CREEP OF FIBRE REINFORCED CONCRETE - FLEXURAL TEST ON BEAMS

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Abstract

The creep-time behaviour of cracked concrete beams reinforced by structural fibres under sustained load in a bending test was investigated by many laboratories. Creep-test results prove that cracked beams reinforced by fibres show, depending on the load level and temperature, 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.

In this paper long term creep tests are presented according to the Austrian Guideline Fibre Reinforced Concrete. Creep-time curves of FRC with several different fibres are presented. At the load level of 60%, beams with several fibre types started deforming faster and the test ended up in a creep failure. But the most alarming fact is that beams with some fibre-types may fail after 7 years of loading.

Keywords: structural fibres, creep testing, flexural test, creep deformation, creep rupture

1. Introduction

Creep is defined as a phenomenon in which strain in a solid increases slowly with time, when the stress producing the strain is constant. It is a viscous deformation with some delayed elastic deformation included.

Regarding fibre reinforced concrete, creep is a topic under investigation in several labs. RILEM has formed 2014 a technical committee CCF collecting all relevant information on creep of fibre reinforced concrete. 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 test on beams will be discussed. When designing fibre reinforced concrete in Germany the DAfStb-Guideline steel fiber reinforced concrete [1] is used, whereas in Austria the OEBV-Guideline “Fiber reinforced concrete” [2] 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 [2] 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 [3, 4].

As for all materials, which show visco-elastic behaviour, data regarding time dependent deformation and maximum long time load, is necessary for a proper design. Creep

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behaviour in compression of fiber reinforced concrete is nearly the same as of normal concrete. But the deformation behaviour of cracked fibre reinforced concrete is influenced by the fibre material and geometry, the amount of the fibres, the properties of the matrix the fibres are embedded, the environment (humidity and temperature), the load level and the time. Too high crack mouth opening displacements must be avoided and the maximum possible long term load must not be exceeded, prohibiting creep rupture.

In figure 1 the vertical axis represents the deformation of the material, the horizontal axis the duration of the test under constant load [5]. Three stages can be identified. The stages are described as [6]: Primary: a period of decreasing creep rate. Secondary: a period of nearly constant creep rate. In tests that do not end in failure, this is the final stage. Tertiary: a period of increasing creep rate, prior to failure. If the load exceeds the material long-term strength, the secondary creep will rise more steeply and at the tertiary stage deformation will be seen, which inevitably will lead to failure. A creep rupture will occur. The load just below this load level is called the long-term resistance or creep resistance.

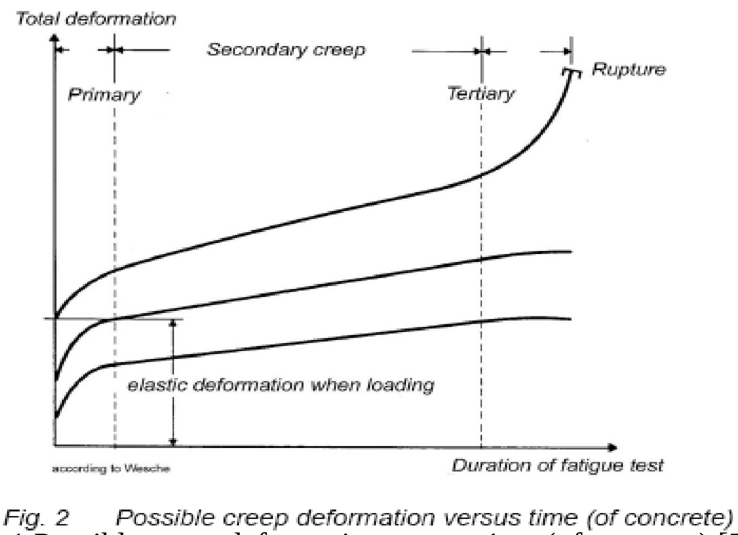

Fig.1 Possible creep deformation versus time (of concrete) [5]

2. Literature review on flexural creep testing on beams

In comparison to panel testing, only a small amount of fibres is oriented in the main stress direction, when using beams. In flexural creep test a mixed deformation is monitored resulting from deformations in tensile and compression zones of the cross section. Direct uniaxial tests don't show this disadvantage, but are more sophisticated to perform. Deformation in beam test is less geometrical hindered then in panel tests, especially in panels which are supported along all four sides.

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. 2). In many cases the creep test results in creep rupture and no further testing is possible.

Tab. 1: Creep tests on beams reported in literature

Literature	**Dimensions mm n..notched**	**Span mm**	**Specifi-cation**	**De-flection**	**Load level**	**Single/ multi set up**	**Load-transfer**	**Climate**
Arango [7, 8]	150x150x600 n	500 450	EN 14651	0.5 mm CMOD	60% 80%	3	lever arm	20°C/50% rH
García-Taengua [9]	150x150x600 n	450		0.5 mm CMOD	60-80%	3	lever arm	20°C/50% rH
Barragán [10] Zerbino [11]	150x150x600 n	500 450	EN 14651	0.5 mm to 3,5 mm CMOD	59% 60%	3	lever arm	16-22 °C 22-64% rH
Bast,Eder [3, 12] Kusterle [4] OeBV [2]	150x150x500	450	OVBB Guideline	1.75 mm	50% 60%	1	lever arm	Sealed by Alumin-um, 20°C
BEKAERT [13, 14] Lambrechts [15]	150x150x500	450	4 point	5 mm	50%	1	Dead load	Not reported
Ratcliffe [16, 17] Buratti [16 to 22]	Same as [15] 300x120x 2000 n	 800	4 point EN 14651	5 mm 0.2 mm CMOD	50% 60-70%	1 1	Not reported Dead load	room 20/60
Savoia [23]	300x120x 2000 mm n	750	4 point	0.2 mm CMOD	50%	Same as Buratti	Dead load	20-40°C/rH not rep.
Chanvillard [24]	150x200x700 n	600	-	0.3 mm 0.6 mm	72-80%	3	jack	20/50
Cochrane [25] MacKay [26]	100x100x350 n		ASTM C1399	< 0.2 mm	20,40, 60% of ARS	3	Lever arm	30-60°C
DIBt [27]	150x150x700 100x100x500	600 450	DBV EN 14651	0.3 mm	50%	Not spec.	Not spec.	20°C, rH not spec.
Gossla [28]	150x150x700 150x300x700	600 600	DAfStB	0.5 mm	40-50%	3	Weight + canti-lever	20/60
Granju [29]	150x200x700 n	600	-	0.3 mm CMOD	100 cycl. loaded 50-80%	1	Not reported	Not reported
Kanstad [30]	120x150x600 n	450	-	0.2 mm CMOD	50%	1	Hydr.cylinders	20/50
Kaufmann [31]	150x150x550 n 150x150x700	500 600	EN 14651	0.5 mm	25-91% of first crack	3	Gas cy-linders	20/70
Kurtz [32]	100x100x350	300	ASTM C1399 + modific.	0.75 mm	25-4 %	1	cantilever	20/50
Larsen [33]	40x60x600	550	4 point	Not reported, uncracked	35, 50, 60% of 28 days	Not reported	Not reported	23/65 23/65-95 outdoor
Tan [35]	100x125x 2000 reinforced	1800	6 point	un-cracked	35-80% of P_u	1	Dead load	Not reported
Theodorakopoulos [35]	tx100x500	450	4 point	uncracked	18-75% of P_u	2	spring	indoor

Remark: Large beam tests are not reported here.

Following these examples the creep test starts at different age of the beams as well as different dimensions and storage conditions are used. Notched and unnotched beams have been used for this purpose.

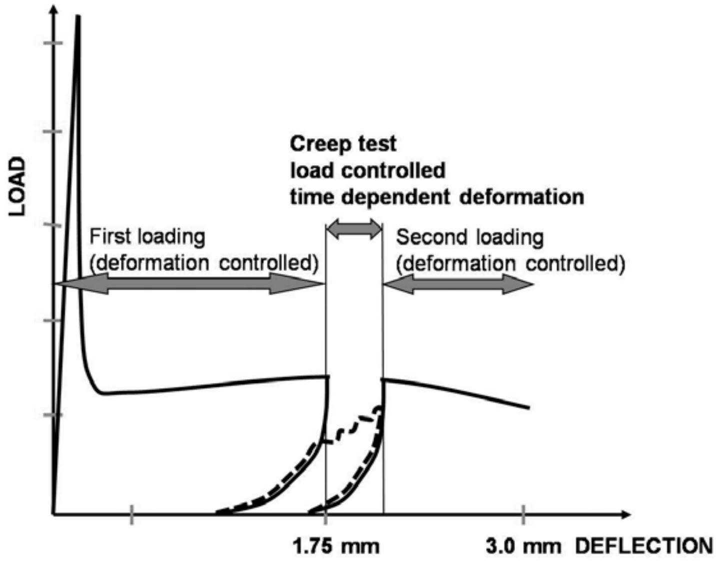

Fig 2. Idealized plot obtained after complete testing of a beam specimen. Bending test after creep test is seldom performed.

Some tests use uncracked beams, most use precracked beams, crack width varying between 0.2 mm to 5 mm.

The test rigs used for creep testing often use lever arm loading, sometimes hydraulic or spring type loading. The loading levels differ a lot and refer sometimes to the ultimate flexural strength, mostly to the load at the maximum deflection in residual strength testing. 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 ended too early. Other test show creep rupture after years of loading.

As the creep deformation 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 test have been done at elevated temperature; other tests cover the beams by aluminium sheets to prevent evaporation. As we speak of quite small deformations, 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.

The OeBV-guideline [2] is the only available guideline at the time being dealing with flexural creep testing of FRC!

3. Test procedure used for the tests

Testing was performed on beams in accordance with the testing procedure from the Guideline for Fibre Reinforced Concrete published by the Austrian Society for Construction Technology [2]. Six beams 150 x 150 x 500 mm were cast, and cured under water up to 28 days. Shortly before testing the beams were prepared for testing.

3.1 Concrete mix design

A common used mix-design for FRC was used for all tests:, 370 kg/m³ CEM II A-S / 42.5 R, 1747 kg/m³ Danube sand and gravel 0/16 and w/c = 0.5.

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 6 MPa. The fibre dosage was quite low. About the same amount of fibres, calculated by volume, were added for steel (30.0 kg/m³) and polymer fibres (4.5 kg/m³) 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 reference [4]. 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.

3.2 Testing post crack behaviour

Testing was performed on beams under third-point flexural loading with a span of 450 mm. For the purpose of this investigation the beams 150 x 150 x 500 mm were first tested under third-point flexural loading up to a deflection of 1.75 mm. The beams were then unloaded and prepared for creep test.

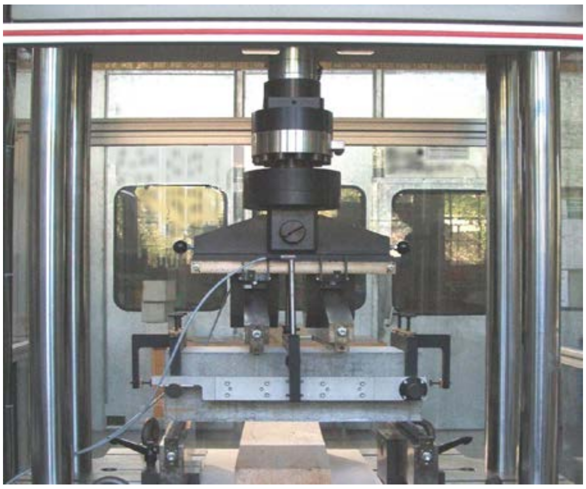

Fig. 3: Testing flexural post crack behavior on beams using electronic transducer mounted at mid-span to a yoke that is held to the beam at mid-height of the beam and directly over the supports excluding any support deformations and twist

3.3 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 (figure 7). This long-term test was carried out using 12 special test rigs. The chronological order of testing is shown in figure 2. 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 (figure 8). Lubricants were used to minimise friction at the supports.

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.

Creep load is applied using a balance. When increasing the load, the necessary dead weight and the leverage arm length has to be calculated. The creep deformation versus time was 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 even to 70% and 80 %.

Fig. 4: Applying the exact creep load. (Note: supporting rollers in this equipment, not sufficient moveable, instead lubricants are used)

Fig. 5: The simple, but sufficient stiff test-rig used for these tests.

Fibre counting in cross section after the tests is recommended for proper interpretation of results.

3.4 Discussion and possible improvements

The OeBV 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.

Beams with cross section of 150 x 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 [1].

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.

4. Results of creep tests

Test results are available now up to more than 3000 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 high percentage of post-crack load for extended periods and fail due to creep failure.

Some typical results of individual specimens are shown in figures 6 to 15:

Beams with fibres D could not withstand the 50% load level and broke within days (figure 6), beams with fibres of type C could not withstand load level 60% and collapsed within days. Beams with type A steel fibres (figure 7) showed a high residual strength at 1.75 mm deflection and therefore were loaded with a high sustained creep load. They performed well for a time, but started tertiary creep and failed after 170 to 680 days at load level of 60%.

While beams with type F fibres (figure 8) show the best behaviour up to now, the beams with type E fibres (figure 9) showed slight, but ever increasing secondary creep, which ended up in creep rupture after 190 to 2770 days.

Figure 10 and 11 show the influence of the load applied, relatively always 60%, but absolutely with 60% difference.

During testing the crack width amounts for one specimen to nearly 1 cm (figure 12). But the most alarming fact is that beams with some types of fibres can fail after a long period of testing, e.g. 500 days (figure 7) and even after 6 or 7 years (figure 8 and 9). Up to 1.5 years or even longer the graphs of deformation-time still look quite encouraging!

Beams with common steel fibres (low carbon cold drawn wire fibre with hooked ends) are still performing excellently (figure 13 and 14) at load levels of 60% and 70%. Beams 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.

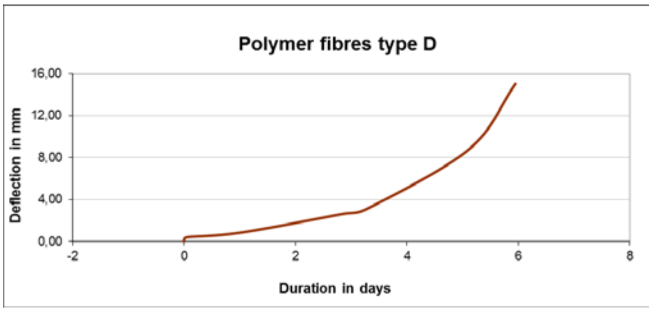

Fig. 6: Creep deformation of one beam with type D polymer fibres, leading to creep rupture shortly after loading. Load level 50%

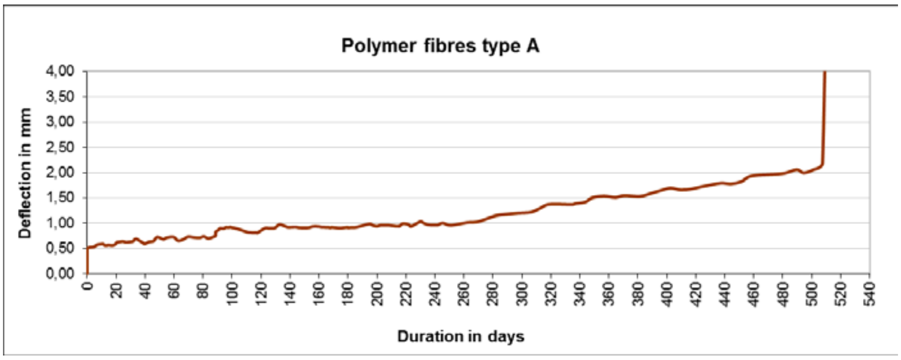

Fig. 7: Creep deformation of one beam with type A polymer fibres, leading to creep rupture after 515 days. Load level 50%, rose to 60% after 88 days

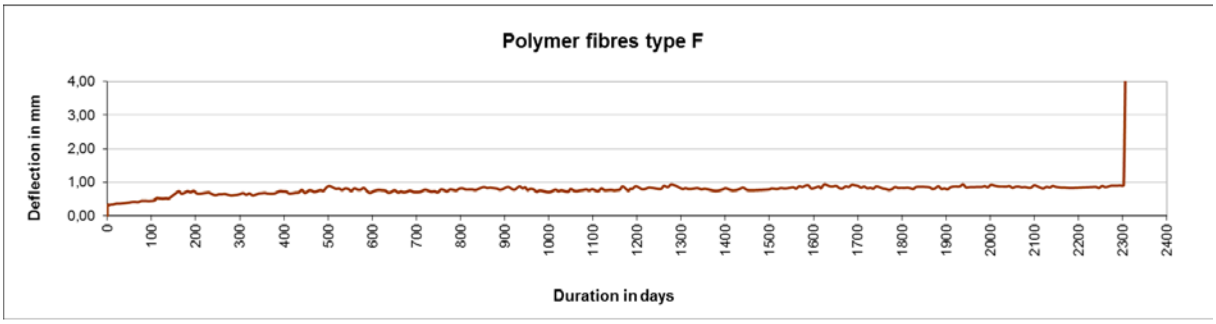

Fig. 8: Creep deformation of one beam with type F polymer fibres, leading to creep rupture after 2300 days. Load level 60%. Total deflection before tertiary creep very low. The other two beams are still carrying the sustained load.

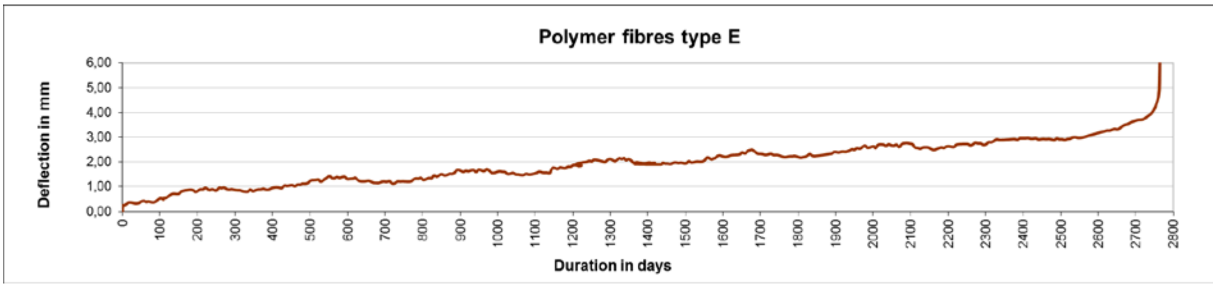

Fig. 9: Creep deformation of one beam with type E polymer fibres, leading to creep rupture after 2770 days. Load level 60%. Total deflection before tertiary creep is moderate. The other two beams collapsed after 190 and 260 days.

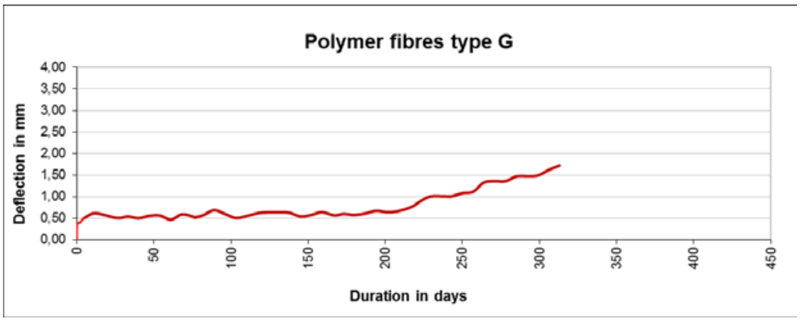

Fig. 10: Creep deformation of one beam with type G polymer fibres, leading to creep rupture after 313 days. Load level 60%. Notice: absolute sustained load applied higher, than in figure 11, as the load reported at 1,75 was 60% higher for this beam than for the beams reported in figure 11

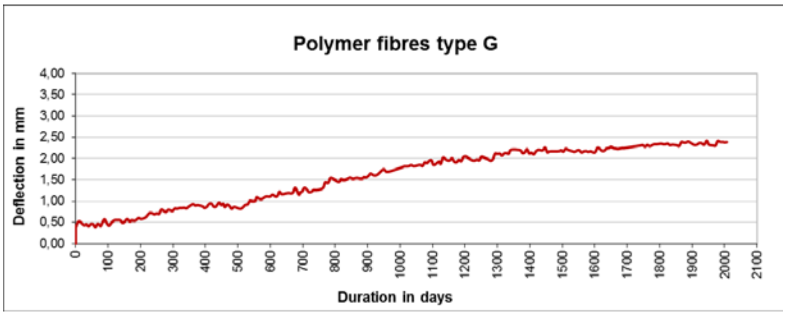

Fig. 11: Creep deformation of another beam with type G polymer fibres, still carrying the sustained load. Load level 60%. The third beam shows about the same behavior.

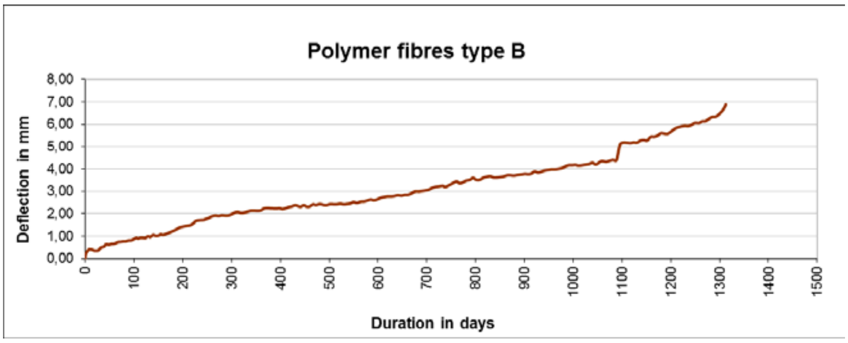

Fig. 12: Creep deformation of one beam with type B polymer fibres, leading to creep rupture after 1300 days. Load level 60%. Very high total deflection.

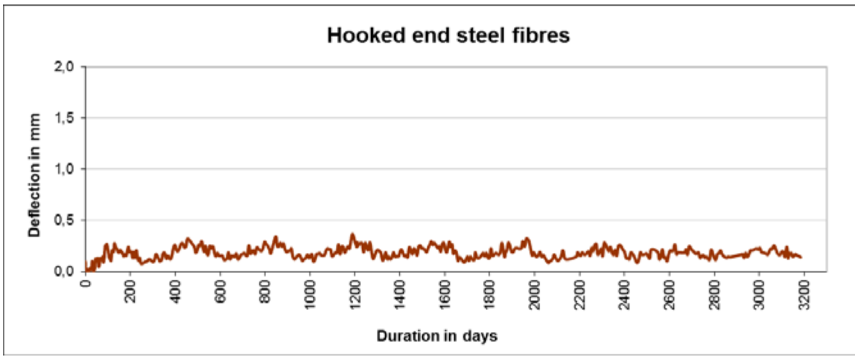

Fig. 13: Creep deformation of one beam with a typical steel fibre, at load level 3 (50% up to 85 days, 60% to 3180 days, after that the load was increased to 70%

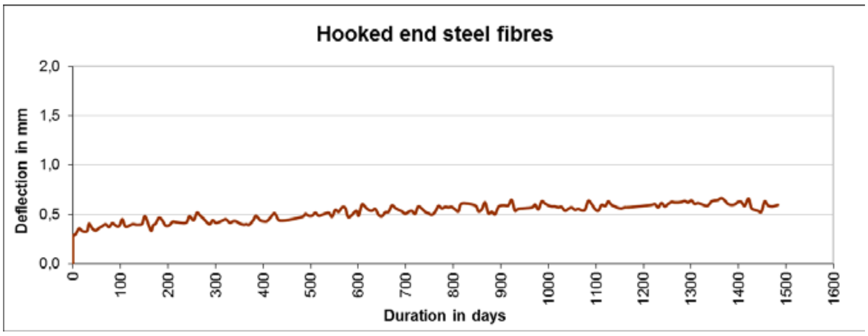

Fig. 14: Creep deformation of one beam with a typical steel fibre, at load level of 70% from the beginning

4.1 Failure mode

Load at 1.75 varied between 4 kN and 15 kN for all beams tested. While the short-time load deformation curves for steel fibre reinforced beams are constantly decreasing with increasing deflection, 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 different from those using 3 beams packed together and loaded by a mean value of the load. The latter is performed for practical reasons in other investigations.

Beams with synthetic fibres show big differences in the results, depending on fibre type. Actually, fibres type B showed very high deformations, but carrying the sustained load for long time, while type F fibres showed small deformations and up to now, only one sample reached the creep resistance after 2316 days of loading at 60%. Most synthetic fibres reached after a quite long period the tertiary creep stage and failed. The failure mode may not be identified very easy, 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% to 85 % results in immediate creep rupture, due to fibre pull out. The pull out action can be heard during testing by a “click” noise.

5. Conclusions

Testing flexural creep of fibre reinforced concrete is an important input for securing durable FRC structures.Numerous tests according to the Austrian Guideline Fibre reinforced Concrete have been performed on beams with different fibres, but same dosage. The test equipment withstood the test.

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.

Following above stated test conditions it may be concluded:

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 getting 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. More data has to be collected. Beams with some synthetic fibres tend to 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% to 85%.

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References

[1] DAfStb: *Guideline steel fibre reinfoced concrete* (in German Richtlinie Stahlfaserbeton). Berlin, 1996.

[2] OeBV (Austrian Society for Construction Technology): *Guideline Fiber Reinforced Concrete* (in German: Richtlinie Faserbeton). Vienna, 2008.

[3] Bast, T.; Eder, A.: *Untersuchungen zum Langzeitstandverhalten von gerissenen Faserbetonen unter Biegezugbeanspruchung*. Diploma-thesis, OTH Regensburg, 2007.

[4] Kusterle, W.: *Viscous Material behavior of Solids- Creep of Polymer Fibre Reinforced Concrete.* In: Proc. 5th Central European Congress on Concrete Engineering. OEBV, Baden, 2009.

[5] Wesche, K.: *Baustoffe für tragende Bauteile*. Volume 1, Bauverlag GmbH, Wiesbaden and Berlin, 1996.

[6] Kurz, S., Balaguru, P.: *Postcrack creep of polymeric fibre-reinforced concrete in flexure.* Cement and Concrete Research 30 (2000).

[7] Arango S.; Serna P.; Martí-Vargas J.R. & García-Taengua E.; *A Test Method to Characterize Flexural Creep Behaviour of Pre-cracked FRC Specimens.* Experimental Mechanics, 2012.

[8] Arango, S.; Taengua, E.; Vargas, J.; Serna, P.; *A comprehensive study on the effect of fibres and loading on flexural creep of SRFC.* Barros, J. (Ed.); BEFIB2012- Fibre reinforced concrete, UM, Guimaraes, 2012.

[9] García-Taengua E.; Arango S.; Martí-Vargas J.R. & Serna P.; *Flexural creep of steel fiber reinforced concrete in the cracked state.* Construction and Building Materials 65, 2014, pp321-329.

[10] Barragán B. & Zerbino R.; *Creep behaviour of cracked steel fibre reinforced concrete beams.* Proceedings of the 7th International RILEM Symposium on FRC: Design and Applications. BEFIB, Chennai, 2008.

[11] Zerbino R. & Barragán B.; *Long-Term Behavior of Cracked Steel Fiber-Reinforced Concrete Beams under Sustained Loading.* ACI Materials Journal, 109, 2, March-April, 2012, 215-224.

[12] Bast, T.; Eder, A.; Kusterle, W.: *Kriechversuche an Kunststoffmakrofaserbetonen. Untersuchungen zum Langzeitverhalten von Faserbetonen unter Biegezugbeanspruchung – ein Zwischenbericht.* 11. Vilser Baustofftag, Reutte, 15. 3. 2007, Zement + Beton Handels- und Werbeges. m. b. H., Wien.

[13] BEKAERT; *Creep Test.* Bekaert internal report, 21-03-07, 2007.

[14] BEKAERT; *Creep Test*. Bekaert internal report, June, 2009.

[15] Lambrechts, A. N.: *The technical performance of steel and polymer based fibre concrete.* In: Concrete for a new world, Technical symposium, The Institute of Concrete Technology, 4/2005.

[16] Ratcliffe R.; *Steel versus Synthetic fiber reinforcement in shotcrete*. Shotcrete for Underground Support X, ASCE, 2006, 215-227.

[17] Ratcliffe, R.: *Fibre reinforcement steel versus macro (structural) synthetic*. Concrete Engineering International, Spring 2007.

[18] Buratti N.; Mazzotti C. & Savoia M.; *Long-term behaviour of steel- and macrosynthetic-fibre reinforced concrete beams*. CPI - Concrete Plant International 5, 2010.

[19] Buratti N.; Mazzotti C. & Savoia M.; *Long-Term Behaviour of Fiber-Reinforced Self-Compacting Concrete Beams, Design, Production and Placement of SCC.* Khayat, K.H; Frey, D. (Eds.) Design, Production and Placement of Self-Consolidating Concrete, RILEM Bookseries 1, Montreal, 2010.

[20] Buratti N.; Mazzotti C. & Savoia M.; *Long-term behaviour of cracked SFRC beams exposed to aggressive environment.* Oh, B. et al. (Eds.); Fracture Mechanics of Concrete and Concrete Structures, Korea Concrete Institute, 2010,1512-1517.

[21] Buratti N.; Mazzotti C.; Savoia M. & Rossi B.; *Temperature and loading level effect on the long-term behaviour of MSFRC and SFRC.* Fibre Concrete 2011, Prague, September 8-9, 2011.

[22] Buratti N. & Mazzotti C.; *Effects of different types and dosages of fibres on the long-term behaviour of fibre-reinforced self-compacting concrete.* 8th RILEM international symposium on fiber reinforced concrete BEFIB, Guimaraes, Portugal, 2012.

[23] Savoia M.; *Long-term behaviour of cracked FRC specimens subject to medium temperature: comparison between steel and macro-synthetic fibres.* Lab for structural testing, University di Bologna, Pos. 162/10, January, 2011.

[24] Chanvillard G. & Roque O.; *Behaviour of fibre reinforced concrete cracked section under sustained load.* 8th RILEM international symposium on fiber reinforced concrete BEFIB, Guimaraes, Portugal, 1999.

[25] Cochrane J. T.; *Flexural creep behaviour of Fiber Reinforced Concrete under high Temperatures.* Master thesis, Dalhousie University, Halifax, Canada, August, 2003.

[26] MacKay; J., Trottier, J.-F.: *Post-crack creep behaviour of steel and synthetic FRC under flexural loading*. In: Bernard, E. (ed.): Shotcrete: More Engineering Developments – Taylor & Francis Group, London, 2004.

[27] DIBt; *Prüfplanung für die Zulassungsprüfungen von Polymerfasern*. Deutsches Institut für Bautechnik, Berlin, January, 2013.

[28] Gosla U. & Rieder K.-A.; *Time Dependent Behaviour of Fibre Reinforced Concrete - Fundamentals and Applications.* In: Proc. 5th Central European Congress on Concrete Engineering. OEBV, Baden, 2009.

[29] Granju J.-L.; Rossi P.; Chanvillard G.; Mesureur B.; Turatsinze A. & Farhat H. et.al; *Delayed Behaviour of cracked SFRC beams.* 2000.

[30] Kanstad T. & Zirgulis G.; *Long-time creep testing of pre-cracked Fibre Reinforced Concrete beams.* Barros, J. (Ed.); BEFIB 2012- Fibre reinforced concrete, UM, Guimaraes, 2012.

[31] Kaufmann J.; Bader R. & Manser M.; *Untersuchungen zum Biege-Kriechverhalten von Faserbeton mit makro-synthetischen bikomponentenfasern.* In: Kusterle, W. (Ed.) Spritzbeton-Tagung 2012, Alpbach, Austria, January, 2012.

[32] Kurtz, S., Balaguru, P.: *Postcrack creep of polymeric fibre-reinforced concrete in flexure.* Cement and Concrete Research 30 (2000).

[33] Larsen, E. S.: *Durability of polypropylene fibre reinforced concrete under sustained load.* In: Brandt, A.; Li, V.; Marshall, I (eds.); Proc. Int. Symp. „Brittle Matrix Composites 4", Warsaw, 1994.

[34] Tan K.-H.; Paramasivam P. & Tan K.-C.; *Creep and shrinkage deflections of RC beams with steel fibers.* Journal of Materials in Civil Engineering, Vol. 6, No. 4, ASCE, 1994.

[35] Theodorakopoulos D. D.; *Creep Characteristics of Glass Reinforced Cement under Flexural Loading.* Cement & Concrete Composites 17, 1995, 267-279.