Chapter 48
Uniaxial Tensile Creep Behavior of Two Types of Polypropylene Fiber Reinforced Concrete

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Structural polymeric macrofibers can be added to concrete to increase the residual capacity after matrix cracking. Polymeric fiber reinforced concrete (PFRC) can be designed according to the Model Code 2010, but no design guidelines are given to take creep behavior into account. In this work, the results of a multiscale experimental campaign into the crack-widening mechanisms of PFRC are detailed. Two different commercially available polypropylene fibers from the same manufacturer are tested. In the tests, individual fibers are subjected to long-term loading and the elongations are recorded. Furthermore, precracked PFRC cores are tested in a uniaxial tensile creep test at two load levels. The fiber creep tests highlight significant differences between the two fibers: the creep coefficient can differ an order of magnitude at similar load ratios. However, despite the much better performance at the individual fiber level, the FRC creep behavior does not vary to that degree. By comparing the single fiber performance with the FRC creep, it is found that pull-out creep and rupture can offset superior fiber creep performance.

1 Introduction

Since the introduction of fiber reinforced concrete (FRC) in the Model Code 2010 (MC2010) [1], designers can use this composite material in structural applications. While design rules are given to take the post-cracking tensile capacity of the material into consideration, long-term performance due to creep is not accounted for. Creep

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of FRC under tension is of high importance in structural design and the subject has been gaining attention in recent years. Different test methods have been proposed to study time-dependent crack width or deflections ranging from bending tests on prisms [2, 3] or panels [4] to uniaxial tension tests on prisms or cylinders [5, 6]. As fibers only take up forces after matrix cracking, all test methods use precracked specimens in which the fibers take up the forces in the cracked section. Creep of FRC in a cracked section is composed of up to three mechanisms: (1) compressive concrete creep in the case of bending tests, (2) time-dependent fiber pull-out, and (3) individual fiber creep in the case of polymeric FRC.In this work, uniaxial tension creep tests on two types of polypropylene (PP) FRC are discussed. Two different types of embossed PP fibers are used, and creep tests are performed on both individual fibers and the composite material.

2 Experimental Program

In the experimental program, two types of PP fibers are considered (designated as type A and B) and both fiber types are characterized according to EN 14889-2 [7]. The declared geometry (diameter d and length l) and the mechanical results (fiber strength f_t and cord modulus E) are summarized in Table 48.1.

Both fiber types are tested in a creep setup as described elsewhere [8]. The setup allows for different fibers to be tested independently in separate creep frames. For the creep test, three different load ratios are considered: 36%, 43%, and 53% of the fiber strength f_t.

In addition to the individual fiber creep tests, uniaxial tensile creep tests are performed on precracked PP FRC specimens. For both fiber types, 1 V% of fibers is added to a normal strength concrete with an average cube compressive strength of the concrete is 43 MPa as determined by EN 12390-3 [9]. The creep specimens are cored from a prism used in a characterization test according to EN 14651 [10]. The European Standard identifies the post-cracking tensile capacity of FRC in a displacement-controlled three-point bending test on a notched beam. The post-cracking tensile strength for specimens with type A and type B fibers is 1c and 2d, respectively. At the end of the test, cores are taken from these beams with a nominal diameter and height of 100 mm and 300 mm, respectively. At mid-height, the cylinders are notched to a diameter of 80 mm and the notched cores are precracked to an initial crack width of 0.2 mm in the notched section. The precracking is done in a custom designed precracking frame which allows eccentric load application in order to achieve uniform crack width growth after matrix cracking. The load is applied manually by three technicians and after the initial precrack width of 0.2 mm

Table 48.1 Geometry and mechanical properties of the fibers

Property	d (mm)	l (mm)	f_t (MPa)	E (MPa)
Type A	0.9	45	451	4400
Type B	0.7	55	490	7900

is achieved, the load is gradually removed and the sample is placed in a cantilevered creep frame. The creep load is applied centrically and is expressed as a percentage of the residual post-cracking tensile strength measured during the precracking procedure. Two different load ratios (LR) are considered: 30% and 45% of the residual uniaxial strength. Each specimen is placed in a separate creep frame, and all testing is done in a climate controlled chamber at a constant 20 °C and 60% relative humidity. Further details about the precracking procedure and the creep setup can be found in literature [11].

3   Results and Discussion

The single fiber creep results are shown in Fig. 48.1 and highlight a significant difference between the two fibers. Note the different time scale in the figure. The stiffer fiber type B outperforms type A with respect to time to failure as well as total strain at failure. This is clearly indicated for the highest loaded samples, i.e., LR = 53%. In the case of type A, the fibers fail after 3 days at a total strain of 70%, while the first failure of a type B fiber at that LR was after 235 days at a strain of 40%. Similarly, the samples at 43% failed after 54 days at $\varepsilon = 98\%$ for type A, and no failure has been observed after 270 days at strains $\varepsilon < 16\%$.

The difference in single fiber creep behavior can be explained in terms of the creep compliance, i.e., the ratio between the creep strain and the applied stress. In an ideal viscoelastic material, the creep compliance is a function of time but not of the load ratio. Consequently, in a viscoelastic material, the compliance curves are superimposed and any deviation from the ideal behavior indicates the onset of plasticity in the fibers. The creep compliance is shown for the two fiber types in Fig. 48.2 on a double-logarithmic scale. For the type A fibers, a clear onset of plasticity is found at all load levels, with 53% samples already deforming plastically after 4 h and even the lowest loaded fibers exhibit plastic deformations within a week. In contrast, the creep compliance curves for type B remain superimposed until
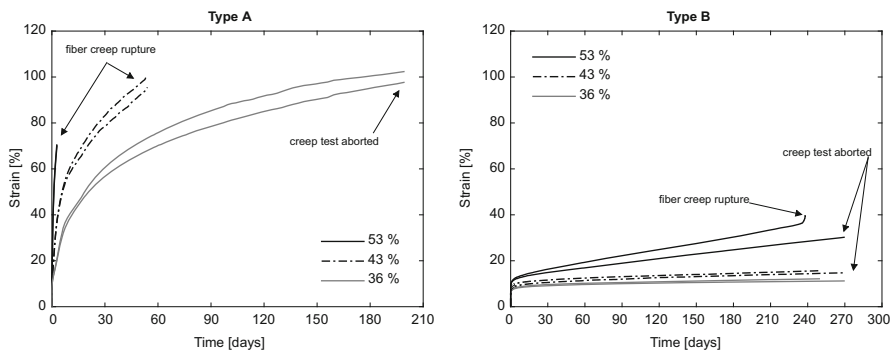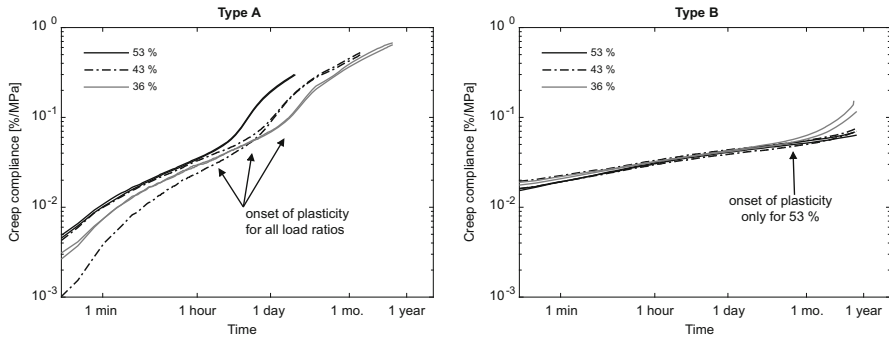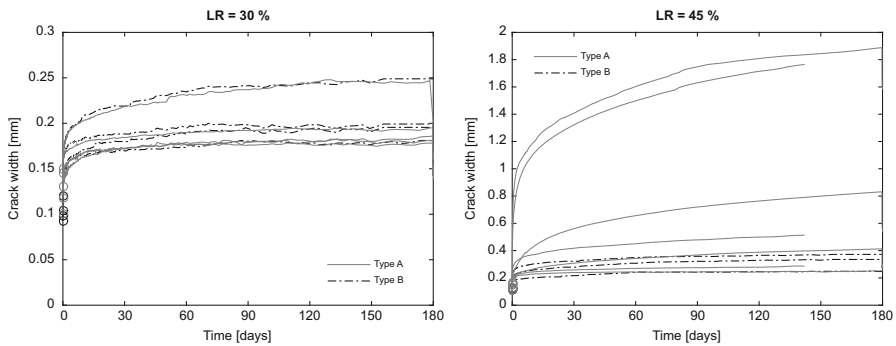

Fig. 48.1 Single fiber creep for type A (left) and type B (right)

Fig. 48.2 Creep compliance as a function of time for type A (left) and type B (right)

Fig. 48.3 Crack width evolution for LR = 30% (left) and 45% (right)

the highest loaded samples deform plastically after 20 days. Furthermore, no plasticity is recorded for the samples at 43% and 36% after 270 days under load.

The results of the FRC creep tests are presented in Fig. 48.3 for the samples loaded at 30% and 45% after 180 days under sustained tensile loading. Note the different y-scales in the figure. The tests clearly show that at 30%, both fiber types exhibit a nearly identical crack width evolution and that in most cases, the average crack width remains below the 0.2 mm limit found in Eurocode 2 or MC2010. However, the samples exhibit very different behavior at 45%. In this case, the average crack width evolution of type B FRC corresponds to the best performing type A samples.

Comparing the single fiber creep with the FRC creep results, it is argued that part of the fibers in the cracked section deforms plastically for the type A FRC at 45%, causing the large crack widths observed for some specimens. Fiber type B exhibits practically no plasticity, thereby preventing excessive crack widths to form under creep loading. However, the differences in FRC creep are not as pronounced as in the single fiber creep results, leading to two conclusions. First, fiber creep alone cannot

explain FRC creep, and time-dependent fiber pull-out should be considered as well. Tests on the short-term pull-out behavior have shown that type B fibers tend to rupture rather than pull out from the matrix owing to their smaller diameter. The smaller fiber diameter also increases the number of fibers in the cracked section with respect to type A at equal V%. The average fiber stress for type B fibers will be lower, but due to their higher tendency to rupture during pull-out, the better fiber creep behavior is partly offset by the increased chance of fiber rupture. A second consequence of the less pronounced FRC creep difference is that the fiber stress level is lower in the FRC specimens than the stress levels considered in the single fiber creep tests. At lower stresses, the type A fibers will not exhibit plastic deformations within a few hours or days but rather within several months. Since the fibers in the cracked section are not deforming plastically, the overall deformation and difference between the fibers will be smaller at lower load levels. Lastly, given the random distribution and orientation of fibers in FRC, large variations between different specimens can be expected. This is specifically an important issue for the specimens of this research as the cracked section is only 5000 mm^2, compared to nearly 19,000 mm^2 for the EN 14651 bending test.

4   Conclusion

In this chapter, the results of an experimental campaign into the creep behavior of normal-strength polymeric fiber reinforced concrete are presented in which two different polypropylene fiber types are considered. Owing to the different tensile strength and diameter of the fibers, the effect on the post-cracking tensile strength is significant. An increase from class 1c to 2d was observed when using the thinner, stronger fiber.

In the experimental program, creep tests were performed on individual fibers at three different load ratios: 36%, 43%, and 53% of the tensile strength. A clear difference in fiber creep performance is found, with the stiffer and stronger fiber creeping to a much lesser degree. Furthermore, the tendency for fiber creep failure was strongly reduced as well. Analysis of the creep compliance found that the difference between the two fiber types can be attributed to the onset of plastic deformations. Plasticity occurred within hours at 53% load for the weaker fiber and was only observed after 20 days in the stronger fiber.

In a second part of the experiments, notched FRC cores are subjected to sustained uniaxial tensile loads and the time-dependent crack widening is measured at loads of 30% and 45% of the residual tensile strength. No difference between the two fiber types was observed at the lower load level, but at the higher load, excessive crack widening was measured for the weaker fiber.

The comparison of the single fiber and FRC creep suggested that single fiber creep alone does not explain FRC creep and that time-dependent pull-out should be taken into account. For the samples considered in this research, it was found that the superior single fiber performance of one fiber type was partially offset by its higher

tendency for fiber rupture during pull-out. Secondly, it is suggested that the fibers in the cracked sections are subjected to stress levels below the ones considered in the single fiber creep tests. Nevertheless, the coefficient of variation of all specimens was rather high and additional testing on more fibers is needed.

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