Energy
National Research Programmes 70 and 71

Project

Pre-stressed carbon-fibre concrete

Prestressed concrete with carbon fibres and little cement: an environmentally friendly variant

Prestressed concrete with carbon fibres and little cement: an environmentally friendly variant

Prestressed concrete is normally reinforced with steel, meaning it has an especially high load-bearing capacity. However, steel could soon be displaced by carbon fibre – making the concrete more environmentally friendly.

As the name suggests, prestressed concrete is prestressed, giving it greater tensile strength. *Source:* Wikicommons/Michael Schmahl

At a glance

- Prestressed concrete elements can be strengthened with carbon instead of steel without any sacrifices having to be made in terms of their mechanical properties.
- High-strength concrete containing little cement could also replace conventional cement.
- These two innovations make prestressed concrete massively more energy efficient and environmentally friendly.

The construction of a building is an energy-intensive process: the production of both the used concrete and the steel requires a great deal of energy and causes CO_2 emissions. Low-energy concrete and constructions without steel can therefore make an important contribution to the implementation of Energy Strategy 2050. In this project, researchers from the Swiss Federal Laboratories for Materials Testing and Research (Empa) and ETH Zurich attempted to identify environmentally friendly variants for classic prestressed concrete.

While concrete has high compressive strength, it is not good at withstanding tension. Like conventional concrete, prestressed concrete is strengthened with steel elements. In order to give it even greater tensile strength, however, the steel wires inside it are tensioned. This provides the concrete construction with a higher load-bearing capacity.

Prestressed concrete with carbon instead of steel

An already existing alternative to steel wires are pretensioning wires made from plastics reinforced with carbon fibres. The researchers investigated and improved the load-bearing strength and stiffness of such wires. The manner in which the wires connect to the concrete is decisive here. The scientists therefore investigated highly rigid, sand-coated pretensioning wires made from plastics reinforced with carbon fibres (UHM CFRP).

They tested the pull-out behaviour of the wires with various sand coatings as part of calculations and experiments. In order to determine when the wires fail, the researchers used X-ray computed tomography and scanning electron microscopy. It was shown that the pull-out behaviour of the wires is dependent on the longitudinal rigidity of the UHM CFRP tension wire. On the other hand, the maximum bond strength between the sand-coated tension wire and the concrete was only dependent on the selected sand coating and not on how stiff the tension wire was.

High-strength concrete with little cement

However, the researchers did not only investigate new variants of the tensioning elements, but rather also the concrete itself. The most energy-intensive material in concrete is cement. It also impacts the environment: during burning, each tonne of cement produces more than half a tonne of CO_2. The researchers therefore developed a high-strength, low-energy concrete by replacing up to 70 % of the cement with other materials such as limestone, metakaolin and silica fume.

Here, the researchers developed three new recipes with a reduction in cement of 54 %, 58 % and 70 %. The measured compressive strength of the three mixes was between 77 and 88 megapascal, meaning they are classified as “high-strength”. Due to their greatly reduced cement content, these mixes also exhibited much improved contraction and creep behaviour, which is enormously beneficial for prestressed concrete.

Test on prestressed bending beams

Both new materials, i.e. the sand-coated carbon wire and low-cement concrete, were subsequently tested in a construction: to this end, the researchers developed three-metre-long, prestressed girders. Fibre-optic sensors were integrated in the tension wires in order to determine the prestressing losses under experimental conditions. As expected, a prestressing loss was recorded for the carbon wires. However, this could be compensated for – at least in part – by the new concrete mixes.

Overall, the researchers concluded that the girders made from the new materials are ultimately superior to girders produced using conventional concrete and the carbon wires used until now.

Massively energy-saving

The researchers also calculated the life cycle assessment of the new prestressed concrete. In comparison to a steel-concrete construction, up to 80 % of the grey energy and 90 % of CO_2 emissions could be saved with the new prestressed concrete elements. The new materials are also lighter, meaning lower transport costs and that less steel and concrete is required in foundations.

The prestressed concrete reinforced with carbon wires can be applied in practice without the need for significant changes. This would make a considerable contribution to optimising the CO_2 balance of future buildings. However, an unresolved issue is the durability of the new materials. This is now being tested in a multi-year Empa project.

Produkte aus diesem Projekt

- Bond Performance of Sand Coated UHM CFRP Tendons in High Performance Concrete
  Date of publication: 30.12.16
- Low clinker high performance concretes and their potential in CFRP-prestressed structural elements
  Date of publication: 30.10.19
- Transient Thermal Tensile Behaviour of Novel Pitch-Based Ultra-High Modulus CFRP Tendons
  Date of publication: 24.10.16
- Development of novel low-clinker high-performance concrete elements prestressed with high modulus carbon fibre reinforced polymers
  Date of publication: 30.10.19
- Verbundprojekt "Energiearmer Beton"
  Date of publication: 20.12.16

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All information provided on these pages corresponds to the status of knowledge as of 17.12.2018.