UHPC using standard cement without silica fume for wind turbines and other practical applications

Less CO_2 through using high-performance concrete

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Concrete has a great number of advantages compared to other building materials, not least from the viewpoints of climate protection, resource conservation and recycling. The primary energy requirement for constructing buildings with concrete is generally reasonable and allows for durable, structurally complex and high load-bearing solutions. CO_2 emissions are unavoidable in producing cement as a binding agent due to the chemical reaction during the deacidification necessary for limestone and due to fuel consumption in the subsequent sintering process at 1,450 °C. Numerous efforts are being undertaken on a global basis to modify cement as a binding agent and concrete as a construction material with regard to CO_2 emissions or to replace both with alternative materials. Irrespective of these important objectives, a reduction in construction component dimensions can not only cut CO_2, but also reduce the need for natural raw materials such as sand. Modern high-performance cements enable concretes to be created with exceptional property profiles that open up new possibilities in terms of strength, durability and processability. The following report describes successful projects carried out by Drössler/Ventur, a precast company from Siegen, in cooperation with Dyckerhoff, a cement manufacturer from Wiesbaden.

Developing high-performance concretes based on special cements

More than 20 years ago, Dyckerhoff installed a system for manufacturing ultra-fine cements at its Neuwied cement production facility that initially produced ultra-fine cements for injections in geotechnical engineering as well as for strengthening building structures. With the increasing knowledge of their exceptional properties, these ultra-fine cement components were soon being employed for tempering mortars and eventually for denser cement paste microstructures in standard cements as well. Investigations into their performance properties have been the subject of numerous research projects and, in 2009, close cooperation between Dyckerhoff and Drössler/Ventur in the BMBF OLAF project [1] became the start for many joint innovative projects with high-performance concretes.

Fig. 1: Ventur 4.0 wind turbine

Filigree stairways

One result of the OLAF project was the Nanodur Compound 5941 binding agent premix, which for the first time allowed UHPC Ultra High Performance Concrete to be produced easily with conventional aggregates in normal concrete mixing facilities.

Drössler/Ventur has been producing Ultralith UHPC recipes based on the Dyckerhoff Nanodur Compound 5941 since that time.

On its stand at the Bau 2011 exhibition in Munich, Dyckerhoff presented a fair-faced concrete stairway manufactured by the Benno Drössler construction company that was concreted standing with UHPC of only 29 mm in thickness and with both sides of more than 1 m in height smooth from the formwork. The surface bonding strength of the UHPC is so great that, in this case, the precast elements were able to be attached to

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the glass sides merely by means of bonding (without bolts). Load tests at the Siegen manufacturing facility and at the Technical University of Dresden indicated a load-bearing capacity of around 2 t weight per step.

The new Axel Springer building in Berlin was officially occupied in June 2020. In 2019, angled steps with a differing double flight design made of UHPC were utilised on its exte-

Fig. 2: Stairway demonstrator, BAU 2011, Munich

Fig. 3: New Axel Springer Building, Berlin

rior stairway. Large double steps were installed on the right alongside the standard-sized steps on the left. In this project, the self-compacting UHPC generated a significant reduction in the weight of the individual precast concrete elements and, in addition to their filigree construction method, scored points for their attractive surface appearance.

Fish breeding pool

The topic of bonding UHPC elements was taken up again in 2014 as regards manufacturing fish breeding tanks. Modular elements made of UHPC were in this case an economically and ecologically interesting alternative to a steel structure with plastic tanks. Clear advantages were shown over a steel structure requiring elaborate protection particularly in the highly corrosive environment of the pools filled with 30°C warm salt water. At that time, Betonwerk International BWI 6-2014 reported as follows:

"Starting from a bonded pool prototype as a trade fair exhibit at EUROTIER 2012 (Fig. 4), Drössler began to develop fish breeding facilities made of individual UHPC elements bonded together as a modular structure of any size. A two-story structure 35 m in length and 5 m in width was designed for a Grevesmühlen shrimp breeding facility (Fig. 5). Its three-dimensional individual elements with a wall thickness of only 6 cm were manufactured with self-compacting Drössler Ultralith concrete at their Siegen production facility.

Fig. 4: Fish pool at EUROTIER 2012

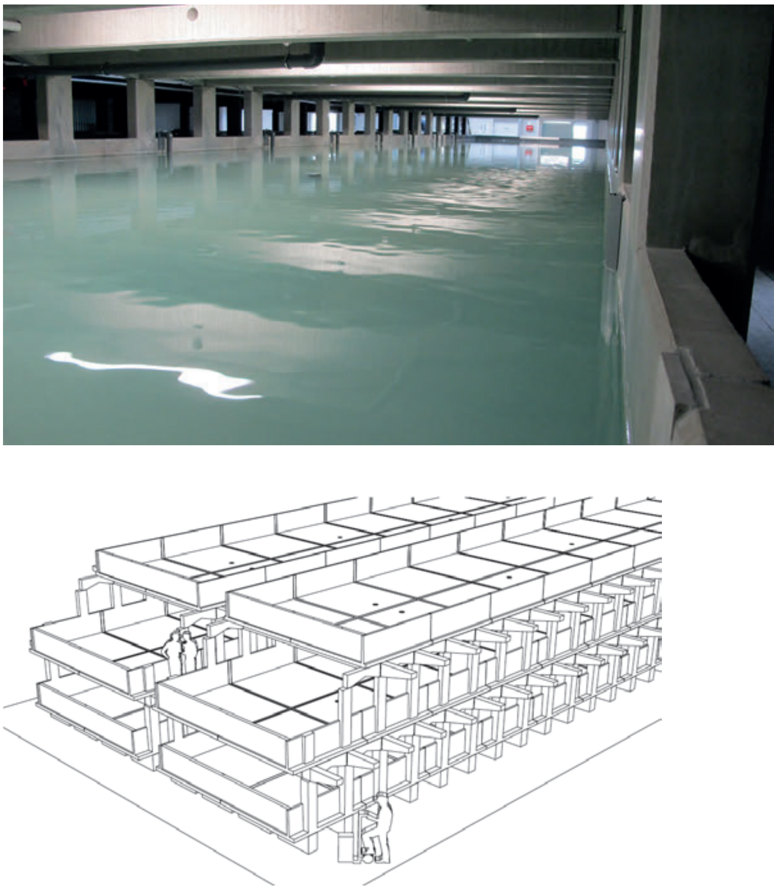

Fig. 5: Grevesmühlen shrimp breeding facility

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The UHPC does not contain any reinforcement and the elements for the lower pool were cast in one operation already equipped with supports for the upper pool. After positioning the lower UHPC pool elements on prepared concrete beams and elastomeric strips, the upper UHPC elements were placed on beams and crossbeams made of high-strength standard concrete. When the installation had been completed, the joints were sealed by gluing in fishplates with reaction resin adhesive. A hydraulic mortar with drinking water approval was applied to seal the joints between the fishplates and the pool elements [2]".

Slim large format façade panels

The first applications of Drössler Ultralith UHPC in construction practice in 2012 were 4 cm thick unreinforced façade panels in the new Ferchau company headquarters building designed by Gerber Architekten in Gummersbach (Fig. 6).

Architects Ahlbrecht, Felix, Scheidt, Kasprusch were entrusted with its entire implementation planning and construction supervision. Façade specifications were the creation of a conventional curtain wall with a thickness of up to 12 cm. The fair-faced concrete's grey colour was intended to match the neighbouring buildings, which were also finished in fair-faced concrete.

However, during the initial discussions with the contractors, the following difficulties arose. On the one hand, the inner patio, and especially the roofed four-storey foyer made of conventional and thus very heavy precast concrete elements, was very difficult to access.

On the other hand, space for the façade elements on the very slender shell was severely restricted and further impaired by adhesive work around the window areas. This made any assembling of precast concrete curtain façade elements very difficult with conventional fastening systems.
The problem was solved by minimising the thickness of the concrete panels to facilitate their installation in the areas of difficult access (patio and roofed areas) and in order to reduce their width for fastening them to the load-bearing structure. After inspecting the sample panels, the architects and building owner decided on a design with 4 cm thick elements made of smooth, grey UHPC with an identical surface finish to conventional fair-faced concrete or even better [3].
At the Ferchau company headquarters in Gummersbach, 900 m² of façade surface were constructed with UHPC elements of only 4 cm instead of 12 cm standard concrete thickness. Taking into account differing cement contents, this saved around half of the CO_2 from the Portland cement fraction. The significantly lower weight of the unreinforced Ultralith also allowed for a considerably simpler metal load-bearing structure. The overall CO_2 emissions were only one third of a conventional reinforced concrete construction thanks to these additional savings on steel as well as transport and crane operations (Table 1).

Table 1: Comparison of CO_2 emissions for a 900 m² façade area

CO_2 Fraction	12 cm steel reinforced concrete	4 cm UHPC
Concrete	24 t	13 t
Steel reinforcement	16 t	0 t
Transport	0.7 t	0.2 t
Crane operations	5 t	1.7 t
Total	**45.7 t**	**14.9 t**

After this successful pilot project, further buildings with a comparable design were erected on the two adjoining properties in Gummersbach as well as at numerous other locations. Apart from their benefits in new construction work, unreinforced UHPC façades are particularly advantageous at the end of their service life, as the high-quality material can be recycled very easily and returned to the construction industry material cycle.

Fig. 6: Façade panels at the Ferchau company headquarters in Gummersbach

Ventur 4.0 wind turbines

In addition to the previously described Ultralith applications in the construction industry, the Nanodur Compound 5941 binding agent premix has been demonstrating its worth for more than 10 years now in what are now 5 digit UHPC quantities as an economical and, above all, ecological alternative to polymer concrete and grey cast iron in manufacturing machine beds and die base frames [4].

In Germany, the building authorities have as yet not introduced any regulations for high-performance concretes. However, the DAfStb has for years been making extensive efforts in various working groups in this regard to be able to provide a guideline for UHPC that will in future supplement the Eurocode. Successful implementation is already taking place in other countries, such as France or Switzerland, where innovative construction methods are regulated by the SIA 2052 code of practice.

High-performance binding agent premixes (compounds) for applications not covered by the concrete block standard currently require general building authority approvals and/or approvals in individual cases in Germany. In the search for alternatives, a UHPC recipe with a very low w/c ratio in the range of 0.20 was therefore developed on the basis of a standard Variodur 40 CEM III/A 52.5 R cement also produced with Dyckerhoff Mikrodur technology in combination with high-performance superplasticisers. A detailed report of this binding agent concept was published in Concrete Plant International CPI 2/2020 [5].

No multi-component mix of special aggregates with special mixing technology is necessary in this case as opposed to classical high-performance concrete recipes with silica fume. Standard Variodur cement facilitates producing UHPC simply employing standard concrete mixing technology and using only conventional quarry and crushed sands as well as high-grade chippings – this considerably reduces production and approval costs.

As a result, Ventur has received general building approval for its "VenturCrete C120/140" concrete, which sets new design standards. Minimum compressive strengths of 120 MPa with cylinders and 140 MPa with cubes as well as a modulus of elasticity of 50 GPa generate significant reductions in component thicknesses of almost 50 % when manufacturing wind turbine towers made of precast concrete elements with the Ventur construction system. These high-performance concrete elements made from VenturCrete C120/140 are produced in a concrete mixing unit belonging to the Ventur production facility in Siegen (Fig. 7) [6].

Fig. 7: Ventur concrete mixing unit, Siegen

Fig. 8: Ventur 4.0 assembly work

Fig. 9: Ventur precast elements

The slim design of the "Ventur 4.0" sustainably improves the advantages of the Ventur system that has been well proven in series production over many years. The construction method is particularly competitive due to its light elements that are only 3 m wide and 10 m long. They can be transported on normal low-loaders and place moderate demands on the mobile crane size when being assembled using a modular principle with internal prestressing (Fig. 8).

Ventur 4.0 shows in a differentiated way how high-performance construction materials and clever design can open up new performance perspectives synergistically. These production-friendly components manufactured flat offer ideal conditions for the targeted use of a high-performance construction material. The smooth surface is impressive in its durability and aesthetics (Fig. 9).
High-performance concrete substantially reduces the quantities of concrete and reinforcing steel utilised with the Ventur 4.0 construction method, thus saving on resources and CO_2 emissions. Innovative construction concepts employing specifically developed high-performance concretes thus lead to an overall economical and ecological use of concrete as the construction material of the future.

Once again, in addition to the economic aspect, special mention should be made of the large savings on CO_2 due to reduced component dimensions for the approximately 100 m high hybrid wind turbine tower concrete structures with a hub height currently at 164 m.

In conjunction with the lower weight of the precast concrete elements during transport and crane operations, CO_2 emissions per tower drop significantly to 65 % compared to the standard construction method (Table 2).

Outlook

It will still take some time until completely new low CO_2 cement and concrete concepts are ready for the market and proven in practice. By way of contrast to this, the increase in the proportion of clinker substitutes that has begun to supplement the familiar blast furnace slag, e.g. in the new

Table 2: Comparison of CO_2 emissions with Ventur concrete towers for wind turbines

CO_2 Fraction	High strength C 70/85 concrete 30 cm element thickness	Ultra high strength C120/140 concrete 18 cm element thickness
Concrete	217 t	142 t
Steel reinforcement	80.5 t	52.5 t
Transport	17.5 t	10.5 t
Crane operations	7.9 t	4.7 t
Total	**322.9 t**	**209.7 t**

CEM II/C cements, is real and very promising. In 2020, Dyckerhoff was the first German cement manufacturer to receive approval from Deutsches Institut für Bautechnik DIBt in this area [7].

However, far greater leverage for cutting CO_2 is already available today by reducing component mass in conjunction with resource conservation through employing high-performance binding agents and concretes. The greater durability of high-performance concretes, which has already been proven in numerous research and practical projects, is another important reason to review the obstacles to their utilisation from the approval side and to speed up the processes. As the examples provided show, there are many ways to correct the often negative ecological image of concrete construction methods in the public eye through innovative concrete types and clever designs - they just need to be implemented on a much larger scale in construction practice. ■

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