Fourth International Conference on FRP Composites in Civil Engineering (CICE2008)
22-24July 2008, Zurich, Switzerland

Durability and bond durability of composite rebars

A. Weber
R&D, Schöck Bauteile GmbH, Baden-Baden, Germany

ABSTRACT: GFRP rebars have been developed to solve the corrosion problems often encountered with steel reinforcement. Durability tests on GFRP rebars under different conditions and in different applications throughout the world provide no uniform conclusions regarding the permissible design stress levels in GFRP bars. Long term field tests in Canada have shown excellent long-term properties of certain bars, while the results of tests on the same materials in a hotter climate are inferior.

The first coherent approach to bringing the results of the various test series together was developed by the fib. In this procedure secure design values of the tensile strength for any GFRP material is derived under any given environmental condition. The resulting values apply to any type of structure in environments ranging from Canada to the Arabian gulf region.

The bond between the GFRP bar and the surrounding concrete is also of great importance. It must be proven that the brittle material has a ductile bond behaviour. Furthermore it must be shown that the bar can transfer its force into the concrete and vice versa over the full design life-time of the structure. The results of long-term bond tests under different environmental conditions for a specific GFRP rebar are discussed. Bond creep curves for up to 2000 hours are presented.

Using the newly developed approach of the fib and applying it to a modern material it is possible to define safe, yet not exceedingly conservative, design values for any possible application of any particular GFRP rebar.

1 INTRODUCTION

GFRP-rebars have been developed, to solve the corrosion problem within bridges and other concrete structures. One component of these rebars, the glass fibre itself, is, however, susceptible to corrosion in the highly alkaline environment of concrete. This is especially the case in moist and warm concrete, as it is frequently encountered, for instance, on the Arabian peninsula. To show that a glass fibre reinforced polymer (GFRP) rebar is able to transfer the specific design loads over the required service life of a concrete structure, long-term test are necessary to verify the load-bearing capacity of the bar.

2 DESIGN VALUE FOR TENSILE STRENGTH

The GFRP-rebar presented in this paper has a high glass content, which leads to a comparatively high modulus of elasticity / Young´s modulus of 60.000 MPa. The material behaviour is linearly elastic until failure, which occurs, depending on the diameter of the bar, at values far greater than 1000 MPa.

In figure 1 a schematic comparison of the stress-strain behaviour of steel-rebars (as they are commonly used in Germany) and of this particular GFRP-rebar is shown. While the German grade 500 steel rebar yields at a stress level of 500 MPa, the GFRP rebar continues to behave linearly at strain levels greater than 0,8%.

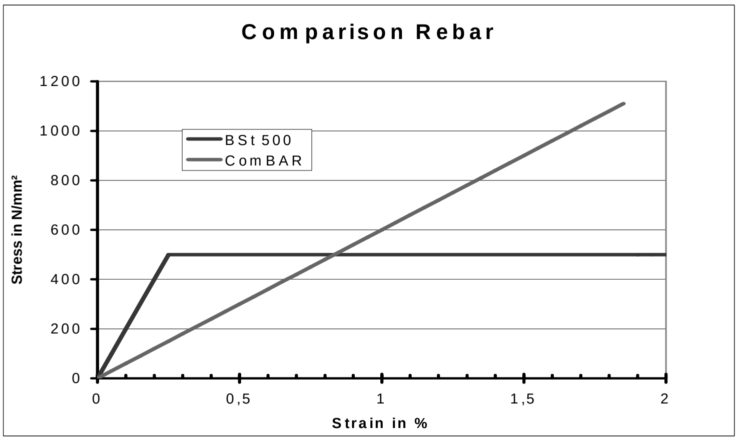

Figure 1. Schematic stress strain behaviour for different rebars (values for d=32mm)

The characteristic value of the short term tensile strength of this GFRP rebar is, independent of the bar diameter, far greater than 1000 MPa. Due to the unique material properties of GFRPs, secure long-term design values can not be simply inferred from the results of short term strength tests. As the manufacturing methods and consequently the material composition of the various GFRP rebars available on the world market vary significantly, it is not possible to specify universally applicable reduction factors for the determination of long-term strengths based on short-term test results. The fib has proposed a procedure for the derivation of long term design values which is applicable to all GFRP materials. This procedure is an alternative to procedures in some of the older GFRP guidelines.

In contrast to steel rebar, which is protected against corrosion by the high ph environment of the concrete, the material strength and the durability of glass fibres is less at higher ph-values. The durability of the material depends on the service life and is influenced by the ambient temperature, humidity and ph value and by the stress level in the bar.

Keeping this in mind, the test setup shown in figure 2 has been developed to determine the long term properties of GFRP bars. This test setup has been approved by the German Institute for Construction Technology (DIBt) and the KIWA Netherlands, and is instroduced in the upcoming fib Bulletin on FRP-reinforcement.

Figure 2 shows the test setup. A cylinder of high ph concrete (Na2O content 1,2%, w/c = 0,5) is cast around the GFRP-rebar. The cylinder is embedded in a water reservoir to assure that the concrete is kept continuously moist. A constant tensile force is applied to the bar. For this particular rebar the stress was chosen to be in the range of 650 to 1200 N/mm². A large number of identical concrete cylinders is tested. They are either kept at room temperature or at a specific elevated temperature throughout the test. Depending on this temperature and the applied stress, the GFRP bars fail inside the concrete cylinder after as little as 10 or as much as 5000 hours.

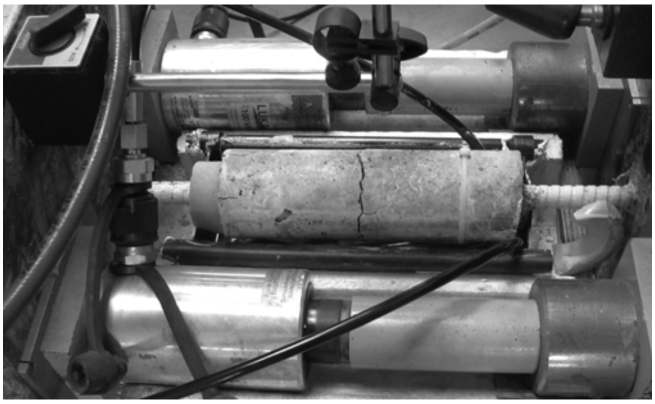

Figure 2. Test setup with GFRP rebar in concrete prism in a water bath under constant hydraulic load.

In each test the displacement of the cylinder head and the hydraulic pressure, that is the force on the bar, are recorded regularly. Figure 3 shows four creep-curves for different loads at a temperature of 40°C. The measured total elongation over the length of the test specimen is the sum of the elastic strain and the creep strain of the rebar itself, and of the bond slip and the bond creep between the bar and the concrete.

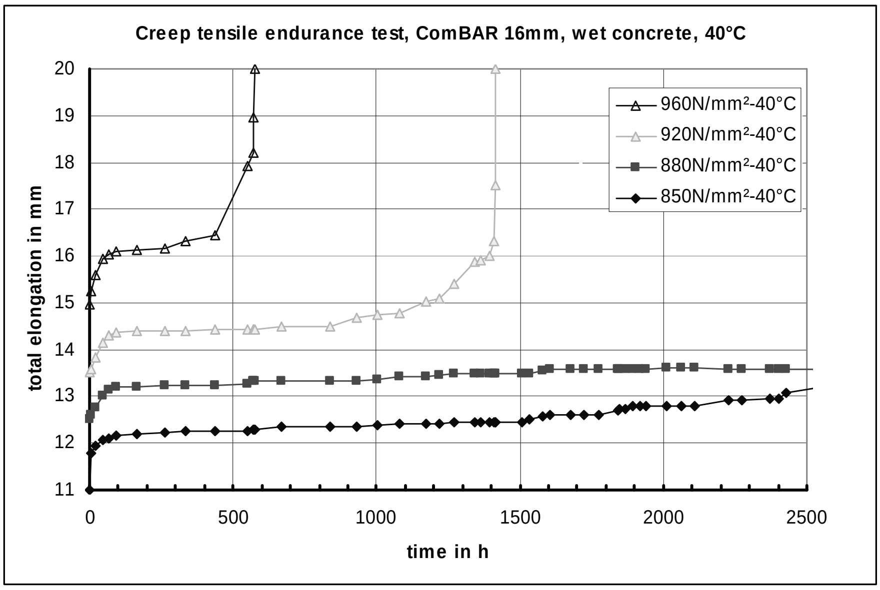

Figure 3. creep curves for GFRP rebar under constant load.

Using the creep curves such as the one shown in figure 3, the times to failure, in this case 574 hours at 960 MPa and 1414 hours at 920 MPa, are recorded as a function of the stress on a doubly logarithmic scale. The results of more than thirty similar tests are summarised in figure 4. Based on these results, times to failure can be extrapolated for a specific stress level according to the procedure described in DIN 53768. The expert committee on non-metallic rebar at the DIBt has required supplementary tests at elevated temperatures to allow for an even greater extrapolation range.

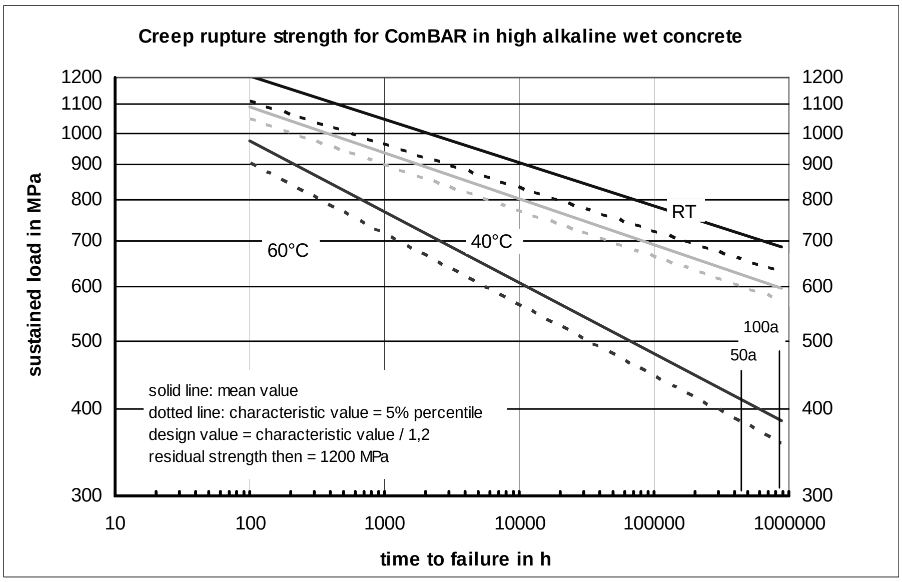

Figure 4. Summarised stress rupture performance at different temperatures

The durability of GFRPs is governed by a function similar to the law of Arrhenius, as the log-log-charts at three different temperature levels confirm. The tests at 40°C and at 60°C can be considered to be accelerated tests for longer term applications in chemically aggressive environments at room temperature. As a result, a sufficiently conservative extrapolation of the long-term strength for a service life of 100 years or more from failure data of up to 6000 hours is possible.

The characteristic value of the tensile strength for temperatures up to 40°C and a design service life of 100 years is certified by the DIBt to be 580 MPa. In other words, the probability of failure after 100 years of this GFRP rebar is less than 5% when it is installed in a constantly moist concrete element at a constant temperature of 40°C and subjected to a sustained load of 580 MPa over its entire service life. Obviously a concrete structure is rarely, if ever, exposed to these extreme environmental conditions for a duration of 100 years.

A number of specimen tested according to the above procedure was unloaded shortly before they were expected to fail. The specimen were experiencing a stable creep development at this point in time. The residual strength of these GFRP bars was tested in a conventional tensile test. All bars had a residual tensile strength in the order of magnitude of the strength of a new bar.

The partial factor of safety for this particular GFPR rebar was statistically determined to be 1.2. Using this factor, a conventional bending design can be performed with a design value of the tensile strength of as much as 480 MPa. On the safe side, the authors proposes using the same design value as that of steel reinforcement (exact values depending on the specific design code). Tables and design aids for the specific GFRP rebar presented here are available on the web.

3 BOND BEHAVIOUR

In the development of the various GFRP rebar systems different approaches have been followed to achieving good bond behaviour. The bond-slip vs. stress relationships for four different GFRPs are shown in figure 5. The surface structure and geometry of these bars ranged from a rough grainy surface to a ribbed bar surface. The bond stresses in all bars are greater than the design value of the bond strength of normal grade concrete. In the serviceability limit state all rebar types behave more or less similarly to steel rebar. That is, the concrete corbels shear off before the surface or the ribs of the bar are damaged.

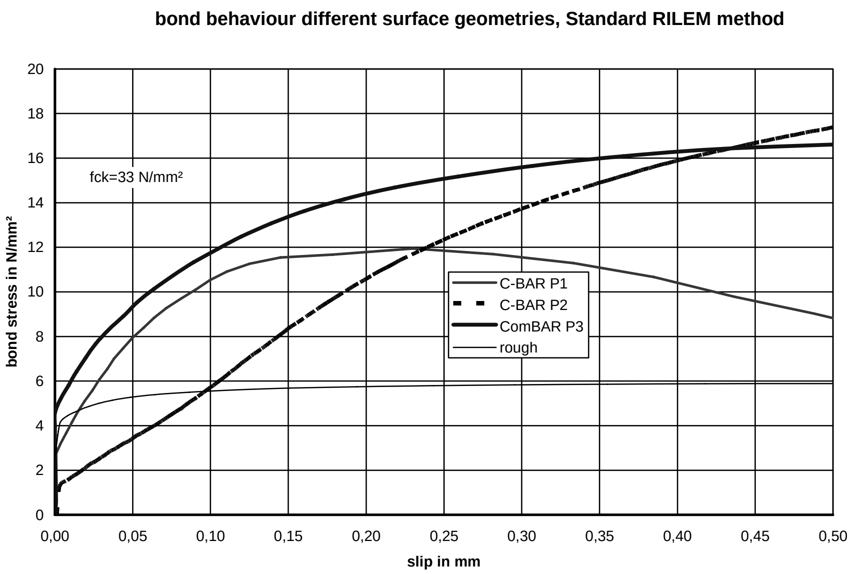

Figure 5. Bond slip relationship for different composite rebar concepts

The safety considerations regarding GFRP rebars are more critical at the ultimate limit state. The two central issues are the failure mode and the bond creep behaviour. The optimized geometry of the bar ribs and the linearly oriented parallel fibres in combination with the high performance resin used in the bar presented herein guarantee that the bond behaviour is more than sufficient in any environment at all times. In normal grade concretes, with compressive strengths up to 70 MPa, the bond slip behaviour is governed by the shearing off of the concrete corbels. Bond slip values are in the range of 0,35 mm, an acceptable value in real-life structures. No damage to the ribs of the GFRP bar is observed. Even in higher grade concrete the bond behaviour is ductile. In figure 6 test results of a bond creep test are shown. In this test the bars are tested after having reached the maximum bond stress (test of the bond creep). The eventual failure mode is a combination of shearing off of the concrete corbels and shearing off of the bar ribs.

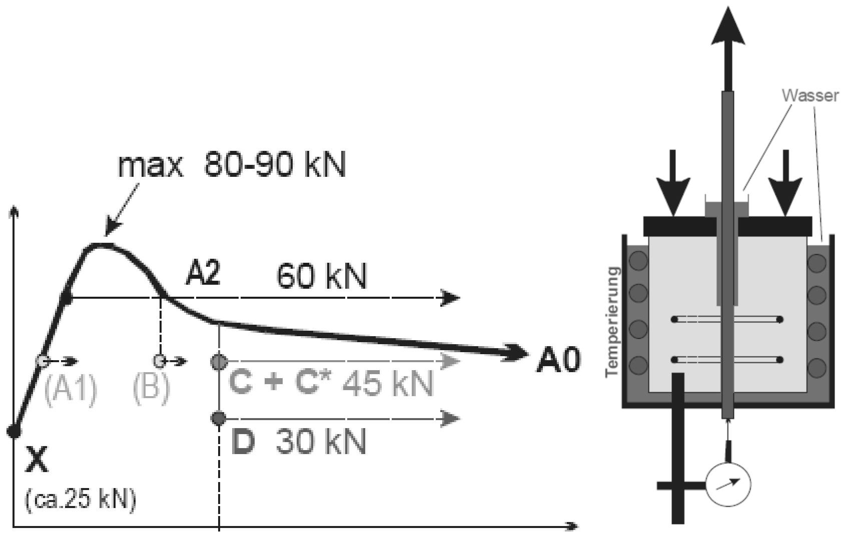

Figure 6. Schematic bond slip relationship, test setup for bond creep

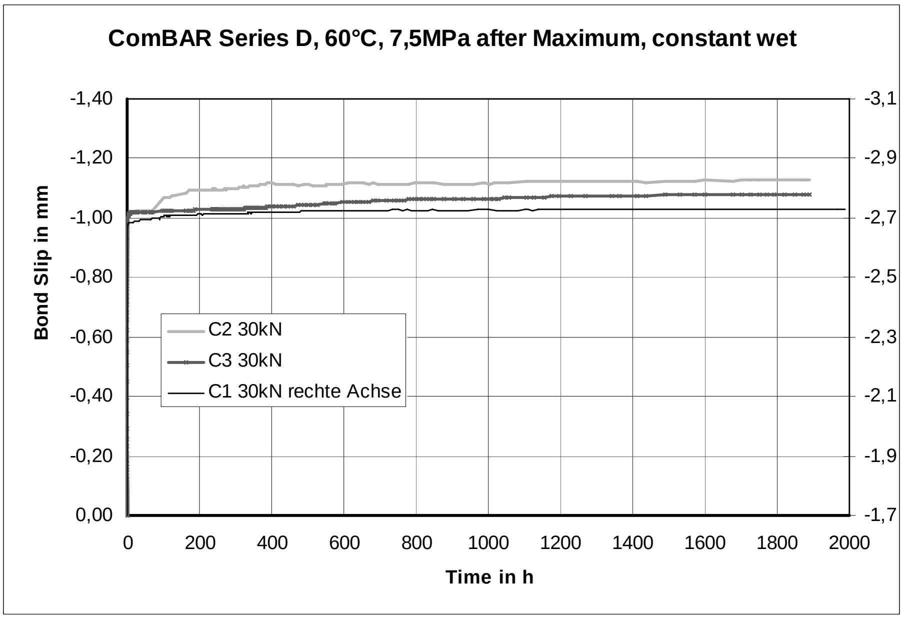

Fig. 7. Creep curve for bond stress of 7,5 MPa in high strength, high alkaline wet concrete [Schießl 07]

The regressive bond creep curve shows that bond stresses can be sustained in a concrete member which has been loaded beyond the design load. These stress values, in the severely disturbed bond section of the concrete member, are much greater than the design value of the bond strength. A sufficient level of safety is therefore guaranteed in the design. The ductile bond behaviour is insured under all imaginable conditions.

4 SUMMARY

Secure design values for reinforcement materials with time dependent behaviour can only be determined securely using long term tests. The proposed test setup for long term tests of GFRP rebar takes all essential influences on the strength of the bar into account. The test results show that it is safe to use the same design values as those of steel reinforcement in a bending design of the particular bar presented in this paper. The standard design procedure of R/C structures has to be modified by taking the absence of yielding and the lower modulus of elasticity of the material into account.

The design values of the bond strength are determined in short term and long term tests. For the specific rebar presented here they depend solely on the concrete strength, and can be used for the design of an bar end anchorage and of lap splices.

REFERENCES

American Concrete Institute Committee 440: ACI 440.1R06 “Guide for the Design and Construction of Concrete Reinforced with FRP Bars”, 2006.

Canadian Standards Association: S806-02 “Design and Construction of Building Components with Fibre-Reinforced Polymers”, Toronto 2002.

Mufti, A.; Onofrei, B.; Benmokrane, B. Banthia, N. Boulfiza, M. Newhook, J.: Report on the Studies of GFRP Durability in Concrete from field demonstration structures; Proceedings of the CCC05 p.889 July 2005, Lyon.

Al-Zahrani M., Effect of accelerated laboratory conditions on tensile strength and moisture absorption of two types of GFRP bars Proceedings of the CCC05 July 2005 Lyon.

Byars E, Weber A et al.: fib Task Group 9.3. Draft: Design and use of Fibre Reinforced Polymer Reinforcement (FRP) for Reinforced Concrete Structures. FRP Reinforcement for RC Structures. Chapter 3 Durability: Performance and Design, February 2006.

Weber A: Bond Properties of a Newly Developed Composite Rebar, Proceedings of International Symposium on Bond Behaviour of FRP in Structures (BBFS 2005) Chen and Teng (eds) 2005 International Institute for FRP in Construction.

Weber A: Advanced Reinforcement Technology with GFRP Rebar; Proceedings 2nd International fib Congress. Naples 2006 .

Braasch H. Weber A: GFRP Rebar for permanent application – Design procedure Proceedings Symposium on connections between steel and concrete, ed. Eligehausen. Stuttgart 2007.

Schießl P. Volkwein A.: Gutachterliche Stellungnahme Teil A2 zum Antrag der Fa. Schöck beim DIBt auf allgemeine bauaufsichtliche Zulassung einer Betonbewehrung aus GFK-Stäben mit der Handelsbezeichnung "ComBAR" 07/051/1.2.1 vom 5.12.2007.