CPi

Concrete Plant International
www.cpi-worldwide.com

February 2012 1

CONCRETE TECHNOLOGY

Uses of UHPC on the basis of the special binding agent in construction and mechanical engineering

SPECIAL PRINT
CPI 12/01

Concrete application outside the construction industry

Uses of UHPC on the basis of the special binding agent in construction and mechanical engineering

Nanodur® Compound 5941 is a special binding agent for Ultra High Performance Concrete (UHPC) made by Dyckerhoff AG. Its special properties enable cement bound concrete to also be used outside the construction industry. Structural applications are illustrated by the examples of adhered stairs at the Bau trade fair in Munich, wardrobe panels for the Bible museum in Frankfurt and the fair-faced concrete façade of the Ferchau office building in Gummersbach. Examples from mechanical engineering illustrate the requirements that have to be met for solid machine beds and frames and how these challenges with regard to accuracy and freedom from cracks can be overcome with concrete elements manufactured on the basis of Nanodur Compound 5941.

■ Bernhard Sagmeister, durcrete GmbH, Germany
Thomas Deuse, Dyckerhoff AG, Germany ■

The characteristics of Nanodur concrete

In normal UHPC, a high packing density is achieved by the use of industrial by-products such as silica dust. Very high compressive strengths are attained by optimising the packing density through the use of these additions in conjunction with PCE-based high-performance superplasticisers. Nanodur Compound 5941 takes a different approach to increasing the packing density. Following the grinding of cement components, a sifting or classification process takes place (Mikrodur technology). Fines from this process are recombined with basic standard cements as well as mineral ultrafines in a precisely specified grain size/grading curve. Nano-structured synthetic silicic acids are used to control hydration. Nanodur Compound 5941, which was developed for industrial customers, is a special binding agent exclusively for UHPC applications. Concretes made from it exhibit advantages over classic recipes with regard to simple raw materials and mixing technology as well as workability and economy.

Nanodur concrete is considerably less sticky and viscous than classic UHPC with silica dust. Therefore no special mixers are needed - the trough mixers or twin-shaft mixers that are to be found in every precast or ready-mix concrete plant can be used. Nanodur concrete can even be mixed using a kitchen mixer for trial purposes. Slight modifications to the scrapers and water inflow are sometimes necessary with older plants. The mixing time per batch is approx. 10 minutes, with a maximum utilisation of the mixer capacity of 50 %.

The sand and grit fractions used influence the concrete characteristics only to a small extent. Hence, regionally available, naturally moist pit sand 0/2 and hard rock grit such as basalt with a granulation of 1/3 or 2/5 or 4/8 mm can be used.

The precast plant or ready-mix concrete plant only needs to provide one silo for the special binding agent, which is delivered as loose material. Overseas dispatch of the Nanodur Compound 5941 is possible worldwide and licence-free by means of containers.

Only about 18 kg/m³ PCE superplasticiser are required for the optimised concrete recipe. Locally available products can be used, whereby good experience has been had with the globally available BASF Glenium ACE 430 and Grace ADVA Flow 375. The robust concrete mixture is self-compacting.

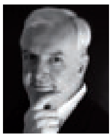
Not reinforced, fibre-free, thermally untreated Nanodur concretes exhibit a flexural strength of 15-25 N/mm² in the standard test on mortar prisms, depending on the recipe. Hence, this concrete remains for a very long time in a crack-free condition. It can thus be used economically in applications in which cracking is not permitted and in which the tensile strength of the material is the determining criterion. Reinforcements and fibres can be omitted in these applications, resulting in considerable cost advantages. If shrinkage reducers are used, the rate of shrinkage is approx. 0.5 to 0.6 mm/m and roughly corresponds to that of normal concrete.

Despite these special characteristics, concrete based on Nanodur Compound 5941 is a 'normal' concrete with all of its possibilities, but also its limitations, and therefore remains a building material for professionals. This is to be taken into account in particular with optical requirements, because the usual occupational experience is needed here in order to counteract effects such as efflorescence, blue discolourations, grey

Raw materials of the mixture

Mixing Nanodur concrete

■ Dipl.-Ing. Thomas Deuse studied civil engineering in Siegen. After activities as an application consultant for construction chemistry products from Degussa and Ceca, he moved in 1996 to Dyckerhoff AG. He was heavily involved in the development of Nanodur and is responsible for product development and sales of special building materials at Dyckerhoff AG in Wiesbaden. Thomas.Deuse@dyckerhoff.com



■ Dr.-Ing. Bernhard Sagmeister studied civil engineering in Munich and attained a doctorate in Darmstadt. Following activities as a structural engineer, construction manager and chief construction manager at the Philipp Holzmann Group, he moved to the building materials industry, where he was managing director of precast plants for many years. In 2010 he founded durcrete, which concerns itself with consultation and the development, calculation and sales of products made of Nanodur concrete. sagmeister@durcrete.de

Table 1: sample recipe

Material		Weight
Grit, e.g. basalt 1/3 or 2/5 or 5/8 mm, naturally moist	kg/m³	880
Sand 0/2 mm, naturally moist	kg/m³	430
Nanodur Compound 5941	kg/m³	1050
Superplasticiser and shrinkage reducer	kg/m³	26
Water cement ratio, approx.		0.26
Density, approx.	kg/m³	2,500

tone fluctuations, curvature of thin slabs and sensitivity to restraint stress at an early age with considered action. If you have this under control with normal concretes, you don't need to worry about using UHPC with Nanodur Compound 5941.

Applications in the construction industry

Research into UHPC and its description has been going on for several years in Germany with the aid of DFG funding programmes. Nevertheless, it is used only rarely. It is not only very expensive: an approval in an individual case is often required for the usual recipes with silica dust and, on top of that, the sensitive recipes are difficult to process. With Nanodur Compound 5941, a product is now available that considerably facilitates and simplifies the production and marketing of UHPC.

The white fair-faced concrete stairs at the Dyckerhoff AG booth at the Bau 2011 trade fair in Munich (January 2011) showed that upright concreting with a thickness of 29 mm and formwork-smooth on both sides is possible over a height of 1 m. The surface adhesive tensile strength of the concrete is so large that the folded plate was fastened here to the glass cheeks without bolted connections, using only an adhesive. Load tests took place in the manufacturing works at the Benno Drössler construction company in Siegen in which a weight of almost 2 t was applied per step. Despite this load the stairs remained in a crack-free condition, so that the performance of the steel fibres contained for reasons of ductility and safety was not called into action.

Stairs in Munich, front view

Stairs in Munich, side view

The wardrobe panels of the Bible museum in Frankfurt are made of white fair-faced concrete using Nanodur Compound 5941. The 2.90 m high, 1 m wide and 5 cm thick elements are implemented formwork-smooth. These items of furniture designed by interior architect Peter Harroider from Dreieich contain neither reinforcements nor fibres and bear loads only on account of the tensile strength of the concrete.

A suspended, rear-ventilated grey fair-faced concrete facade made of UHPC on the basis of Nanodur Compound 5941 was mounted on the office building of the engineering company Ferchau (builder FFI Frank Ferchau Immobilien). The unreinforced and fibre-free facade elements measure up to 2.92 m in length and up to 0.55 m in width. The panels extend with a thickness of 4 cm over approx. 2.90 m and are fastened directly to the steel reinforced sub-construction using anchor pins without rail systems in accordance with DIN 18516. From the point of view of statics a thickness of 3 cm would have sufficed, but the draft planners Gerber Architekten and the creators of the façade concept, the general planners Ahlbrecht, Felix, Scheidt, Kasprusch from Essen, wanted to optically retain the solidity of the concrete.

The 1,120 individually formed panels (approx. 900 m²) were manufactured true to size on steel formwork tables. The general contractor for the façade, Benno Drössler GmbH & Co. Bauunternehmen KG in Siegen, was responsible for the statics, production and assembly. With an existing test certificate from durcrete GmbH, no approval in an individual case was necessary, since the external supervisor was able to classify the concrete as concrete caststone according to DIN V 18500 due to the special concrete recipe without silica dust.

'Kohlebeisser' from the University of Applied Sciences in Lausitz

In 2011 in Magdeburg, several teams took part in the 'Concrete Canoe Regatta' – a student competition that takes place every two years – with constructions on the basis of Nanodur Compound 5941. The winner in the open class for the 3rd time in a row was the team from the University of Lausitz with a 5-tonne floating concrete replica of a brown coal excavator. A multitude of new methods of design, formwork and reinforcement for thin-walled UHPC components were developed during the design and construction. Not only were building-like components such as truss members and joints,

Bible museum in Frankfurt

Bible museum in Frankfurt

floating caisson boxes for the pontoons as well as the shells for the impellers manufactured in concrete, but also components typical of mechanical engineering. This is particularly true of a concrete drive shaft with a concrete gear wheel, which was borne on a concrete ball bearing with concrete balls. The plate-shaped elements of the impeller were fastened to the bearing ring and the drive shaft using concrete nuts and bolts.

Applications in mechanical engineering

The high-tech material based on modern binding agent technology also unlocks new fields of application in mechanical engineering thanks to its outstanding characteristics. These include in particular solid machine beds and tool frames, which are used in order to achieve faster precision machining in conjunction with shorter cycle times and lower tool wear. On account of their high damping, polymer concrete and natural stone have become generally accepted for this purpose in mechanical engineering until now. The choice of materials is now extended by the innovative material UHPC. Elements and components made of UHPC are comparable to natural stones such as granite in terms of strength, modulus of elasticity and thermal behaviour. In particular they exhibit high internal damping. The special concrete absorbs vibrations up to 80 % faster than conventional cast steel constructions. With the concrete bed, therefore, the machine attains new dynamics, which are expressed in higher feeding speeds and axis accelerations. The service lives of the tools are extended. A further advantage: the non-combustible material reacts only slowly to changes of temperature due to its thermal inertia, thus enabling high accuracies. It can also be used at temperatures exceeding 100 °C. In addition it has a flexural strength of 15 to 25 N/mm². This value can be improved still further by prestressing the concrete element. The most diverse built-in parts, from threaded sleeves to steel rails, can be integrated, i.e. cast or glued into the concrete. Channels, slopes and cable passages can be realised with the aid of intelligent formwork construction.

Characteristic values for UHPC in mechanical engineering

Nanodur concrete consists of grit, sand, rock flour and the purely mineral binding agent Nanodur Compound 5941. Water is necessary in small measures as a chemical reaction partner. Since the mixture is still a grained state following the addition of water, the liquefying, self-compacting and self-deaerating properties of the material are produced by means of a PCE-based superplasticiser. The material costs of this recipe amount to only 50 % of the material costs of polymer concrete. Light, durable and inexpensive formwork can be used, including plastic formwork, since compaction takes place without vibration.

Design and construction in mechanical engineering

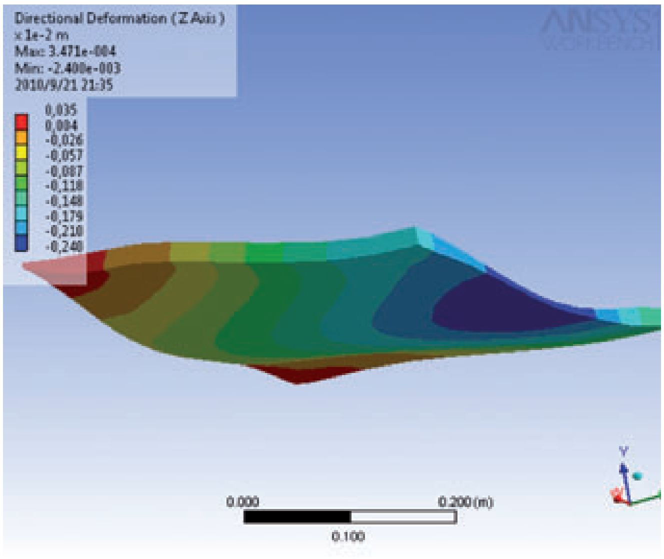
The mechanical engineering industry needs machine beds with a defined rigidity, deformation and damping. It is indispensable to design and produce crack-free structural

Ferchau office building, overall view

Ferchau office building, joint design

Concrete bolt as a component of a concrete canoe

Concrete body of a machine bed



Example of an FE calculation

elements. Tests ensure that each machine bed is delivered free of cracks and with a defined rigidity. In the case of a hairline crack the machine bed must be discarded and disposed of, which represents a great challenge to production, but which also facilitates static calculation immensely. The bed can be analysed by means of a linear elastic FEM calculation, whereby volumetric elements are used. In order to err on the safe side, reinforcing steels or fibres are not taken into account in the calculation, since these only have an effect following the development of a crack. In any case they are not actually needed, because in the event of a crack the mechanical component is already destroyed. Reinforcement is regularly used only for the fastening and earthing of built-in parts, while fibres are used only in case of spalling at the edges during transport with the forklift truck. The limiting factor in the dimensioning is thus the flexural strength, which can be improved by prestressing.

Accuracy in mechanical engineering

Using special measures, the German precast plant Sudholt-Wasemann achieves an evenness accuracy of approx. 0.1 mm over a length of 2 m just by means of the formwork construction and skilful storage. This accuracy already allows linear guide rails to be bolted on with no prior machining. A positional accuracy of better than 0.5 mm for the cast-in threaded sleeves can be achieved by taking into account the shrinkage shortening.
However, the mechanical engineering industry needs accuracies for the evenness, plane parallelism and perpendicularity of the rectangular or linear mounting surfaces of up to 5 micrometers/m [µm/m] and a positional accuracy of 0.1 mm for the threaded sleeves. This can be achieved through:

- cast-in and anchored steel plates, which are milled, ground and drilled in a metal machining centre.
- milling, grinding and lapping of the concrete surface at a specialised natural stone company and the subsequent drilling and gluing-in of the threaded anchors.
- casting the parts with an epoxy resin lining against a high-precision gauge.

The deformations are so small that they can be measured only with very special precision instruments in a climatic chamber, which prevent the unplanned deformations of the components due to exposure to the sun, higher/lower temperature differences and the influence of humidity.
However, none of the measures listed here make any sense if a concrete component with a length of several metres subsequently shrinks by several millimetres. Deformations due to the setting processes in the concrete can be excluded after heating to 90 °C for at least 24 hours in the manufacturing works or after post-treatment in autoclaves. Furthermore, test series have proven that this process of 'annealing' does not harm the UHPC.
Values of approx. 4.2 N/mm² were proven in annular groove tests of the surface tensile strength, wherein the tear-off always took place in the concrete and never in the contact area between the adhesive and the concrete.

Table 2: Comparison of materials

Material	Density [t/m³]	Compressive strength [N/mm²]	Flexural strength [N/mm²]	E-module [N/mm²]
Nanodur concrete	2.4 - 2.5	> 125	10 - 25	35 - 50,000
Granite	2.5 - 3.0	160 - 240	10 - 30	40 - 60,000
Polymer concrete	2.0 - 2.5	90 – 150	15 - 35	20 - 45,000
Steel / stainless steel / cast steel	7.8 - 8.0	-	200 - 900	170 - 210,000

Machine table from an exhibit

High-precision surface in the Sudholt-Wasemann GmbH concrete plant

Testing the surface tensile strength

Several independent measurements by specialist companies have now shown that the resistance to deformation of the Nanodur concrete is outstanding after fine machining, so that manufacturers of high-precision measuring instruments have also adopted this new material into their product ranges. Company-specific recipes are also used here, such as the InnoCrete product from Johann Fischer Präzisionswerke (JFA) in Aschaffenburg.

Prospects

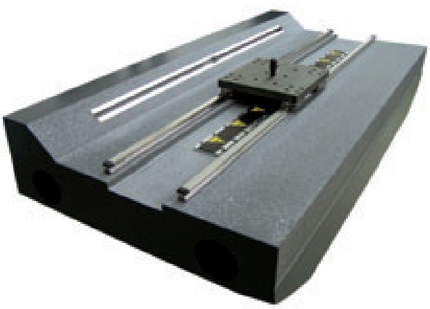
Several precast plants in Germany now produce components made of UHPC using different procedures and recipes. The market is not limited to building constructions, but is constantly expanding in mechanical engineering and other fields, where UHPC is replacing metal or polymer concrete. The active market participants see great potential in the new material, which can be adapted to meet many challenges by means of different recipe variants.

Dyckerhoff AG has developed the Nanodur Compound 5941 special binding agent for UHPC and supports the research, development and sales of structural elements, machine beds and other applications made of Nanodur concrete.

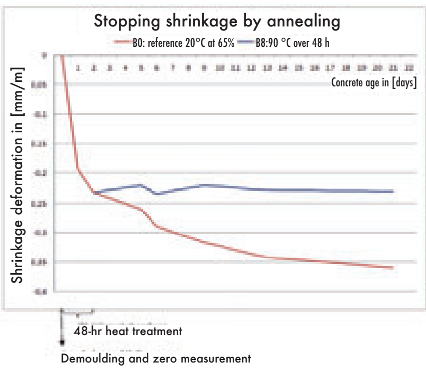
Further literature

[1] Deuse T.; Strunge J.; Parker F.: Nanostrukturierte Steuerungskomponenten in Normzement für ultrahochfeste Betone. Nanotechnologie aktuell, 2008

[2] Ultrahochfestes Maschinenbett in der Reihe Perspektive Management. maschine+werkzeug Heft 7, 2011



Measuring instrument sub-construction made of InnoCrete; photo: JFA



Stopping shrinkage by annealing

FURTHER INFORMATION

durcrete
Ultra High Performance Concrete
pure concrete · pure nature

durcrete GmbH
Frankfurter Straße 9
65549 Limburg/Lahn, Germany
T +49 6431 584 0376 · F +49 6431 584 0377
info@durcrete.de · www.durcrete.de

Dyckerhoff

Dyckerhoff AG
Produktmarketing
Biebricher Straße 69
65203 Wiesbaden, Germany
T +49 611 676 1181 · F +49 611 609 092
marketing@dyckerhoff.com www.dyckerhoff.com