

# Flexural Creep Tests on Beams—8 Years of Experience with Steel and Synthetic Fibres

Wolfgang Kusterle

**Abstract** The creep of cracked fibre reinforced concrete beams has been investigated by many laboratories. Different testing procedures have been used. Creep-test results prove that cracked beams reinforced by fibres show time dependent deformations and therefore increasing crack width with time. Some cannot sustain a high percentage of post-crack load for an extended period and fail due to creep rupture. Determination of the residual strength of FRC according to the Austrian Guideline Fibre Reinforced Concrete was the starting point for the tests. The beams were first tested under four-point flexural loading up to a deflection of 1.75 mm. The beams were then unloaded and three pre-cracked beams were loaded with a sustained load at various percentages of the load reported at 1.75 mm deflection. The used testing procedure, realized and planned improvements are discussed. Typical creep-time curves of FRC are presented. The load level was increased stepwise. Starting point was 50 % of the residual load at 1.75 mm deflection. At the load level of 60 %, beams with several fibre types started deforming faster and the test ended up in a creep failure. An alarming fact is that beams with some fibre-types may fail after 7 years of loading.

**Keywords** Structural fibres · Flexural test · Unnotched beams · Creep · Creep rupture

## 1 Introduction

Creep is defined as a phenomenon in which strain in a solid slowly increases under constant stress. It is a viscous deformation with some delayed elastic deformation included. Creep in post crack stage is of interest for fibre reinforced concrete at

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different load levels and pre-deformation. Data is missing for discrete fibres produced of different materials and with different geometry at low dosage in contact with a cement matrix at different humidity and temperature. Creep in tension of fibre reinforced concrete may be investigated in direct tension tests, in tests on beams and in test on panels. In this paper flexural creep tests on beams are discussed. Tests on beams are usually used for determining the values for design. Therefore it makes sense to use the same or similar testing procedures for creep investigations, too. Direct tensile tests would be more precise, but are much more complicated to perform, there use is limited to research purposes. Tests on panels are more favourable to show the positive effect of fibres, but are one more step from the needed design values. Panels with continuous support along all four sides will have problems with external and internal friction, especially in the case of long term tests at low load level. However, it must be kept in mind, that flexural tests are sensitive to specimen preparation, curing and humidity during testing, resulting in high scatter of the results. The load-deflection graph is instable after the first crack and often influenced by the loading speed and the used testing machine.

## **2 Literature Review on Flexural Creep Testing on Beams**

Proper creep tests are time consuming and expensive, as good equipment is needed for a long time in a controlled climate. There are many influencing factors, which have to be investigated. Several investigations have dealt with the monitoring of creep deformation on beams reinforced with steel and polymer fibres in flexural tensile tests. A literature review is given in Table 1.

Starting point for most tests is the determination of the residual strength of FRC, according to well-known standards. Usually the creep test starts immediately after the residual strength test and in some cases the residual strength test is continued after creep testing (Fig. 1). In many cases the creep test results in creep rupture and no further testing is possible.

While some tests use uncracked beams, most use precracked beams. The crack width varies between 0.2 and 5 mm.

The test rigs used for creep testing often use lever arm loading, sometimes hydraulic or spring type loading. The loading levels differ substantially and refer sometimes to the ultimate flexural strength, mostly to the load at the maximum deflection in residual strength testing.

Table 1 Creep tests on beams reported in literature [1]

Literature	Dimensions (mm) n: notched	Span (mm)	Specification	Deflection	Load level	Single/Multi set up	Load-transfer	Climate
Arango	150 × 150 × 600 n	500 450	EN 14651	0.5 mm CMOD	60 % 80 %	3	Lever arm	20 °C/50 % rH
García-Taengua	150 × 150 × 600 n	450		0.5 mm CMOD	60–80 %	3	Lever arm	20 °C/50 % rH
Barragán Zerbino	150 × 150 × 600 n	500 450	EN 14651	0.5–3.5 mm CMOD	59 % 60 %	3	Lever arm	16–22 °C 22–64 % rH
Bast, Eder Kusterle	150 × 150 × 500	450	obv Guideline	1.75 mm	50 %	1	Lever arm	Sealed by Aluminium, 20 °C
BEKAERT Lambrechts	150 × 150 × 500	450	4 point	5 mm	50 %	1	Dead load	Not reported
Ratcliffe	Same as Lambrechts		4 point	5 mm	50 %	1	Not reported	room
Buratti	300 × 120 × 2000 n	800	EN 14651	0.2 mm CMOD	60–70 %	1	Dead load	20/60
Savoia	300 × 120 × 2000 n	750	4 point	0.2 mm CMOD	50 %	Same as Buratti	Dead load	20–40 °C/rH not rep.
Chanvillard	150 × 200 × 700 n	600	–	0.3 mm 0.6 mm	72–80 %	3	Jack	20/50
Cochrane MacKay	100 × 100 × 350 n		ASTM C1399	<0.2 mm	20, 40, 60 % of ARS	3	Lever arm	30–60 °C
DIBt	150 × 150 × 700 100 × 100 × 500	600 450	DBV EN 14651	0.3 mm	50 %	Not spec.	Not spec.	20 °C, rH not spec.
Gossia	150 × 150 × 700 150 × 300 × 700	600 600	DAISIB	0.5 mm	40–50 %	3	Weight + cantilever	20/60
Granju	150 × 200 × 700 n	600	–	0.3 mm CMOD	100 cycl. loaded 50–80 %	1	Not reported	Not reported

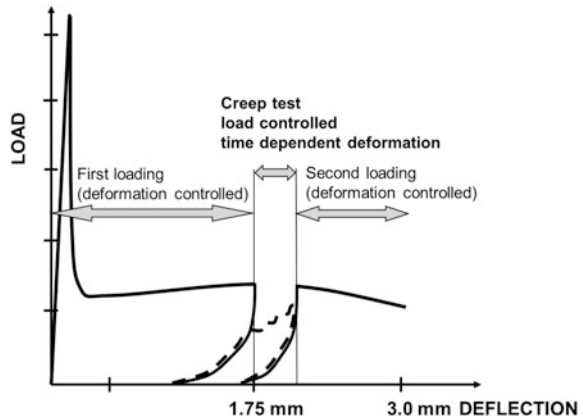
(continued)

Table 1 (continued)

Literature	Dimensions (mm) n: notched n	Span (mm)	Specification	Deflection	Load level	Single/Multi set up	Load-transfer	Climate
Kanstad	120 × 150 × 600 n	450	–	0.2 mm CMOD	50 %	1	Hydr. cylinders	20/50
Kaufmann	150 × 150 × 550 n 150 × 150 × 700	500 600	EN 14651	0.5 mm	25–91 % of first crack	3	Gas cylinders	20/70
Kurtz	100 × 100 × 350	300	ASTM C1399 + modifc.	0.75 mm	25–40 %	1	Cantilever	20/50
Larsen	40 × 60 × 600	550	4 point	Not reported Uncracked	35, 50, 60 % of 28 days	Not reported	Not reported	23/65 23/65–95 outdoor
Tan	100 × 125 × 2000 reinforced	1800	6 point	Uncracked	35–80 % of P <sub>u</sub>	1	Dead load	Not reported
Theodorakopoulos	t × 100 × 500	450	4 point	Uncracked	18–75 % of P <sub>u</sub>	2	Spring	Indoor

Remark Large beam tests are not reported here. See Ref. [1]

**Fig. 1** Idealized plot obtained after complete testing of a beam specimen. Bending test after creep test is seldom performed



### 2.1 Discussion of Test Procedure

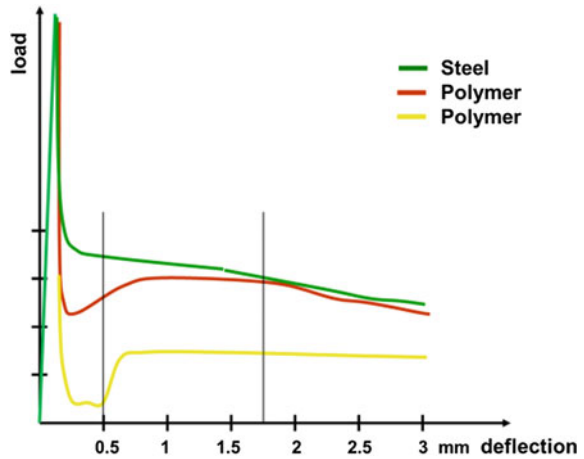
In comparison to panel testing, only a small amount of fibres is oriented in the main stress direction, when using beams. It is therefore necessary to use beams with a large cross section to reduce scatter in results. The span of the beams should not be too small, otherwise you test vault effects instead of real bending.

Notched beams, using centre point loading, have the advantage of direct correlation between load and crack mouth opening displacement, but give higher results (up to 15 %) than tests on unnotched beams in four-point loading. Furthermore the cross section is reduced compared to unnotched beams. As the creep is assessed as a percentage of load at a given deformation, the creep load is effected, too. For practical reasons (stability) many creep tests on notched beams have been performed in four-point loading.

Bending tests on steel fibre reinforced beams often result in different shape of the load-deformation graphs in comparison to beams with synthetic fibres. Both rise and reach a peak when the “first” crack occurs. The graphs of the samples with steel fibres then fall steadily, when the fibres are pulled out. Opposite to this behaviour, samples with synthetic fibres fall sharp before they recover. They reach a second peak before they start falling again (Fig. 2). The deflection, at which they hit a low, often can be 0.1–0.6 mm (tests with 450 mm span). This is in the area of deflection, many creep tests use as starting point. The post crack parameters used for design may be nearly the same for both materials. But, when one compares the behaviour of beams with different fibres, a creep load of the percentage of the residual load at defined deflection is used. The load of beams with steel fibres is much higher in this area of deflection than that of beams with synthetic fibres. The relative elongation of the synthetic fibres is quite low, they are at this period of the test not loaded to the same extend as the much stiffer steel fibres. This may result in misleading conclusions.

In flexural creep test a mixed deformation is monitored resulting from deformations in tensile and compression zones of the cross section. As the creep deformation

**Fig. 2** Typical load-deflection graphs of FRC with steel fibres and synthetic fibres



measured by crack mouth opening or net deflection is a mixture of creep and shrinkage of the concrete and the creep and slip out of the fibres, additional testing or calculations for these properties would be necessary, but are often not available. The environment during testing is mostly kept at ordinary lab conditions, some tests have been done at elevated temperature; other tests cover the beams by aluminium sheets to prevent evaporation. Temperatures higher than 40 °C will clearly increase the deformations, when synthetic fibres are used. The slip of all fibres will be influenced, when the humidity of the concrete matrix changes between water saturated and completely dry conditions.

As quite small deformations are considered, it is of importance that the supports are allowing these deformations with as little friction as possible. As many test rigs are produced as low cost prototypes, these requirements are often not fulfilled completely.

Due to limited access to test rigs and limited space in climate chambers, often several beams are loaded together and the load level is increased stepwise during time. This results in imprecise load levels and lack of data for creep models, which need data from uniform loading at different load levels. Due to lack of time, many tests end too early.

### 3 Investigations at the OTH

When designing fibre reinforced concrete, in Germany the DAFStb-Guideline “Steel fibre reinforced concrete” [2] is used, whereas in Austria the obv guideline “Fibre reinforced concrete” [3] is used. Both guidelines use unnotched beam testing for the determination of flexural strength and post crack strength. Therefore it makes sense to use the same test procedure for flexural creep testing.

In [3] a test procedure for creep tests is included in the informal part of this guideline. Tests done by the author of this paper have been the basis for these recommendations [4, 5]. This test procedure was followed, when performing the tests described in this paper. First tests started in autumn 2006, and since then the 12 test rigs have been used continuously.

For each type of fibre six beams  $150 \times 150 \times 500$  mm were cast and cured under water up to 28 days. Shortly before testing the beams were prepared for testing.

### ***3.1 Testing Post Crack Behaviour***

Testing was performed on beams under four-point flexural loading with a span of 450 mm. For the purpose of this investigation the beams were first tested under four-point flexural loading up to a deflection of 1.75 mm. The beams were then unloaded and prepared for creep test.

### ***3.2 Flexural Creep Test***

Three pre-cracked beams were loaded with a sustained load at various percentages starting with 50 % of the load reported at 1.75 mm bending deflection. The chronological order of testing is shown in Fig. 1. The limited number of rigs was the reason why different load levels were performed using one specimen. The creep rig is designed similarly to the testing machine used for the flexural test. However, the load is kept at a constant level by simple leverage (Fig. 3). Lubricants were used to minimise friction at the supports. Later on roller bearings were installed at one support.

The test results combine both the creep of concrete in compression and the creep of the fibres in tension. There is also creep deflection due to fibre pull-out over time. The beams have to be kept at constant humidity. Therefore, they were protected from drying out by aluminium sheets. The creep rigs are situated in the basement of the OTH lab with quite uniform climate conditions, but unfortunately not that uniform as in a climate chamber.

Creep load is applied using a balance (Fig. 4). When increasing the load, the necessary dead weight and the leverage arm length has to be calculated. The creep deformation versus time is registered for all specimens in given time intervals. For most samples, the test started with a load level of 50 % of the load at 1.75 mm deflection and was increased after about 90 days to a load level of 60 %, some at later age even to 70 and 80 %.

Mass lost during testing and fibre counting in cross section after the tests were done in a last step for proper interpretation of results.

**Fig. 3** The simple, but sufficient stiff test-rig used for these tests



**Fig. 4** Applying the exact creep load. *Note* Supporting rollers in this equipment not sufficiently moveable, instead lubricants are used





### 3.3 Discussion and Possible Improvements

The obv guideline uses a deflection of 1.75 mm for precracking, which is the mean deflection for the determination of ultimate limit state calculation. Most other authors use the deflection for service state calculations (e.g. 0.5 or 1.0 mm). This approach might be more realistic. But the discussion under 2.1 should be kept in mind.

Beams with cross section of  $150 \times 150$  mm and a span of 450 mm will not give such a realistic bending situation as beams with 600 mm span, which are recommended by DAfStb [2].

The influence of humidity, shrinkage and creep of concrete in the compression zone has not been investigated in detail yet. Small temperature changes in our test environment also result in small changes of deformations. Unfortunately it was not possible to test 50 and 60 % loaded specimens in parallel due to limited test facilities. Therefore long-time experience with 50 % is lacking.

The supports were improved by installation of supporting rollers.

Up to now for most tests one mix design has been used. 2015 a RRT started with other mix designs and fibre dosages.

### 3.4 Concrete Mix Design

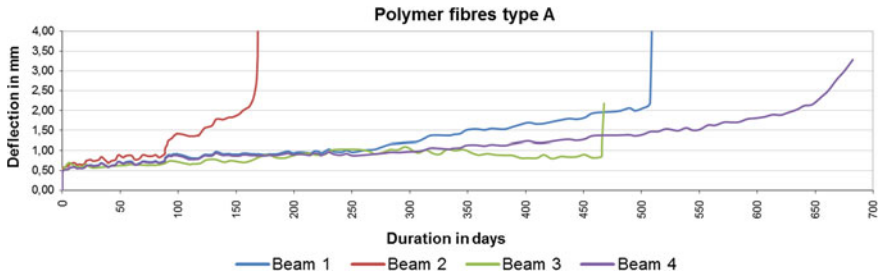
A common used mix-design for FRC was used for all tests:  $370 \text{ kg/m}^3$  CEM II A-S/42.5 R,  $w/c = 0.5$ ,  $1747 \text{ kg/m}^3$  Danube sand and gravel 4/16.

Consistency was controlled by different dosages of Sika Viscocrete 1020X at 450 mm on the spread table, 28 days compressive strength reached 60 MPa, first peak strength about 6 MPa. The fibre dosage was quite low. About the same amount of fibres, calculated by volume, was added for steel ( $30.0 \text{ kg/m}^3$ ) and polymeric fibres ( $4.5 \text{ kg/m}^3$ ) in all tests reported here.

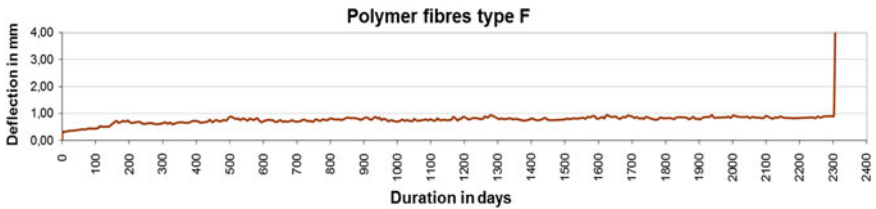
For these tests 9 different fibres, representing commonly used types, were used, 8 synthetic macro fibres and one type of a typical steel fibre as Ref. [5]. As structural synthetic macro fibres did improve since 2006, when the tests started, it makes no sense to identify specific fibres. The fibres vary in their material composition and dimensions. The results should mainly give an overview on possible creep deformations with different fibres.

## 4 Results of Creep Tests

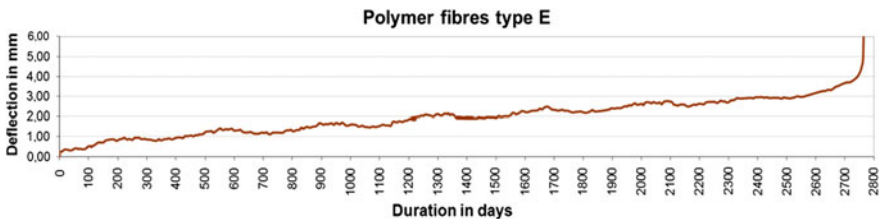
Test results are available now up to more than 3200 days or 8 years. The results show higher deformation for cracked beams reinforced by synthetic fibres at the same load level and therefore wider cracks than for SFRC. Some cannot sustain a



**Fig. 5** Creep deformation of the 4 beams with type A polymer fibres, leading to creep rupture after different period of time. *Note* The creep load is 50 % of the load at 1.75 mm up to 90 days, and then increased to 60 %. The absolute values of creep load are not the same for all 4 beams



**Fig. 6** Creep deformation of one beam with type F polymer fibres, leading to creep rupture after 2300 days. Load level 60 %. Total deflection before tertiary creep very low. The other two beams are still carrying the sustained load after 2694 days

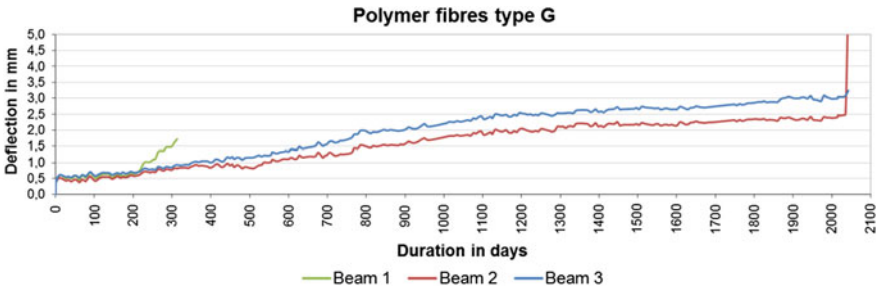


**Fig. 7** Creep deformation of one beam with type E polymer fibres, leading to creep rupture after 2770 days. Load level 60 %. Total deflection before tertiary creep is moderate. The other two beams collapsed after 190 and 260 days

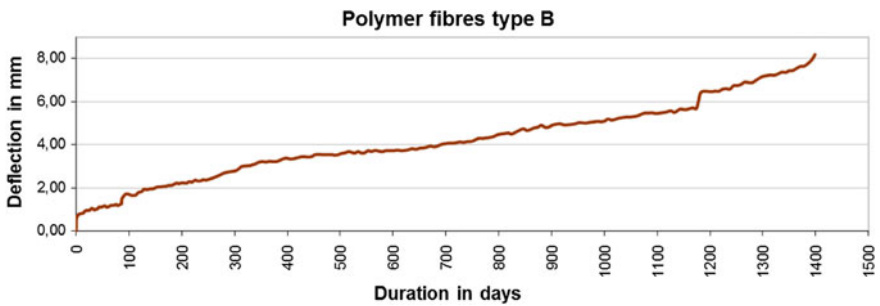
high percentage of post-crack load for extended periods and fail due to creep failure.

Some typical results of individual specimens are shown in Figs. 5, 6, 7, 8, 9 and 10.

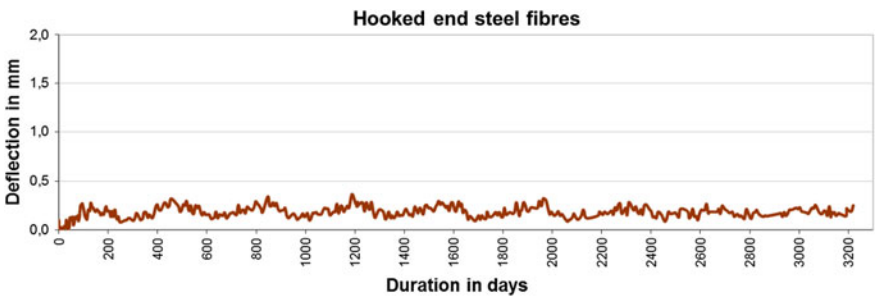
Figure 5 gives an overview of 4 test results for a typical synthetic fibre in 2006. All 4 samples could not withstand the 60 % of short time load.



**Fig. 8** Creep deformation of three beams with type G polymer fibres: *Beam 1* experienced creep rupture after 313 days. Load level 60 %. Notice Absolute sustained load applied was 60 % higher, than for beam 2 and 3. *Beam 2* collapsed after 2041 days. *Beam 3* was still carrying the sustained load. The test was finished at the collapse of beam 2. For both load level 60 % had been changed to 65 % after 1203 days



**Fig. 9** Creep deformation of one beam with type B polymer fibres, leading to creep rupture after 1400 days. Load level 60 %. Very high total deflection. The other two beams collapsed after 1062 days at 11 mm deflection and 3000 days at 5.5 mm deflection



**Fig. 10** Creep deformation of one beam with a typical steel fibre, at load level 4 (50 % up to 85 days, 60 % to 3180 days, 70 % to 3190 days, after that the load was increased to 80 %)

While beams with type F fibres (Fig. 6) show low deformation and only one collapsed up to now, the beams with type E fibres (Fig. 7) showed slight, but ever increasing secondary creep, which ended up in creep rupture after 190–2770 days.

Figure 8 shows the influence of the load applied, relatively always 60 %, but absolutely for beam 1 with 60 % difference (10.44 kN instead of 6.42 kN).

The crack width for one specimen reached nearly 10 mm (Fig. 9). But the most alarming fact is that beams with some types of fibres can fail after a long period of testing, e.g. after 6 or 7 years (Figs. 6 and 7). Up to 1.5 years or even longer the graphs of deformation-time still show low rates of creep deformation.

Beams with common steel fibres (low carbon cold drawn wire fibre with hooked ends) are still performing excellently (Fig. 10) at load levels of 60 and 70 %. Note, that the concrete properties will have changed after 3200 days. Beams at 28 days with the same steel fibres under 75 % and up to 85 % of the residual load were tested as well. They failed within minutes due to fibre pull out at this load level.

#### **4.1 Failure Mode**

Load at 1.75 mm varied between 4 and 15 kN for all beams tested. While the short-time load deformation curves for steel fibre reinforced beams are constantly decreasing with increasing de-flection, the curve for synthetic fibre reinforced beams may reach a maximum between 0.5 and 2 mm deflection, depending on the fibre type. But in the testing procedure a load at 1.75 mm is fixed and the sustained load is fixed by a percentage of this load. The results obtained from individual creep tests performed in these investigations are therefore different from those using 3 beams packed together and loaded with a mean value of the load.

Beams with synthetic fibres show big differences in the results, depending on fibre type. Actually, fibres type B (Fig. 9) showed very high deformations, but carrying the sustained load for long time, while type F (Fig. 6) fibres showed small deformations and up to now, only one sample reached its creep resistance after 2316 days of loading at 60 %. Most synthetic fibres reached the tertiary creep stage [1] after a quite long period and failed. The failure mode is not easily identified, as an investigation of the fibres with different sizes is not that easy after the test. However, if the elongation of the polymer gets too high, it can be expected that the fibre material will fail, maybe partly combined with a pull out of the fibres. Beams with the investigated steel fibres with end hooks, showed the lowest deformation in this post crack creep tests. However, there is also an upper load limit for these fibres. Increasing the load to 75 % through 85 % results in immediate creep rupture, due to fibre pull out. The pull out action can be heard during testing by a clicking noise.

## 5 Conclusions

For durability and serviceability reasons, design of FRC structures has to avoid too high long term deformations and creep rupture. Therefore more knowledge regarding creep of cracked FRC is necessary. Up to now no international specification for tests is available. Numerous tests according to the Austrian Guideline “Fibre reinforced Concrete” have been performed with different fibres, but same dosage. Unnotched beams with a span of 450 mm, precracked to 1.75 mm deflection were loaded with 50 % of short time residual load, which was stepwise increased to higher levels.

The results give a clear indication, how cracked FRC will behave under sustained load. However, the test results may only be applied to the fibre dosages and the quite high crack mouth opening displacement used in these tests prior to the creep test. Creep and shrinkage of the concrete was not eliminated from the data.

The used testing equipment stood the test. The supports have been improved recently. The influence of the storage climate has still not proved satisfactory.

Following above stated test conditions it may be concluded for the tested fibres: Beams with low quality synthetic fibres will not withstand a sustained load of 50 % of short time residual strength. Beams with most synthetic fibres will perform well at a load level of 50 %, but experience problems at a load level of 60 %. Creep rupture may occur immediately or after some years of loading. Therefore, it is difficult to predict the creep behaviour in advance. Beams with some synthetic fibres tend to suffer very high deformations not ending up in failure before some years of loading have passed. Beams with the hooked end steel wire fibres started with a slip out from the matrix and creep rupture occurred within several hours at load levels of 75–85 %.

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## References

1. Kusterle, W.: Creep of fibre reinforced concrete—flexural test on beams. In: Proceedings of Fibre Concrete 2015, CTU in Prague, Faculty of Civil Engineering, 10–11 Sept 2015, Prague
2. DAfStb: Guideline steel fibre reinforced concrete (in German Richtlinie Stahlfaserbeton). Beuth-Verlag, Berlin (1996)
3. obv (Austrian Society for Construction Technology): Guideline Fibre Reinforced Concrete (in German: Richtlinie Faserbeton), Vienna (2008)
4. Bast, T., Eder, A.: Untersuchungen zum Langzeitstandverhalten von gerissenen Faserbetonen unter Biegezugbeanspruchung. Diploma-thesis, OTH Regensburg (2007)
5. Kusterle, W.: Viscous material behaviour of solids—creep of polymer fibre reinforced concrete. In: Proceedings of the 5th Central European Congress on Concrete Engineering, obv, Baden (2009)