

## Fire-resistance tests on composite rebars

A. Weber

*R&D Schöck Bauteile GmbH, Baden-Baden, Germany*

**ABSTRACT:** The strength-temperature correlation of a material can be determined by tensile tests on the material itself at different temperatures. This was done for a glass fibre reinforced polymer rebar in a series of tensile tests at temperatures ranging from 200 to 550°C. The rebar presented herein contains parallel, linearly oriented ECR glass fibres and a vinyl ester hybrid resin. From the results of the tensile tests a limit temperature in the range of 400°C - 450°C was determined for the bar.

In a second series of tests the bond between the bar and concrete was tested at temperatures in the range between 150 and 400°C. The results show a decrease of the bond strength with increasing temperature. In the range of the glass transition temperature ( $T_g$ ) the bond strength decreases substantially. At lower temperatures, on the other hand, the bond strength depends mostly on the properties of the concrete.

In a full-scale lap splice test a 5 by 2m concrete slab reinforced with GFRP bars was subjected to a predetermined service load (SLS). The load of 116,8kN was applied by four equally spaced load beams. In combination with the dead load of the slab this load caused a stress in the rebar of 300 N/mm<sup>2</sup>. The longitudinal rebars were all lap spliced in the middle of the slab. The length of the lap splices was 1060mm, which corresponds with 66 times the diameter of the 16mm bar. After applying the load, the fire exposure according to DIN EN 1363 was started. The slab withstood this exposure for 90 minutes. The temperature at the centerline of the bars reached approximately 230°C before bond failure occurred.

### 1 INTRODUCTION

The possibility of a fire occurring inside a building can only be excluded entirely for very few types of structures. As a result, most building design guidelines require that the properties regarding the fire resistance of the installed building materials are specified and tested. Steel reinforced concrete combines a high degree of fire resistance with comparatively low construction costs. As of yet, the properties of concrete reinforced with newly developed combustible reinforcement materials, such as fibre composites, are not fully known.

Composite rebars generally consist of a specific type of fibre combined with an artificial resin. These resins are often combustible. The most common fibres are carbon, aramid and glass fibres. Most of the composite rebars available on the market are glass fibre reinforced bars. The material properties of the bars in a fire depend on the resin content and its calorific value, as well as on the properties of the fibres (combustible or non combustible). The calorific value of the rebar presented here is less than 3400 kWs/kg. This value corresponds well with the computed value, based on the resin content of the bar of approximately 13%. Construction materials with a caloric value of this small magnitude are normally classified as class A (non combustible, such as steel, concrete or mineral fibre) according to the European fire classification scheme. As smoke forms when the material is exposed to fire, this classification is, however, not permissible.

More interesting to the designing structural engineer is the capacity of a glass fibre reinforced concrete element to transfer a specific load when the member is exposed to an open fire.

## 2 TEST SETUP MATERIAL TESTS

Various tests have been designed to determine how long a concrete element reinforced with composite rebar can withstand an exposure to fire. These focus on the tensile strength and the bond strength of the rebar.

The strength-temperature correlation of the material is determined from the results of tensile tests on the rebar itself at different temperatures in the range between 200 and 550°C. For these tests the diameter of the bar is turned to 6mm over a length of 30mm in the middle of the test specimen. This section of the bar is then exposed to a constant temperature over 30 minutes. The reduced bar diameter allows for a uniform temperature distribution across this smaller section, whereas the bar can be held tightly by the clamps of the testing machine at both full-diameter bar ends.

In a second test series the bond strength of the rebar was determined at different temperatures. Two different tests were performed. For the first test, from hereon referred to as the push-through test, concrete cylinders of 70 mm diameter and a thickness of 30mm were cast. A piece of composite rebar was placed at the centre of this cylinder. It was 30 mm long. Therefore the ends of the bar were flush with the top and bottom sides of the concrete cylinder (refer to figure 1). A series of these cylinders was heated in a furnace. When the temperature in the furnace and, more importantly, in the specimen had reached the desired level the specimen were removed from the furnace one-by-one. The bond strength of the bars was tested within one minute by pushing on one end of the rebar section with a steel piston.

This testing procedure allows for a uniform temperature across the concrete specimen. It is a comparatively quick procedure. An extensive comparison with the results of tests performed at room temperature showed that the effects of the elevated temperature on the bond stress to slip relationship are negligible.

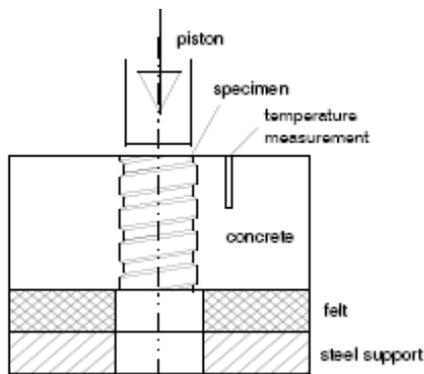


Figure 1. Test setup for the push through test

For the pullout tests specimen were prepared according to the RILEM RC6 setup. They were placed in the heating chamber of a special testing machine at the IBMB in Braunschweig, Germany. A standard pullout test was started once the desired temperature had been reached inside the concrete cube in the vicinity of the bond length. In a second version of this test a constant tensile load was applied to the free end of the bar. The temperature in the heating chamber was slowly increased until pullout failure occurred (Paul 2007).

## 3 RESULTS OF MATERIAL TESTS

Temperature has a significant influence on the strength of most construction materials. Usually the tensile strength decreases significantly at temperatures far below the melting temperature.

The limit temperature of grade BSt 500 S reinforcing steel is known to be in the range of 500°C at a stress in the serviceability limit state of 300 N/mm<sup>2</sup>. In contrast to steel, the strength of the glass fibres used in the bars presented herein gradually decreases from room temperature to a temperature of approximately 400°C. At temperatures above this level the strength decrease is more rapid (refer to figure 2).

Based on the results of a large number of tensile tests at elevated temperatures, a mean-value line of the tensile strengths at various temperatures was computed. The line has a distinct bend at a temperature slightly above 400 °C. Using statistical methods the limit temperature for this material was determined to be 400°C (at a stress of 300 N/mm<sup>2</sup> in the serviceability limit state) by the fire safety institute in Braunschweig (Nause 2005). As a result of the linearly oriented parallel ECR glass fibres and the heat resistant vinyl ester hybrid resin used in these bars, this limit temperature is much higher than that of most other glass fibre reinforced polymer bars.

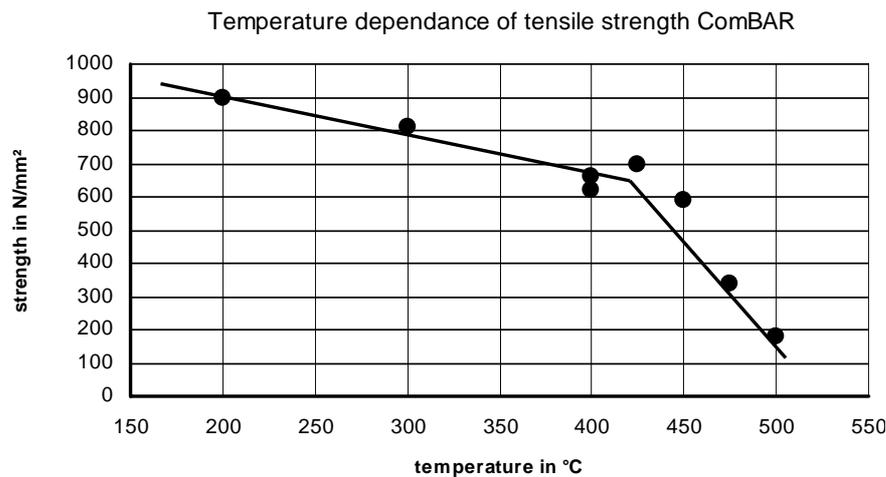


Figure 2. Tensile strength as function of temperature

In the push-through tests (Weber 2005) three different failure modes were observed. At temperatures below approximately 200°C the failure mode is the same as that at room temperature: the concrete corbels are sheared off while the bar was damaged only at its outer surface. In this temperature range the bond strength depends only on the concrete strength. At temperatures between 200°C and approximately 400°C the ribs of the bar were sheared off. At temperatures greater than 400°C only a residual shear strength remained, as the resin began to decompose.

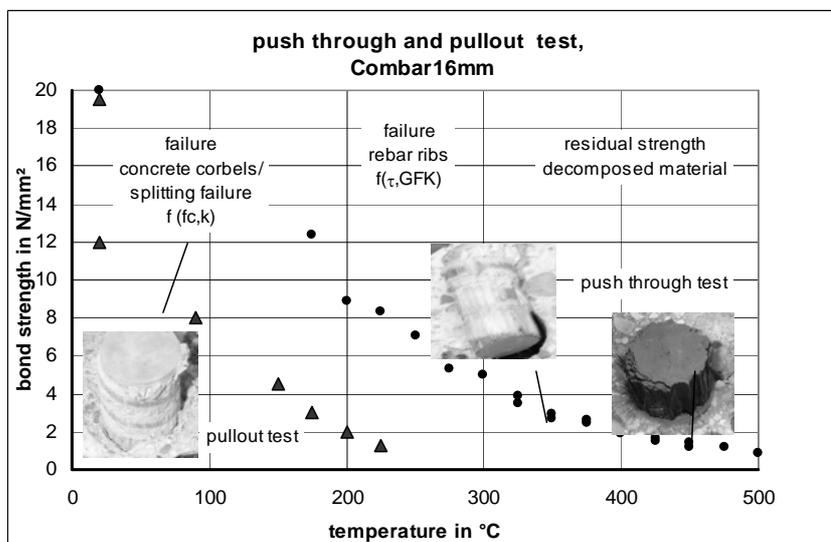


Figure 3. Bond tests at different temperatures

The same failure modes were observed in the pullout tests, only at significantly lower temperatures. Below 180°C, a value close to the transition temperature ( $T_g$ ) of the resin, failure occurred when the concrete cube split. At temperatures above 180°C the failure mode changed to a shearing off of the bar ribs (Paul 2007).

#### 4 FULL SCALE TEST

A full-scale slab test was run to confirm the results of the tests described above. A concrete slab reinforced with the glass fibre rebar discussed herein was placed on top of a fire chamber. After the slab was subjected to a predefined service load a fire was started below the slab until the slab failed. The slab was 5m long and 2m wide. It was reinforced with 16 mm glass fibre bars lengthwise and 8 mm bars as transverse reinforcement in the short direction. The 16 mm longitudinal bars were lap-spiced in the middle of the slab (Paul 2007,2). Bar spacing was greater than ten times the bar diameter. As a result, a reduced splice length of 66 times the bar diameter or 1060 mm was provided. A total load of 116,8kN was applied to the top of the slab by two hydraulic pistons on four steel beams (linear loads). In combination with the dead load of the slab this load lead to a stress in the longitudinal rebars of 300 N/mm<sup>2</sup>. The corresponding bond stress along the rebars was 1,1 N/mm<sup>2</sup>. The longitudinal bars were installed at a concrete cover of 60 mm, which allowed for the concrete temperature to reach 225°C at the centreline of these bars 90 minutes after the fire exposure was started. Prior to testing, the slab was dried for 128 days to achieve a realistic moisture content. The test setup is shown in figure 4.

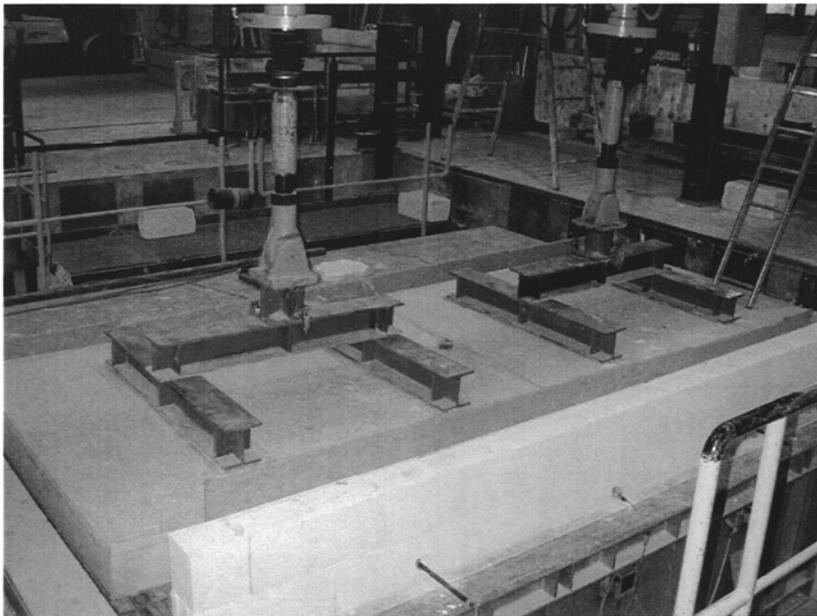


Figure 4. Slab after loading, before fire exposure

After loading the fire exposure according to DIN EN 1363 was started. The temperature development in the fire chamber and at various depths above the bottom of the slab is shown in figure 5. As the glass fibre bars have an outside diameter of 18 mm (16 mm core diameter), the bars were located 60 to 80 mm above the bottom face of the slab.

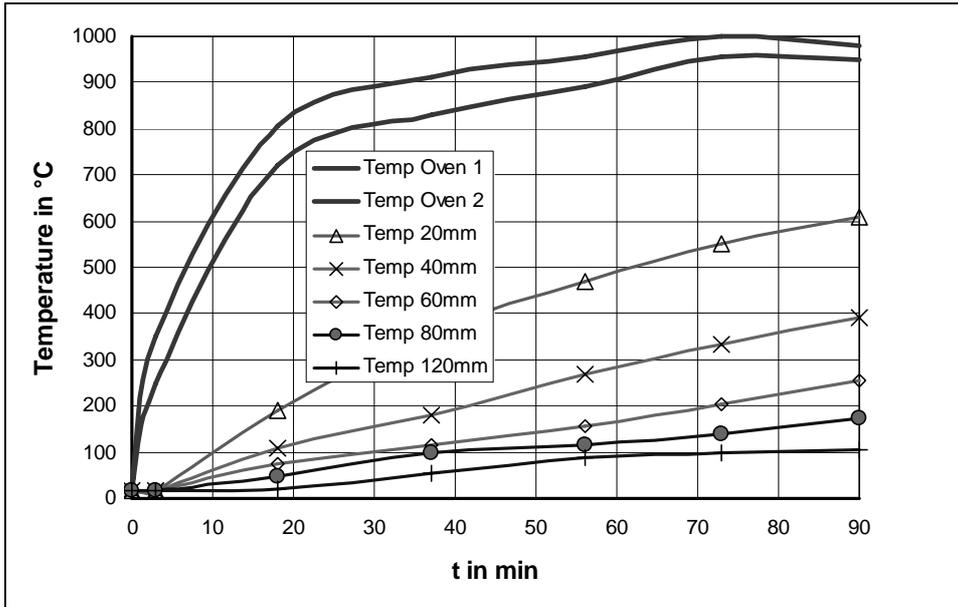


Figure 5. Temperature development in the slab during the fire test

The temperature curves show that the temperature gradient at a concrete depth between 60 and 80mm (measured from the bottom of the slab) is approximately 50 to 70°C. Consequently the top and bottom sides of the bars are exposed to different temperatures. As far as the bond behaviour is concerned, the higher temperature at the bottom of the bars is more relevant in the design than the temperature at the centreline of the bars.

The slab failed 90 minutes after the fire exposure was started (refer to figure 6). The temperature at the centreline of the longitudinal bars reached approximately 225°C shortly before failure occurred. This value corresponds with the failure temperature determined in the bond tests. The results of this full-scale slab test can be applied in the design of other glass fibre reinforced concrete members, such as beams.

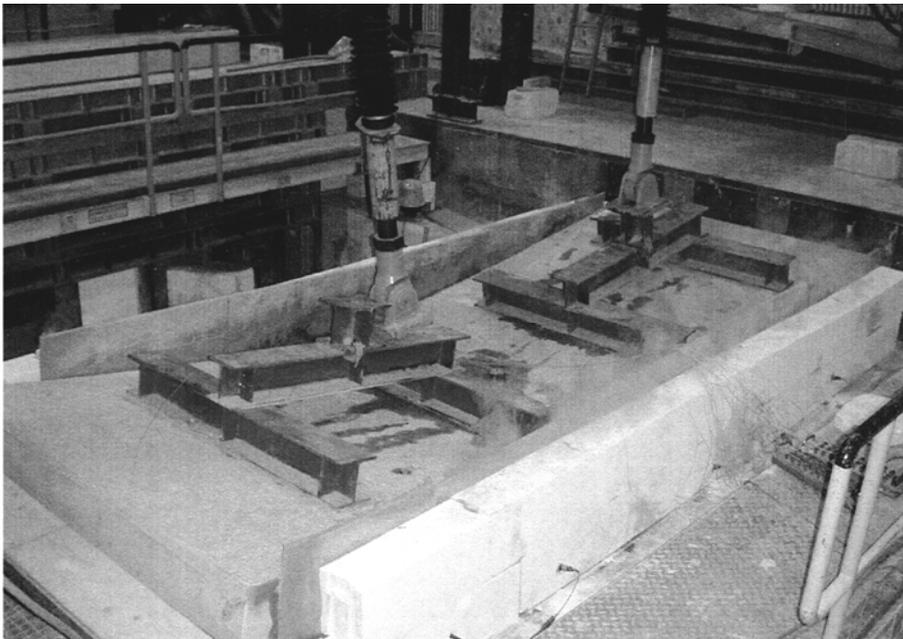


Figure 6: Slab with failure at the end of the lap splice

## 5 CONCLUSIONS

The push through test is a simple and fast test of the behaviour of GFRP bars in concrete elements exposed to fire. However, due to the temperature dependence of the compressive properties of the concrete and the transverse expansion in the GFRP bars, the bond strength is overestimated at high temperatures. Therefore, this test can not be recommended for temperatures above  $T_g$ .

In the pullout test only one specimen can be tempered and tested at a time. The results are more accurate and correspond well with the results obtained in full-size tests. It was shown, that it does not matter in the pullout test whether the load is applied to the previously heated specimen or vice versa. This is not surprising, as GFRPS are comparatively ductile, and as their material properties are heavily temperature-dependent.

Wherever the limit temperature of the bond strength is critical it is better to specify the concrete cover on the rebars rather than the location of their centreline. Regarding the limit temperature for tensile strength, the centreline location of the bars is more significant.

It was shown that two different limit temperatures are critical in the design of GFRP reinforced concrete members for fire exposure. To insure an accurate design the entire concrete structure should be analysed as to where the tensile stress in the bar and where the bond stress along its surface is the limiting factor in the design (in the serviceability limit state). The required concrete cover can then be specified correctly for each region of the structure. Further testing is necessary to develop a more consistent model for fire design.

## REFERENCES

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