building envelope

In Qatar, a filigree building envelope was created from UHPC elements with an average length of 6 m. Doha Cladding Solutions developed a formulation with NANODUR Compound 5941 in combination with a special aggregate possessing a cube compressive strength of between 170 and 180 MPa and a flexural strength of almost 25 MPa after 56 days.

Bridge strengthening

A pilot project initiated by Graz University of Technology in Austria successfully tested the practicability of strengthening bridge constructions: 40 m³ UHPC with NANODUR Compound 5941 were prepared in a ready-mixed concrete production facility and installed as in-situ concrete. The objective was to enhance load-bearing capacity with concurrent waterproofing as a replacement for the bituminous surface.

Building envelope

Bridge strengthening

High Performance Concrete (HPC) for Bridge Strengthening
with Dyckerhoff XPOSAL® 105 (based on VARIODUR® 30 CEM II/B-S 52.5 R)

XPOSAL 105

Application:	road construction, bridges
Compaction:	during laying by paver
Production:	ready-mixed concrete
Type of binder:	standard cement
Color:	gray

Short description

Ewijk Bridge (NL)

XPOSAL 105 from Dyckerhoff Basal

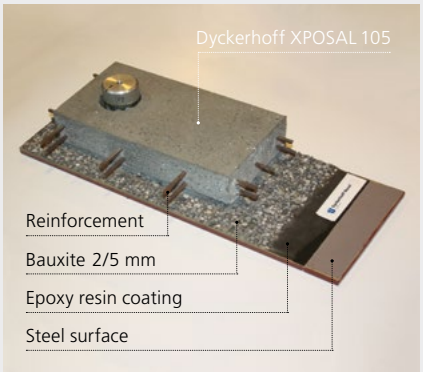
Standard cement for ready-mixed concrete

Bridge renovation with XPOSAL 105 based on Dyckerhoff VARIODUR 30

The old Waal Bridge (Ewijk Bridge) was built in 1976. It is one of the steel bridges in the Netherlands that, prior to renovation, was no longer able to support current traffic levels. A method that has previously been applied many times in the Netherlands consists of strengthening the supporting slab by a deck cover of reinforced high-strength concrete (C90/105). This reduces the stress by up to 80 % in the supporting slab compared to an asphalt cover layer, thereby significantly increasing the service life of the bridge.

The composition of the high-strength concrete was developed by Dyckerhoff Basal in the Netherlands together with the Wilhelm Dyckerhoff Institut in Wiesbaden, Germany. Result: XPOSAL 105 stands for a robust high-strength concrete of compressive strength class C90/105 based on VARIODUR 30 CEM II/B-S 52.5 R. All the concrete was delivered by the Dyckerhoff Basal plant in Arnhem. In 20 working days in the period from June to December 2016, approx. 2,400 m³ of XPOSAL 105 were delivered; on two occasions, concreting also took place at night.

The Dutch contractor consortium consisting of Strukton and Ballast Nedam had developed a special finisher that placed strict requirements on the uniformity of the concrete. The paving equipment used is capable of generating high compaction energy to ensure a very strong bond between concrete and steel over a width of 12 m. At a speed of 20 cm per minute, 100 m of bridge decks were layed in one day. On the steel surface, a bonding course of bauxite and epoxy resin was applied for optimal adhesion. Use was made of both conventional steel reinforcement as well as 75 kg/m³ of steel fibers, added by a new batching unit at the plant.



Concrete-technological data renovation Ewijk Bridge

Strength / exposure class	C90/105; XF4
Flow spread	F3 / F4: 450 – 500 mm
Processing time	≥ 2 hours
Air entrainment	≤ 2.0 %
Density	≤ 2,500 kg/m³ (± 5 %)
Flexural strength	10 MPa (± 25 %)
Young's modulus	50,000 MPa (± 10 %)
Autogenous shrinkage	≤ 3.0 ‰
Resistance to frost/de-icing agents	≤ 100 g/m²
Chloride migration	≤ 2.0 * 10^{-12} m²/sec
Coarse aggregate 2/5 mm	ASR resistant
Steel fibers (l = 12.5 mm, d = 0.4 mm)	≥ 75 kg/m³ (homogeneously distributed)

Ultra High Performance Concrete (UHPC)
with Dyckerhoff VARIODUR® 40 CEM III/A 52.5 R (and UHPC Additive CEM III/C 52.5 N)

UHPC wind power tower VENTUR 4.0

Coarse particle mix

VARIODUR

Application:	construction industry
Compaction:	vibrated concrete
Production:	ready-mixed concrete, precast plant
Type of binder:	standard cement
Color:	gray

Short description

Standard cement for ready-mixed concrete and precast plant

High Performance Concretes are based on optimization of the packing density of the hardened cement paste. This is achieved, as generally known, by filling the structural cavities with special admixtures such as silica fume, which, moreover, due to the pozzolanic reaction of the structure of the cement paste, additionally increases its density. The production in ready-mixed concrete plants is difficult due to high efforts concerning the feeding of raw materials and self-monitoring.

However, high performance concretes can more easily be obtained with modern cement technology as the experience with Dyckerhoff premium cements based on MIKRODUR® technology shows. Single separated components of standard cements with different particle sizes were mixed with a base cement to achieve extraordinary properties.

Dyckerhoff VARIODUR premium cements are standard cements and do not require additional procedures for approval.

The DAfStb guideline on UHPC in progress will contain high-strength classes, which will also be included in the new versions of the concrete standards: C130/145, C150/165 and 175/190.

For verification of performance, a simple UHPC formulation with VARIODUR 40 CEM III/A 52.5 R was tested, without silica fume and without the often performed special granulometric grading of aggregate sizes. Pit sand 0/2 mm and high-grade basalt chippings 2/5 mm were used here, as well as a special superplasticizer based on PCE for adjustment to an easy-to-process consistency for low water/cement ratios.

Cylinders for strength tests

UHPC standard formulations

		Coarse mix		Fine mix
VARIODUR 40 CEM III/A 52.5 R	[kg/m³]	700	900	900
UHPC Additive CEM III/C 52.5 N	[kg/m³]	-	-	80
Fine quartz sand 0.063/0.25 mm	[kg/m³]	-	1,230	1,150
Rhine sand 0/2 mm	[kg/m³]	480	-	-
High-grade basalt chippings 2/5 mm	[kg/m³]	1,300	-	-
Micro steel fibers	[kg/m³]	-	200	200
PCE superplasticizer for low w/c ratios	[kg/m³]	17	25	22
Water (incl. water from PCE)	[kg/m³]	136	196	196
w/c ratio	-	0.20	0.22	0.20
Flow spread	[mm]	430	450	510
Hardened properties concrete after 28 days				
Compressive strength (cube)	[MPa]	162	157	173
Compressive strength (cylinder)	[MPa]	158	145	157
Young's modulus	[MPa]	55,600	43,900	46,800
Flexural strength	[MPa]	-	22.0	22.3

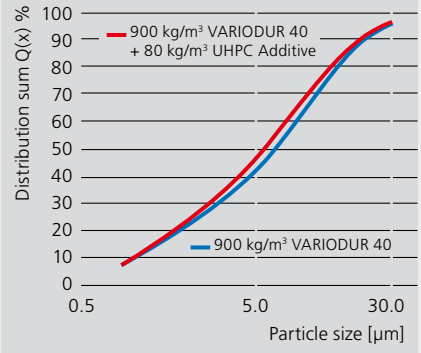
Ultra High Performance Concrete (UHPC)
with Dyckerhoff VARIODUR® 40 CEM III/A 52.5 R (and UHPC Additive CEM III/C 52.5 N)

VARIODUR

Application:	strengthening
Compaction:	during laying by paver
Production:	ready-mixed concrete, precast plant, dry mortar
Type of binder:	standard cement
Color:	gray

Short description

Fine particle mix, approx. 8 % inclined



Particle size distribution

Standard cements for ready-mixed concrete and precast plant

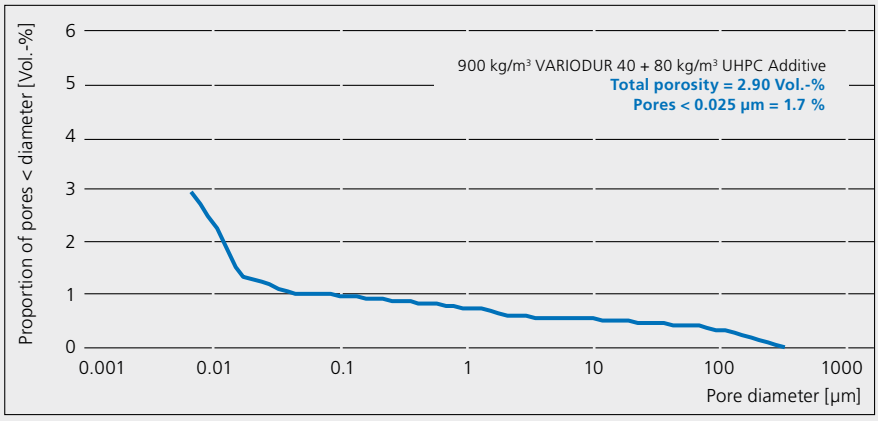
A fine particle UHPC was produced only with VARIODUR 40 CEM III/A 52.5 R, fine quartz sand, micro steel fibers and the special PCE for low w/c ratios to simplify the compositions. C130/145 concrete can be varied according to the application planned with fiber content from 200 to 250 kg/m³, w/c ratios from 0.20 to 0.24 and cement amounts from 42 to 49 % in relation to the dry mix.

UHPC mixes rich in fibers are stable in gradient and well able to be processed when compacted with pavers for the strengthening of bridges. High ductility due to good force transmission to the micro steel fibers, which need to be very densely embedded, is especially important with thin reinforcements.

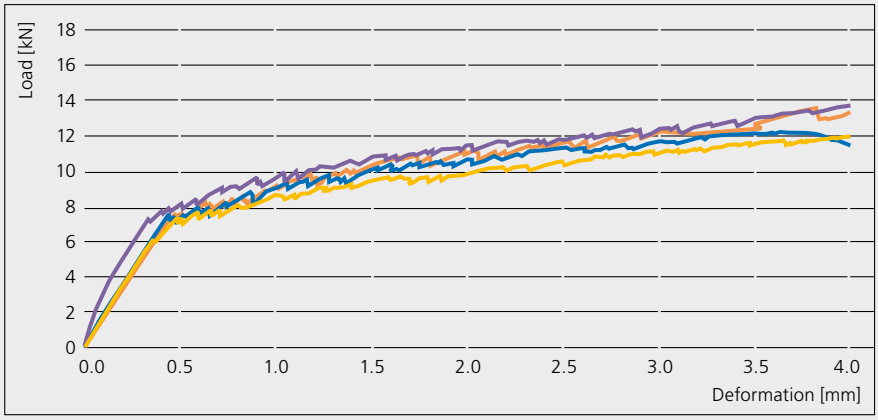
As an additional binder with fine particles (d_{95} < 9.5 µm), the UHPC additive CEM III/C 52.5 N can improve the density of the cement paste. At 80 kg/m³ to the expense of fine quartz sand, the water in the standard fine particle recipe remained constant with just on 200 kg/m³, i.e. the w/c ratio declined from 0.22 to 0.20.

The shift into the finer area of the particle size distribution is visible with laser diffraction when comparing VARIODUR 40 alone and with the addition of the UHPC additive. The improved density of cement paste leads to a high post-cracking tensile strength at beams 36 x 100 x 500 mm³.

Mercury intrusion porosimetry



Force-path diagram



The **Concrete Sustainability Council** (CSC) awarded the **Gold** seal to Dyckerhoff GmbH's Amöneburg, Deuna, Geseke, Göllheim, Lengerich, Neuss and Neuwied cement plants in Germany for responsible environmental, social and economic action.

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