Fibre Reinforced Polymers (FRP) as Reinforcement for Concrete According to German Approvals

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Abstract. This article demonstrates the possibility of the application of joint principles to develop test programs for national approval or European Technical Assessments of FRP reinforcement for concrete. The limits of different systems are shown, which until now have been approved in Germany.

1. Types of FRP reinforcement for concrete approved in Germany

Approvals in Germany and European Technical Assessments are an efficient means to allow innovative products to enter the market. As standards for the use of such products are present neither in Germany nor in Europe, approvals or European Technical Assessments are the only way to lead to a proof of usability.

In table 1 the types of approvals, which until now exist for FRP reinforcement of concrete in Germany, are listed. Since the materials of on surface bonded and in slits near surface bonded CFRP strips (strips of Carbon Fibre Reinforced Polymers) are the same, it can be considered as the same type of FRP reinforcement. But as it is shown in the next two chapters, the test programs for the two types of approvals with the same type of reinforcement are different.

Table 1. Types of FRP reinforcement approved in Germany.

| Subject                                      | Test program                      |
|----------------------------------------------|-----------------------------------|
| On the surface bonded strips of FRP (1995)   | National test program in Germany exists |
|                                              | Draft European Assessment Document (EAD) in work |
| In slits near surface bonded strips of FRP (2002) | National test program in Germany exists |
|                                              | Draft European Assessment Document (EAD) in work |
| Fibre Reinforced Polymers as reinforcing bars for concrete (Schöck-ComBar 2008) | National test program in Germany exists |
|                                              | Draft European Assessment Document (EAD) in work |
| Strengthening with layers of textile concrete (TUDAG 2014) | National test program in Germany exists |
|                                              | Draft European Assessment Document (EAD) in work |

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Regardless of these differences, we can say that at the moment in Germany three types of reinforcement are permitted to be used:

1. CFRP strips bonded on the surface or in slits of the concrete member;
2. GFRP bars (bars of Glass Fibre Reinforced Polymers);
3. Layers of Textile Reinforced Concrete with reinforcement of Carbon Fibre Textiles.

For all these types of FRP reinforcements there are national testing programs in Germany. European Assessment Documents as the basis for implementation of European Technical Assessments are in preparation.

| Property                              | Reinforcing Steel | FRP Reinforcement |
|---------------------------------------|-------------------|-------------------|
| Tensile strength                      | known             | unknown           |
| Bonding strength                      | known             | unknown           |
| Long term tensile strength in alkaline environment | known in the field of application temperatures (-40 to 100 °C) | Unknown |
|                                       |                   | Field of application temperatures has to be defined |
| Long term bond strength in alkaline environment | known in the field of application temperatures (-40 to 100 °C) | unknown |
|                                       |                   | Field of application temperatures has to be defined |

Even if confining ourselves to the static structural behavior, it is important to know that the properties of new reinforcements of FRP are determined not only by their short term characteristics as tensile strength and bonding strength to the concrete. Essential are especially the long-term characteristics, which in case of conventional reinforcement often play no role because they are known for a long time for the region of temperature in which they are applied.

2. Strengthening with CFRP strips bonded on the surface of the concrete member

The first approvals in Germany for FRPs with Carbon Fibres were issued in the mid-nineties of the last century. Those approvals exist until now. In most cases FRPs in the form of prefabricated Carbon Fibre Strips are used, which are bonded with epoxy adhesives on the surfaces of the concrete parts for strengthening them (see figure 1).

From the beginning of this approval area, the opinion of the experts was that it is only necessary to verify that the adhesive after aging under stress is better than the concrete to which it is applied. Therefore, tests were conducted on concrete cylinders of 40 to 50 mm diameter and 100 to 150 mm height. The strength class of the concrete was C50/60. Circular specimens of CFRP strip with the same diameter as the concrete cylinder were glued at one end of these cylinders. Afterwards steel dollies with the same diameter as the concrete were glued at both ends. These specimens were loaded with 30% of the surface tensile strength of the concrete for half a year in the climatic chamber with 95% relative humidity and the maximum application temperature (mostly 40 °C). The requirement for these tests was that no failure occurred during the test time and in the following tensile test failure occurred in the concrete. It was practically the proof that the adhesive after aging under load is still better than the concrete. It is not possible to determine a long term tensile strength of the adhesive in this way. But since in the design model (see [1]) only the strength of concrete is used and within the application time of these systems of more than 20 year no case of damage has become known, the testing program for the long-term behaviour has remained.
Although no cases of damage related to the aging of the adhesive have been recorded, there was a claim with prestressed CFRP strips in Kuala Lumpur which had an influence on the test program. Since it was not a damage case in Germany, DIBt got no detailed information about this case. We only suspected that the reason for failure among others could be alkali sensitivity of some matrix resins of CFRP strips. Therefore, long-term test for CFRP strips in alkaline environment in our national test program has been introduced (see figure 2).

As a result of the investigations, reduction factors related to the short-term strength of the CFRP strips were determined. The values of these factors are based on the results of the tests from 0.85 to 0.9. Since the products of some manufacturers did not fulfil the requirements at pH 13.7, additional information is given in the approval concerning the range of pH values where the reduction factors apply.
3. Reinforcing bar of glass fibre reinforced polymers

A national approval for a reinforcing bar of glass fibre reinforced polymers (GFRP) (see [2]) could be issued in Germany in 2008. For approval of such new objects expert committees have been formed at DIBt, which are composed of experts in the required fields. In the case of this object, scientists in the field of Fibre Reinforced Polymers, structural engineering, reinforced concrete and building materials from three universities of Germany took part in the work of the committee. The discussions on the test program to determine the long term tensile and bond strength of the new reinforcement were particularly difficult. Before issuing the approval (see [2]) of the GFRP reinforcing bar at DIBt, only the structural elements of Fibre Reinforced Polymers carrying loads without contact to concrete were approved. Test programs and evaluation methods for these approvals are based on the recommendations of the construction supervision Association e. V. [BÜV] “Structural plastic elements in the field of construction” (see [3]). The determination of the long-term tensile strength is based on DIN 53768:1990 (see [4]). According to this German standard, an extrapolation of strength test results for long term-tests over 1.5 decades is allowed. If the long-term test, for example, was conducted over 5000 h, the extrapolation to $10^{\left(\log(5000) + 1.5\right)} \approx 158114 \text{ h} \sim 18 \text{ years}$ can be done according to this standard.

As the strength after 50 to 100 years is of importance in the construction industry, three series of tests were carried out to determine the long-term tensile strength of the ComBAR at three different temperatures (20 °C, 40 °C and 60 °C).

![Figure 3. Reinforcing bar of Glass Fibre Reinforced Polymers "Schöck-ComBAR" (short-term tensile strength – 1200 N/mm²; long-term tensile strength – 580 N/mm²; E-modulus – 60,000 N/mm²).](image)

In each series of tests 15 tests were carried out at different stress levels. The longest test duration with the lowest stress level in every test series was over 5000 h. For each test series, the linear regression line of the 5% quantile values of the strength levels in the log (time) - log (stress) diagram was determined in accordance with DIN 53768, Chapter 5. These regression lines have been extended to $10^5$ hours (about 114 years). Afterwards, for a given stress level it has been determined which time until failure is obtained from the 5% quantile regression lines at continuous temperatures of 20 °C, 40 °C and 60 °C and whether the Arrhenius relationship for the three values of time until failure is fulfilled:

$$t = 10^{(a/T+b)}$$

where $t$ – the time until failure in [h] of the creep test at a certain stress level; $T$ – the absolute temperature of the creep test in [K] (0 K = -273.15 °C); $a$, $b$ – constants determined from the creep tests for adjusting the Arrhenius relationship.

Since such Arrhenius relationship could be established, it was agreed between the experts that it is admissible to extrapolate the long-term tensile strength at a maximum continuous temperature of 40°C for an extrapolation of 2.25 decades ($10^{\left(\log(5000) + 2.25\right)} \approx 889140 \text{ h} \sim 100 \text{ a}$).
Figure 4. Creep curves typical for the Schöck-ComBAR.

Figure 5. Schematic representation of the measurement points (to improve the overview here connected by lines) and 5%-quantile limit.

The test set used in this case for creep tests to determine the long-term tensile strength is shown in figure 5.
The ComBAR was set in the concrete on both sides with a long anchoring length. One of the two anchor blocks was movable and the other was fixed. Between the two anchor blocks there was a gap. In the middle of this free length the ComBAR was encased by a concrete cylinder. This concrete cylinder was laid in a water bath which could be tempered. After hardening of the anchor blocks and the concrete casing of the ComBAR, the hydraulic presses were operated and the ComBAR was stretched under the respective stress level. At the same time, the water bath was adjusted to the respective temperature. When stretching the ComBAR in the concrete casing cracks are produced (see expanding body test), the tempered water penetrates into the cracks and provides a realistic alkaline environment for the ComBAR. The press forces were regularly checked during the tests and adjusted accordingly, so that over the entire duration of the experiment, a constant stress level in the ComBAR was assured.

As a result of the investigations, a reduction factor related to the short-term strength of the GFRP bar was introduced. The value of this factor is 0.48.

![Figure 6. Test set to determine the long-term-tensile strength of the SchöckComBAR.](image)

Furthermore, the bond behaviour had to be examined under continuous load. The procedure and test arrangement (see diagram below) to determine the long-term bond behaviour was similar to the one used to determine the long-term tensile strength (see figure 7 left).

Here, the permanent bond force-slip behavior was again checked at certain continuous load levels (see figure 7 right):

- **A2:** “Before maximum” of the bond curve (A0) until ca. 60% of maximum load;
- **C and D:** “After maximum” to approximately 1 mm slip and followed by lowering the load down to 45 kN (level C) resp. 30 kN (level D).
To keep the test effort within the limits, all experiments were carried out at 60 °C. To be on the safe side, the bond strength extrapolated from the results of these tests is used for the application temperature of 40 °C. As a result, the bonding strength corresponding to the load level of 30 kN (level D) was chosen because only at this level the creep curves showed stable behavior similar to the bond creep curves of traditional reinforcing steel. In order to allow such a comparison, three creep bond tests with the same test setup (see figure 7 left) but traditional reinforcing steel were carried out.

4. Strengthening with layers of textile reinforced concrete

The first approval for such a type of reinforcement was issued in July 2014 for the applicant TUDAG (Technical University Dresden Joint-Stock Company) (see [5]). After the sewing, the textile is coated to realise the bond between the single fibres of the multifilament yarns. The approval has been issued for strengthening but this type of reinforcement also may be used for new concrete elements (see figure 8).

At first on the surface of the concrete element, which has to be strengthened, a layer of about 8 mm fine concrete is applied. This may be done by hand or by spraying with a special spraying method which also is laid down in the approval (see [5] Annex 4). Afterwards the textile is incorporated into
the freshly applied layer of fine concrete. Then again a layer of fine concrete is applied either to complete the previous fine concrete layer or to incorporate again a Reinforcing Textile in the fresh fine concrete. According to the approval, in this way up to four layers of Textile Reinforcement Concrete may be applied.

![Layer of Textile Reinforced Concrete](image)

### Figure 9. Materials used for strengthening with Textile Reinforced Concrete.

Material fine concrete:
- deposited at the DIBt (maximum grain size from 1 to 4 mm) Material coated

**Textile:**
- Coating: Polymer dispersion with temperature-dependent mechanical behaviour
- Fibers: carbon fibers
  - Fiber content after coating ~35 V%
- Short-time strength of coated yarns: 1980 to 2940 N/mm²
- E-modulus of coated yarns: 150.000 to 170.000 N/mm²

In the test program for this approval it was intended to apply the same procedure for the determination of the long-term tensile strength as it was used for the Schöck-ComBAR. It was found that the behavior of the Textile Reinforced Concrete was very different in comparison to the behavior of the Schöck-ComBAR. In extensive preliminary tests it was detected that at load levels higher than 70% of the characteristic short-term strength in general failure occurs after a few hours, while at loads below 70% of the characteristic short-term strength after 4000 h still no failure occurs. The tested residual strength of these samples was slightly higher than the average value of the reference samples without preloading.

As a result of the investigations, a reduction factor related to the short-term tensile strength of the Textile Reinforced Concrete was introduced. The value of this factor is 0.6. In addition, another factor for the reduction of the bond strength of the textile in the fine concrete was introduced. The value of this factor is 0.21.

### 5. Conclusions

If new reinforcements for concrete are developed, it is important to define the scope and characteristics of the reinforcement in such a way that it is comparable to the scope and characteristics of the conventional reinforcement. Only in this case the user can determine whether the respective reinforcement is suitable for his purpose or not.

A decisive disadvantage of the reinforcement of Fiber Reinforced Polymers previously approved in Germany is the low maximum application temperature of 40 °C.

A reliable determination of the long-term tensile strength and the long-term bond strength of reinforcement of Fibre Reinforced Polymers is only possible with testing methods, which are equivalent to what has been applied at Schöck ComBar.

The test programs of different types of Fiber Reinforced Polymers as reinforcement for concrete must be coordinated.

The scope of reinforcement of Fiber Reinforced Polymers shall be defined in dependence of the applied testing program and the test results achieved.
The applicants of approvals in Germany but also at European Technical Assessments (ETAs) in the EU should know what options of the test program are available to expand the scope of their approval or ETA.

6. References
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