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Creep behaviour of macro glass fibre reinforced concrete beams

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Abstract. This paper aims to present a creep study on structural concrete reinforced with macro glass fibres and wants to contribute to the understanding of creep behaviour of fibre reinforced concrete (FRC). Fibre reinforced concrete beams have been subjected to bending and tested in cracked state under defined stress levels. Therefore, a four-point- bending test setup was chosen and the creep period was 372d. The aim was to determine creep coefficients and to test residual strength values afterwards. Results show a dependence of residual strength and applied stress level. It turned out, that the beams failed due to tertiary creep at stress levels between 65 and 70% of residual crack load at 0.5 mm pre-crack deflection. Nevertheless, all remaining specimens showed increased loads after creep period. Finally, the evaluation is conducted in comparison to other fibre types.

1. Introduction

Regarding the long-term performance and durability of concrete members it is important to consider shrinkage and creep phenomena. Creep behaviour of plain concrete under compressive stresses is anchored in the codes [1]. Nevertheless, the durability of structural concrete members is mainly influenced under service conditions. In case of FRC this means in cracked state because macro fibres start contributing to load bearing after concrete has cracked. Whereas creep behaviour of FRC under compression is similar to plain concrete, in cracked state additional factors like creep of fibre material and bond of fibre and matrix must be considered next to compressive creep strains in concrete. Therefore fibre only reinforced members show higher structural creep behaviour than reinforced concrete structures [2].

The general creep behaviour of FRC has not been considered in most codes until yet. The only exception is the Austrian ÖBV Guideline “Fibre reinforced concrete”, where a test setup for polymer fibre reinforced concrete beams is proposed in the informal part of the guideline. Since the early 2000 there have been investigations on creep behaviour of cracked steel and polymer fibre reinforced concrete [2–12]. Nevertheless, because of the lack of a regulation it is complicated to compare the results of different investigations due to different test setups, concrete compositions and stress levels. Since 2014 the RILEM technical committee CCF collects relevant information of FRC creep behaviour.

Most researchers chose a defined crack opening between 0.5 and 2.5 mm as starting point for the creep tests. Investigated stress levels are often scaled on either flexural strength value or the respective residual strength value corresponding to the chosen crack opening.

Macro glass fibres (length: 36 mm, $\varnothing_{equ}$=0.54 mm) are relatively new material used to strengthen structural concrete applied in industrial floors [13, 14]. Made of alkali-resistant (AR) glass, they have some advantages in applications where steel reinforcement is not preferred like stables for animals, where glass fibres reduce harming due to surface near fibres or laboratories where undisturbed electromagnetic fields are required. Furthermore, they cannot rust and disperse very well during mixing without tending to segregate or float. It has to be mentioned that in comparison to other fibre materials, glass itself has nearly no viscoelastic behaviour and therefore very little to no tendency to creep [15].

According to international codes like the fib Model Code 2010 [16] glass fibres can substitute mesh reinforcement in statically highly undetermined structures up to a certain extend [13, 14, 17]. In Germany, only steel and polymer fibres may be used in structural concrete. The requirements for these fibres are given in DIN EN 14889-1/2 [18, 19]. Steel fibres may be used to substitute steel bar or mesh reinforcement in serviceability and ultimate limit state according to DAfStb Guideline "Steel fibre reinforced concrete" [20].

2. Test method

The general post cracking performance of FRC is recommended to be tested on bending beams. Therefore, according to codes mainly two different setups are allowed. Firstly the three point bending test on notched specimen according to fib Model Code 2010 [16], EHE-08 [21], ACI 318 [22] and EN 14651:2007 [23]. Secondly some countries like Germany or Austria test FRC in four point bending of unnotched specimens according to DAfStb Guideline „Steel fibre reinforced concrete" [20] or ÖBV Guideline "Fibre reinforced concrete" [24]. It seems suitable to test FRC creep behaviour also according to one of these guidelines.

Both, notched and unnotched beams have advantages and disadvantages when it comes to determine residual strength values. In three-point bending tests on notched specimens crack development is forced at one specific section. Residual strengths acquired on notched beams tend to be overestimated, because the specimen cracks not necessarily at its weakest point. In unnotched beams crack position and therefore crack widths corresponding to certain deflections are not equal in all specimens. The disadvantage of this test comes with the uniformly distributed bending moment in the middle of the specimen between the two loads. Nevertheless, the differences in crack openings at small deflections are very low. Therefore, the authors of this paper decided to use the four-point bending setup to test creep behaviour of macro glass fibre reinforced concrete in cracked state, as it is described in the German Guideline for the four-point-bending test. Only deflections and no crack openings have been measured during creep tests.

With the test setup shown in **Figure 1**, two beams could be tested simultaneously. All in all, there have been six stands, which allowed to test twelve FRC specimens. The specimens have been loaded with a lever mechanism.

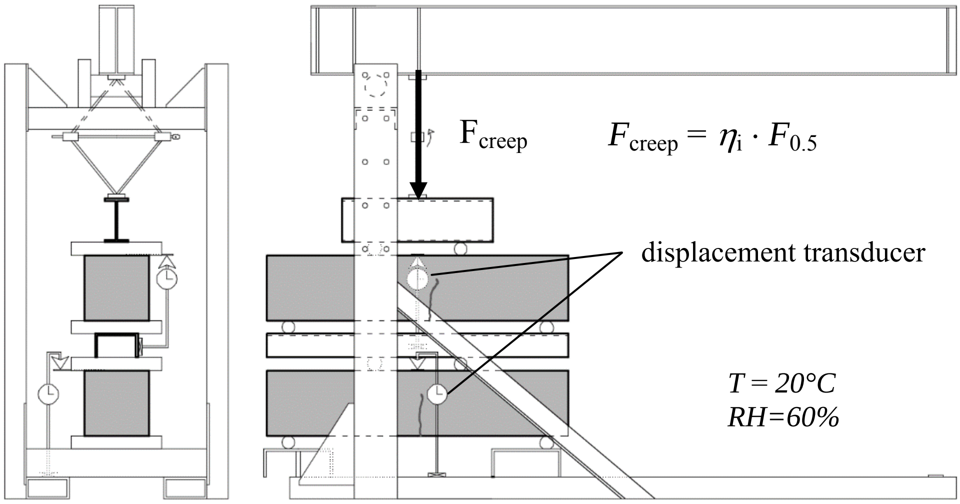

Figure 1. Test setup for creep tests

Before undergoing the creep procedure all beams have been tested in four-point-bending until the defined deflection of 0.5 mm which equals approximately 0.4 mm crack opening. After creep test, all remaining specimen have been tested further on their residual strength values. It must be mentioned that in case of unnotched specimen the crack not necessarily appears in the middle of the beam, which causes the crack width to scatter between around 0.35 and 0.45 mm. Figure 2 shows the complete test procedure. The stress level η_i of each specimen is the ratio between creep load and on the respective residual load $F_{0.5}$ at 0.5 mm deflection.

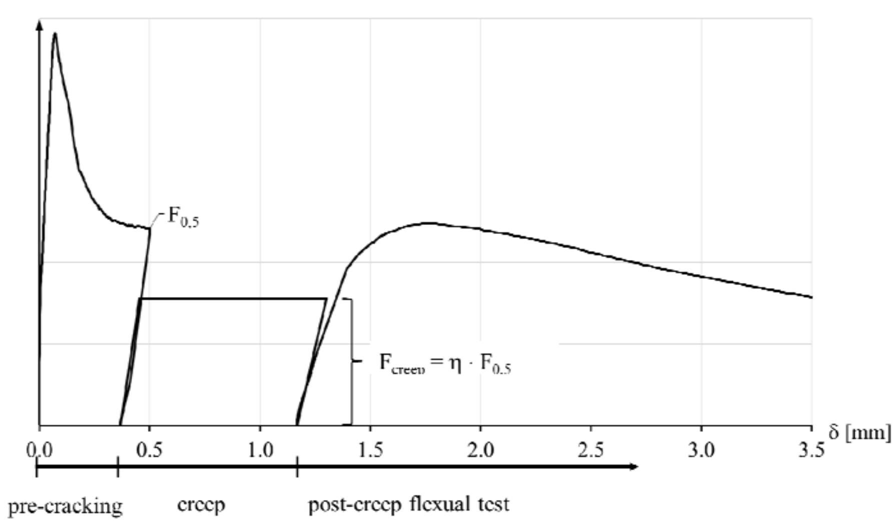

Figure 2. Scheme of the complete test procedure

3. Materials and investigated parameters

The aim of the creep tests was to determine a dependency of different stress levels on the creep deformations and post creep residual strengths. To allow different stress levels, only one glass fibre reinforced concrete mixture has been tested, which is given in Table 1.

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Table 1. Material composition.

	Type	Content
Cement	CEM II/A-LL 32,5R	350 kg
Water		209 kg
Additions	Fly ash (FA)	80 kg
W/(C+0.4 FA)*		0.5
	Macro glass fibres (36 mm)	20 kg
Additives	Superplasticizer (PCE)	0.25 % of cement
Aggregates	0/2	656 kg
	2/8	328 kg
	8/16	656 kg

* equivalent water/cement ratio according to DIN EN 206 [25]

All specimens were cured in the same way. The beams were kept in moulds for two days. Afterwards they were wrapped in foil and stored in a climate room at 20°C, 60% RH until the age of 28 d. Then they were tested in four-point-bending and stored again in climate room until an age of 48 d. Afterwards creep tests with a duration of 372 d were performed. Some of the specimen failed after short time and were replaced. Table 2 gives an overview about all tested specimens in the respective test setups. The respective stress level for each beam has been calculated including self-weight.

Table 2. Arrangement of creep test setups

Stand No.	1	1*	2	2*	3	4	5	6
Age at start [d]	48	32	48	32	48	48	48	48
Stress level η_i top	0.7	0.5	0.7	0.535	0.5	0.6	0.5	0.6
Stress level η_i bottom	0.74	0.469	0.8	0.5	0.546	0.645	0.559	0.615

* after failure of the beams in the first series, new specimens have been produced

The respective stress levels were in range between 46.9% and 80% and have been chosen to exceed the maximum design value according to DAfStb Guideline “Steel fibre reinforced concrete” [20] which may be calculated utilizing different coefficients used for FRC design:

$$\eta_{\max} = \alpha_c^f / \gamma_{ct}^f \cdot \kappa_F^f \cdot \kappa_G^f \cdot 0{,}51 / \gamma_R^f = 0{,}85 / 1{,}5 \cdot 1{,}0 \cdot 1{,}7 \cdot 0{,}51 / 1{,}4 = 0{,}421 \qquad (1)$$

For the design of FRC members under permanent load maximum 42.1% of residual flexural strength values will be considered.

4. Results and Evaluation

As it can already be seen in Table 2 specimens with stress levels 70% and higher failed after around two days. Although steel fibres show higher resistance during very high stress levels like this, the results are in accord with macro polymer fibre reinforced concrete [2]. In the following, not all test data is presented. Only six beams across tested stress levels are shown to provide a clearer view.

Directly after applying the creep load, the elastic deformation $\delta_e(t_0)$ can be measured. Together with the creep deformation $\delta_t(t)$ the creep coefficient $\varphi(t, t_0)$ can be calculated for a defined time point per equation (2).

$$\varphi(t,t_0) = \frac{\delta_t(t)}{\delta_e(t_0)} \tag{2}$$

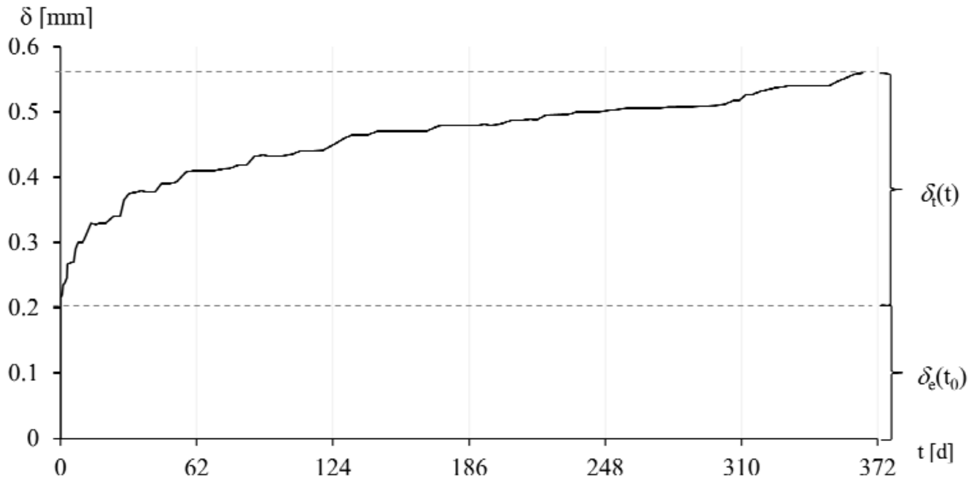

Figure 3. Example for elastic and creep deformations

In the following creep deformations of the beams are presented. It is obvious, that higher stress levels cause larger deformations over time. Although not failed within 372 days of creep stresses it is likely that specimen with stress level over 50% may fail soon due to tertiary creep which is characterized by a change from linear to exponential creep rate until failure.

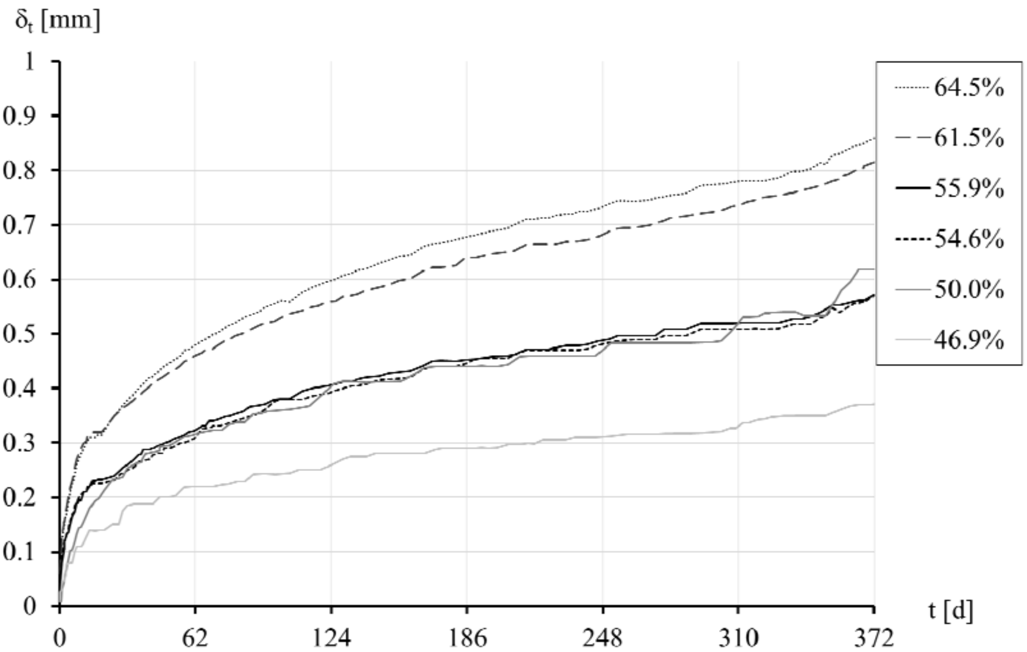

Figure 4. Creep deformations of six specimens

Eurocode 2 (EC2) [1] provides equations to calculate creep coefficients in dependence of cement type, compressive strength, age of concrete at start of creep, creep duration, moisture and temperature. Although the formulas only consider compressive creep stresses, it seems possible to estimate approximate creep coefficients. In case of stress levels above 45% of concretes characteristic compressive strength, non-linear creep must be considered. **Figure 5** shows calculated creep coefficients per equation (2) in comparison with the theoretical creep coefficients according to EC2. The theoretical creep curves are shown for stress levels below 45% and for 64.5% which is the highest stress level which did not fail during the test.

Although some experimental data exceeds the theoretical values after around 320 d, it can be seen that creep behaviour of beams with a stress level below 50% correspond good with the EC2 curve for 45% and below. It is worth to mention that the results from EC2 incorporate a coefficient of variation of 30%.

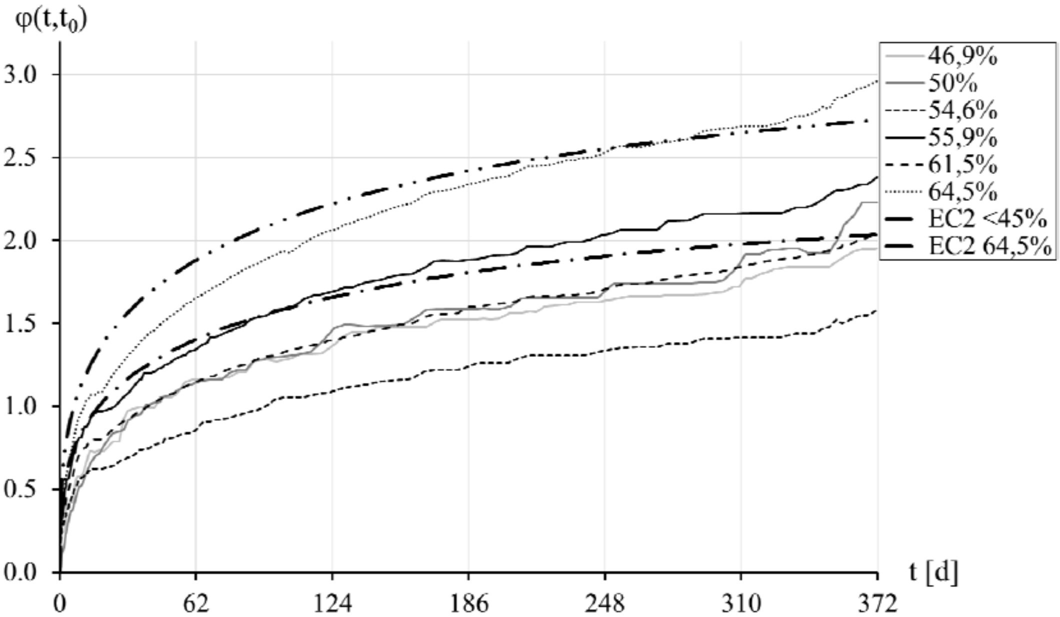

Figure 5. Creep coefficients of specimens compared to calculated creep coefficients from EC2

The results of pre- and post-creep flexural tests are provided in **Figure 6**. The measured creep deformations are also included between those test curves.

All specimen showed increased maximum load after creep duration. This may result from higher concrete compressive strength resulting in better bond between glass fibres and matrix. In contrast, the ratio between post- and pre-creep loads is smaller with increased stress level as shown in **Figure 7**. Obviously higher stress levels cause larger creep deformations as well as bigger crack widths resulting in lesser residual strength.

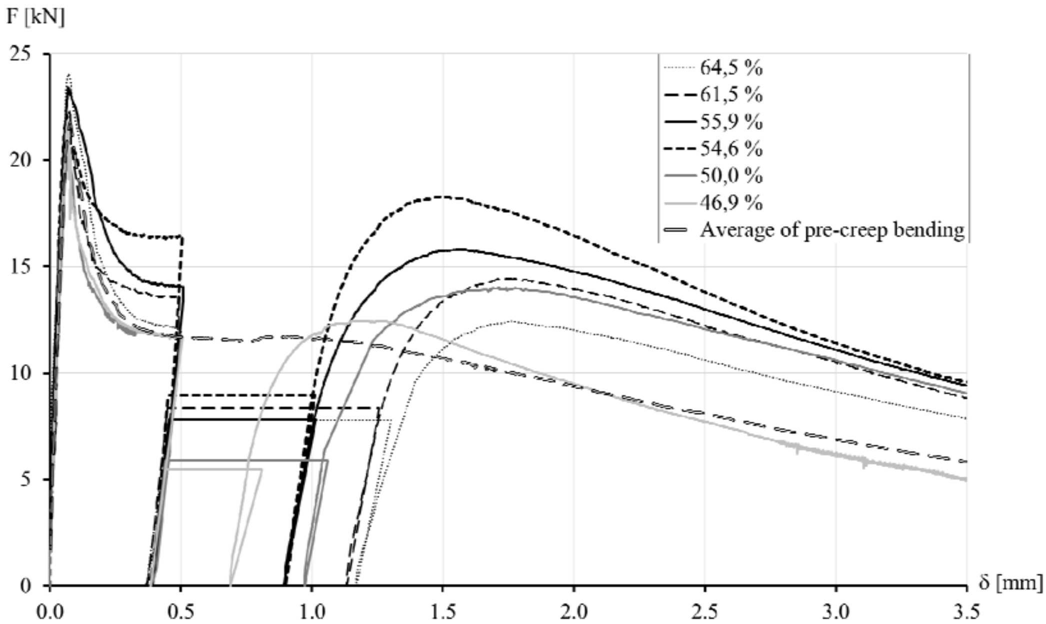

Figure 6. Load vs. deflection of pre-creep, creep and post creep flexural tests

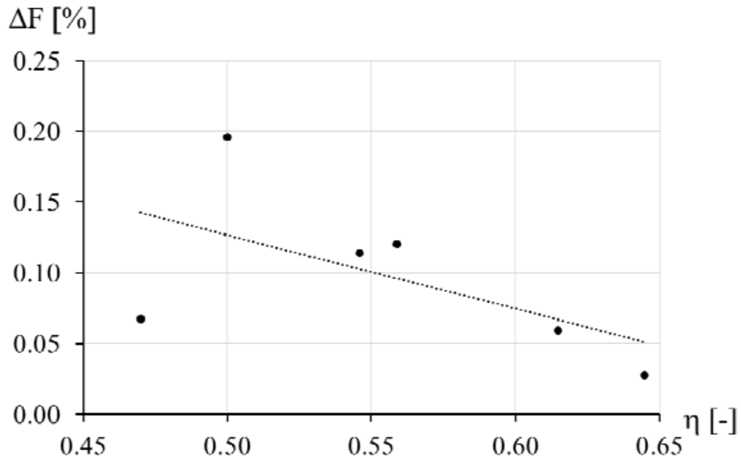

Figure 7. Relative load increase in the post creep flexural tests vs. stress level

5. Comparison

To compare creep performance with other fibre types is very difficult due to the lack of sufficient data. Results from other researchers scatter across a wide range of different concrete types, strengths, specimen types and stress levels. Therefore, it was complicated to find appropriate numerical data in the tested range of parameters (compressive strength, crack opening, stress levels). Nevertheless **Figure 8** shows some results taken from literature [2, 4] in comparison to own results and calculated values according to EC2 [1]. In the presented range, glass fibres show biggest creep coefficients. It has to be considered that these values are still significantly lower than expected by EC2 and range of possible stress levels is larger compared to polymer fibres. In case of presented results for steel fibres, concretes compressive strength was at 70 N/mm² which is much higher than the investigated strength of 40 N/mm² from structural glass fibre reinforced concrete. This leads to significantly reduced creep coefficients. Compared to other results from literature it can be told, that steel fibre reinforced concrete shows least creep deformations.

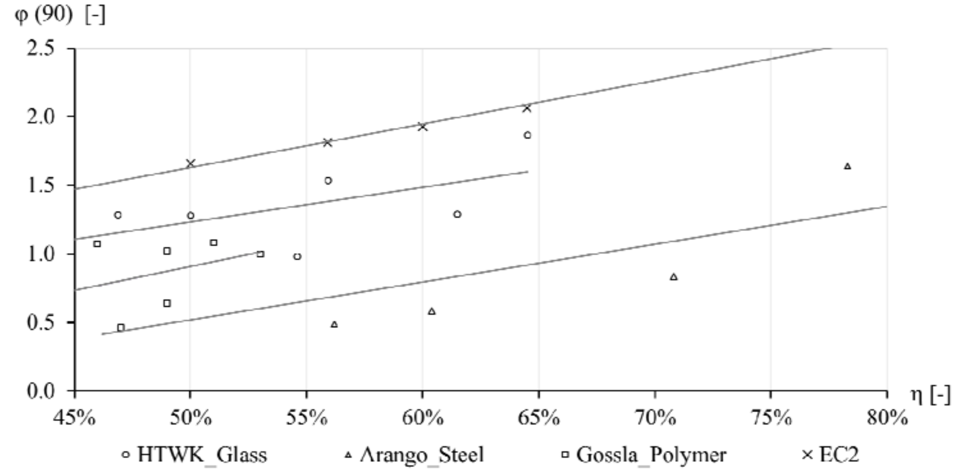

Figure 8. Comparison of creep coefficients after 90 d for different fibre types

As it is visible in **Figure 9**, polymer fibre reinforced concrete tends to show bigger creep deformations with increasing stress level compared to glass or steel fibre reinforced concrete. This can be seen in the gradient of regression graphs. Although low creep deformations at low stress levels, polymer fibre reinforced concrete tends to fail earlier due to tertiary creep especially if stress levels exceed 55%.

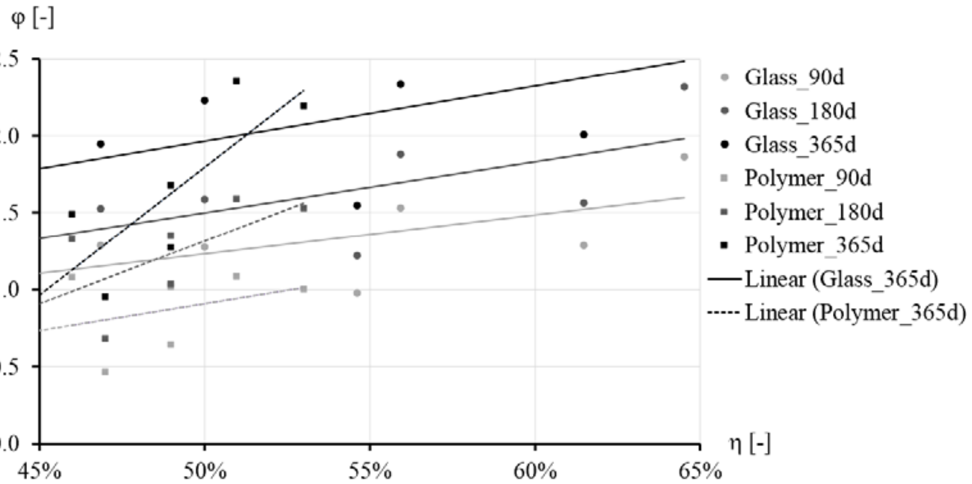

Figure 9. Creep coefficients of macro glass and polymer fibres after different periods

A huge influence is also given by the creep behaviour of the fibre material itself and the bond between fibre and matrix. Whereas glass has nearly no tendency to creep, polymer fibres may show very large creep deformations greatly dependent on their stress level [2, 7, 8]. Steel fibres show very low creep especially when bond between fibre and matrix is enhanced due to hooked ends [4, 8]. This physical bond is a further disadvantage of polymer as well as glass fibres, as it can practically not be improved mechanically. In contrast glass fibres have a good chemical bond to the surrounding matrix because of their mineral properties. However, they may lack in cracked state, because of their composition of many filaments where bond is established only in surface near filaments, where they are penetrated by cement particles up to a certain extend.

6. Summary

With the present study creep as well as post creep bending behaviour of structural glass fibre reinforced concrete beams have been investigated, following other researchers approaches for FRC. The authors want to give a contribution to the increasing interest of creep behaviour of FRC. It could be shown that structural concrete reinforced with macro glass fibres does not show increased tendency to creep. The results are comparable with high quality polymer fibres, although the pull-out procedure of fibres in concrete are different. Furthermore, it has to be mentioned, that creep deformations are greatly dependent of concretes properties such as compressive strength, age and cement type. There is a big need to investigate different matrix-fibre combinations at several stress levels. Parametric studies would be relevant to fully understand FRC creep behaviour. Furthermore, it is important to establish international rules and recommendations for a uniform test setup, specimen type, stress level and climate conditions.

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