Zukunft Bau

Short report

Title

Gap Research of fibre-reinforced polymer rebars.
Investigation of the long-term bond behaviour of reinforcement made of fibre-reinforced polymer.

SWD-10.08.18-17.62

Reason/ Initial position

The durability of reinforced concrete is significantly dependent on the corrosion resistance of the reinforcement. The corrosion protection of steel reinforcement is ensured by the high alkalinity of the surrounding concrete. Chemical and physical environmental influences can influence the alkalinity of the concrete and thus reduce the durability of steel-reinforced concrete. A solution for the problem of limited durability due to steel corrosion is offered by non-metallic fibre reinforced polymer (FRP).

FRPs are often characterized as corrosion-free, but it is legally non-rusting. The word corrosion describes the chemical degradation of a material by its environment. Since FRP is not a metallic material, this reinforcement does not rust, but under specific environmental influences the components glass and polymer are also damaged over time. The corrosion or ageing of glass and polymers as well as the corrosion of metallic materials leads to a measurable degradation of strength. Therefore, this material is also not corrosion-free and the mechanical short-term behaviour deviates from the long-term behaviour. To ensure the service life of structures using this material, the time-dependent material behaviour must be known. It has already been proven that both tensile strength and bond strength degrade over time. In Germany, there is currently no general standardization for FRP rebars. The Canadian and American standards already take into account the long-term tensile behaviour of FRP rebars, but there are no requirements for long-term bond behaviour. In the literature, there is hardly information about the long-term bond load-bearing behaviour.

The ageing of material, as well as the rebar-specific bond behaviour of the FRP rebars, lead to a different bond load behaviour compared to reinforcing steel. Therefore, there is currently an open knowledge gap in the field of the dimensioning of anchorage lengths of concrete components with FRP rebars under short-term as well as long-term loading.

Subject of the research project

This research project aims to contribute to the design of the end anchorage length with FRP rebars based on the current working draft of the new Eurocode 2. The focus is on the adaptation of the design approach considering the short and long-term bond bearing behaviour.

For the investigation of the load-bearing behaviour of the end anchorage under short term loading the influence of the design parameters concrete strength, bar diameter, anchorage length, concrete cover, transverse reinforcement and transverse pressure is investigated (Figure 1). The results shall even indicate which of the respective parameters are dependent or independent of the reinforcement material. Dependent parameters are adapted to the bar-specific behaviour to ensure the load-bearing capacity of the end anchorage under short-time stress by using the design equation of the end anchorage length.

Within the scope of long-term investigations, the effects of ageing and creep stress on the bond between FRP rebar and concrete are investigated. For this purpose, a test bench will be developed (Figure 2) to investigate the degradation of the bond strength under the external influences of moisture, increased temperature and concrete alkalinity. The results obtained are used to define a minimum anchorage length as a function of time and temperature, which ensures the load-bearing capacity of the end anchorage over the entire assessment period.

In the following, the working steps of this project are listed:

1. Literature research of the fundamentals on:
    - bond anchorage of reinforcing steel and concrete.
    - composition and damage behaviour of FRP rebars.
    - different material characteristics between reinforcing steel and FRP rebars and their effect on the bond load-bearing capacity
2. Experimental investigations on:
    - bar-specific bond stress-slip relationship.
    - influence of design parameters on the bond load-bearing capacity.
    - time-dependent bond strength under permanent load and the effects of moisture, concrete alkalinity and increased temperature.
3. Model for calculation of the bond stress curve along the anchorage length to:
    - deduct bond stress in the state of failure.
    - consider the bond creep on the bond load-bearing capacity.
4. Adaptation of the design concept to ensure bond load-bearing capacity:
    - end anchorage length taking into account the design parameters under short-term stress.
    - minimum anchorage length under long-term stress depending on time and temperature.

Conclusion

The short-term bond investigations show that due to the low modulus of elasticity and the different surface profiling, fibre reinforced polymer rebars tend to have an increased splitting effect. In the conducted tests, design composite stresses of $\tau_{bd} = 3{,}7 - 4{,}5\ N/mm^2$ were determined for three different fibre reinforced polymer rebars (named: GFK1-3). These stresses ensure that the bond is not overstressed under unfavourable boundary conditions. This results in anchorage lengths for a normal stress of $f_{nm,k} = 580\ N/mm^2$ of $l_{bd} = 28 - 33 \cdot d_s$. Furthermore, the influence of concrete strength, concrete cover, bar diameter, anchorage length, transverse reinforcement and transverse pressure on the bond load-bearing capacity is investigated. It is shown that the influence of concrete cover, bar diameter, transverse reinforcement and transverse pressure is bar-specific and is insufficiently described by the design approach of the anchorage length. These four parameters show the following influence on the bond load-bearing capacity in the investigations:

Increase of the concrete cover from $16\ (1{,}5\ d_s)$ to $32\ mm\ (2{,}0\ d_s)$:	$+19$ to $+23\ \%$
Reduction of the bar diameter from 20 to $12\ mm$:	$+8$ to $+33\ \%$
Increase of the cross reinforcement from $0{,}0$ to $1{,}0$:	$+18$ to $+36\ \%$
Increase of the transverse pressure from indirect to direct support:	$+24$ to $+45\ \%$

Under favourable boundary conditions such as high concrete strength, good bond conditions and maximum confinement, the design bond stress for the tested fibre reinforced polymer rebars can be increased to a maximum of $\tau_{bd} = 15{,}0 - 17{,}9\ N/mm^2$, reducing the anchorage length to $l_{bd} = 7 - 8 \cdot d_s$.

In order to quantify the long-term bond behaviour, this research project is conducting durability bond tests under permanent load and the effects of concrete alkalinity, moisture and increased temperature. Due to this aggressive environment, a decomposition process of the surface profiling takes place (Figure 3-5), which dissolves the bond between FRP rebar and concrete over time. Experimental investigations have shown that after a test duration of $t = 1{,}000\ h$ and a test temperature of $T = 60°C$, the bond strength of the fiber-reinforced polymer rebars decreases to a level of $47 - 70\ \%$ of the short-term bond strength. If these results are extrapolated to $t = 100$ years, the bond strength at $T = 60°C$ is $26 - 48\ \%$ of the short-term bond strength.

Based on the results of the short-term and long-term studies, the design equation for FRP rebars is adjusted. Equations 1-3 show the modified design equation for the anchorage length. Here, the parameters of the bar diameter n_d, the concrete cover n_c, the transverse reinforcement α_{conf}, the maximum confinement $\alpha_{conf,max}$ as well as the material ageing $\alpha_{T,lb}$, $\alpha_{t,lb}$ and n_t are rebar-specific. These parameters are derived in the context of this project for three different fibre reinforced polymer rebars (Table 1).

$$
\begin{aligned}
l_{bd} &= \boldsymbol{\alpha_{lbs}} \cdot d_s \cdot \left(\frac{25\ N/mm^2}{f_{ck}}\right)^{\frac{1}{2}} \cdot \left(\frac{\sigma_{sd}}{f_{nm,d}} \cdot \frac{\gamma_c}{1{,}5}\right)^{\frac{3}{2}} \cdot \left(\frac{d_s}{20\ mm}\right)^{\boldsymbol{n_d}} \cdot \left(\frac{1{,}5 \cdot d_s}{c_{d,conf}}\right)^{\boldsymbol{n_c}} \\
&\geq \alpha_{lbs,min} \cdot d_s = \left(\boldsymbol{\alpha_{T,lb}} \cdot T + \boldsymbol{\alpha_{t,lb}} \cdot t^{\boldsymbol{n_t}}\right) \cdot d_s \\
&\geq 15 \cdot d_s
\end{aligned}
\qquad \text{(Equation 1)}
$$

$$
c_{d,conf} = c_d + \left(\boldsymbol{\alpha_{conf}} \cdot k_{conf} \cdot \frac{n_l \cdot A_{st}}{n_b \cdot d_s \cdot s_{st}} + 8 \cdot \frac{\sigma_{ctd}}{\sqrt{f_{ck}}}\right) \cdot d_s \qquad \text{(Equation 2)}
$$

$$
c_{d,conf} \leq \boldsymbol{\alpha_{conf,max}} \cdot d_s \qquad \text{(Equation 3)}
$$

Table 1: Rebar-specific parameter.

Rebar	$\boldsymbol{\alpha_{lbs}}$	$\boldsymbol{n_d}$	$\boldsymbol{n_c}$	$\boldsymbol{\alpha_{conf}}$	$\boldsymbol{\alpha_{conf,max}}$	$\boldsymbol{\alpha_{T,lb}}$	$\boldsymbol{\alpha_{t,lb}}$	$\boldsymbol{n_t}$
GFK1	33	0.28	0.30	46	7.5	-	-	-
GFK2	28	0.46	0.25	40	14.4	-0.100	11.973	-0.031
GFK3	30	0.11	0.26	114	15.2	-	-	-

Basic data

Project management:
Prof. Dr.-Ing. Matthias Pahn

Researcher:
Dipl.-Ing. Christian Caspari

Total costs: 272,721.92 €
Share of federal subsidy: 144,670.00 €

Project duration: 34 Month

Figure:

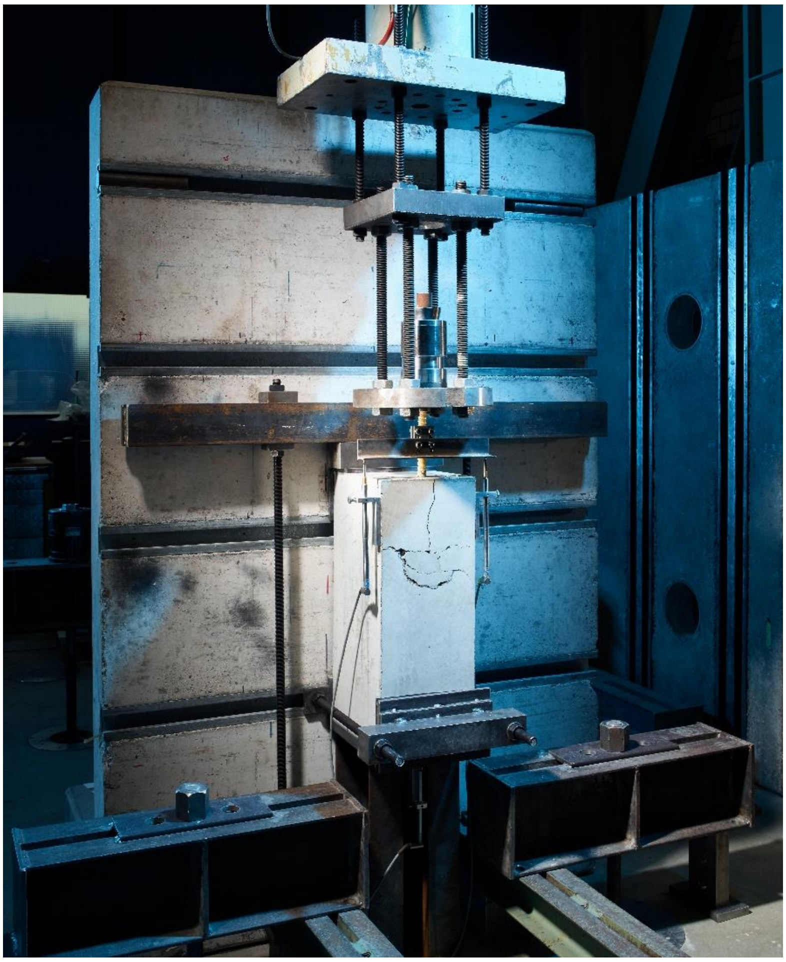

Figure 1: Fracture pattern of a beam-end test after the execution of the test.

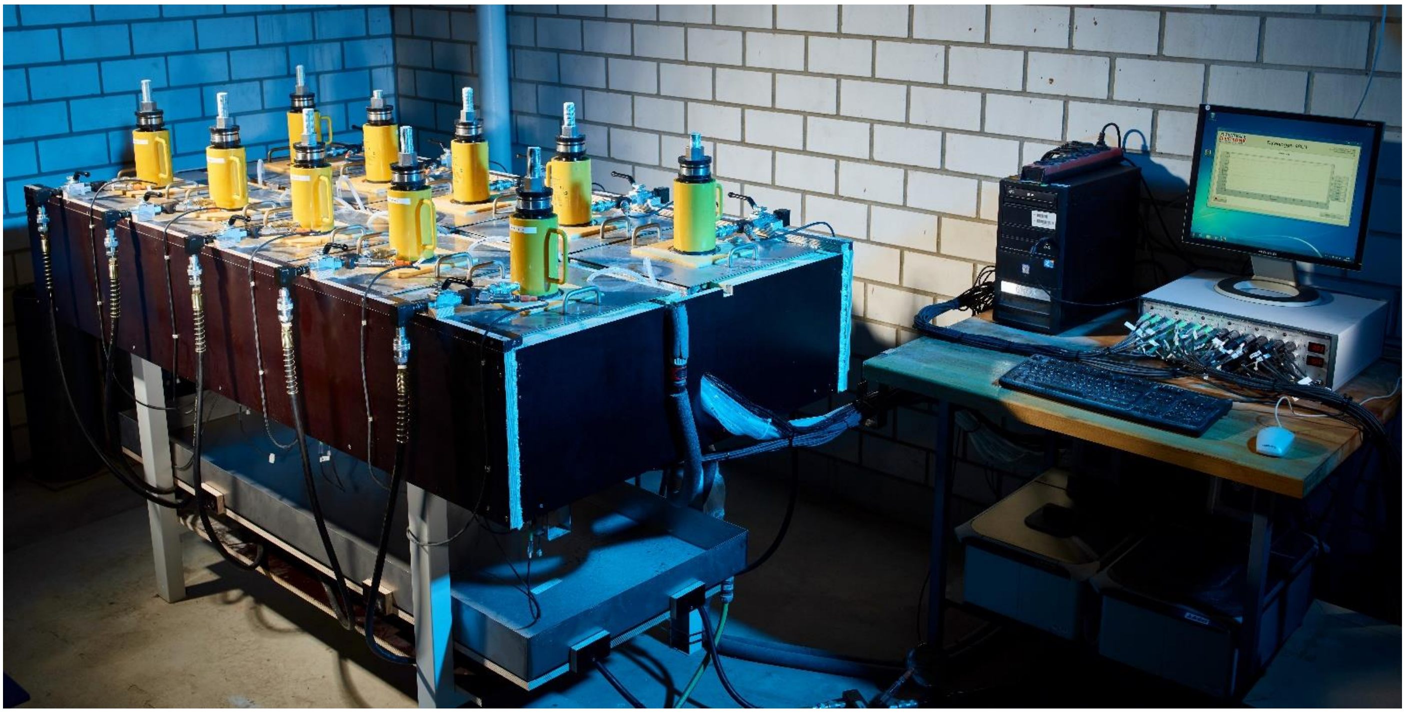

Figure 2: Test bench developed to analyse the time-dependent bond strength under continuous load and the external influences of moisture, increased temperature and concrete alkalinity.

Figure 3: Time-dependent decomposition of the surface profile of GRP1 at 60°C. From left to right decreasing load with increasing service life.

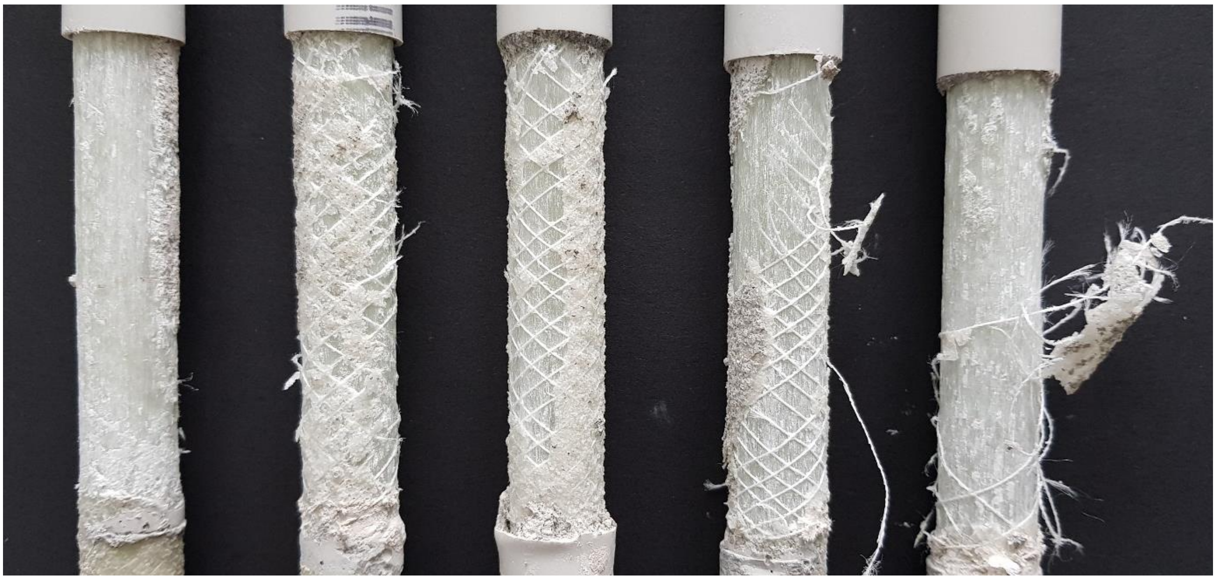

Figure 4: Time-dependent decomposition of the surface profile of GRP2 at 60°C. From left to right decreasing load with increasing service life.

Figure 5: Time-dependent decomposition of the surface profile of GRK3 at 60°C. From left to right decreasing load with increasing service life.