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Effect of applied stress and bar characteristics on the short-term creep behavior of FRP bars

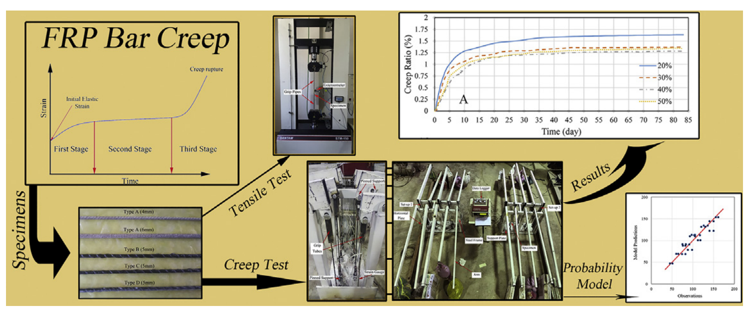
Esmaeil Pournamazian Najafabadi [a], Milad Bazli [b,c], Hamed Ashrafi [b,d], Asghar Vatani Oskouei [b,*]

[a] Civil Engineering Department, Sharif University of Technology, Tehran, Iran
[b] Faculty of Civil Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran
[c] Department of Civil Engineering, Monash University, Clayton, Victoria, Australia
[d] Structural Research Center, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran

HIGHLIGHTS

- The effects of applied stress and FRP bar characteristics on the short-term creep behavior of FRP bars were studied.
- All FRP bars experienced creep strains less than 3% of their initial elastic strains.
- The creep strains increased as the applied stresses increased.
- GFRP bars were the most creep resistant bars while CFRP bars with epoxy resin were the least creep resistant bars.
- The bars with larger diameters showed better creep behavior.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents the creep behavior of various FRP (GFRP, CFRP, and hybrid) bars in order to investigate the effects of different parameters, including the applied stress levels, bar diameter, and the type of fiber and resin in the creep behavior of FRP bars. The creep strains versus time curves were experimentally obtained for 83 days. Moreover, a statistical study, including analysis of variance (ANOVA) and linear Bayesian regression was conducted to investigate the contribution of the studied parameters. The results showed that in GFRP bars the ratio of ultimate creep strain to the initial elastic strain decreased when the applied stresses on the bars exceeded 30% of their ultimate tensile strength. In CFRP bars, the creep ratio decreased by increasing the applied stresses continuously. In addition, it was observed that the GFRP bars were more creep resistant in comparison to CFRP bars and CFRP bars with vinyl ester resins were more creep resistant than those with epoxy resins.

1. Introduction

Fiber-Reinforced-Polymer (FRP) composites, such as FRP bars and tendons made of arranged fibers embedded in resin matrices, are known as alternative and competitive materials in retrofitting, strengthening, and new construction of members [1–4]. FRP bars and tendons offer many advantages over steel bars and tendons such as corrosion resistance, high strength, excellent fatigue behavior, low thermal expansion, and light weight [5–8]. When steel bars and tendons are used in structural members, the short-term mechanical properties of steel are taken into account, but

* Corresponding author.
E-mail address: vatani@srttu.edu (A.V. Oskouei).

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when using FRP bars and tendons as reinforcement bars and pre-stressed tendons, the long-term tensile behavior of these materials must be taken into account in addition to their short-term behavior [9–11]. In order to investigate the long-term tensile properties of FRP bars and tendons, research has been conducted on the stress loss of FRP bars due to relaxation when they are used as pre-stressed tendons [9,12].

However, there is a limited amount of research on FRP bars' creep behavior, which is an important factor in the long-term performance of fiber-reinforced concrete members [13–18]. In FRP-reinforced concrete (FRP-RC) members, extra stress is applied to the concrete because the creep in the FRP bars leads to larger cracks in the concrete. This reduces the moment of inertia in concrete members [19]. Therefore, the creep behavior of FRP bars should be considered in the design of FRP reinforced concrete structures. The creep behavior of FRP materials comprises three stages (Fig. 1). The first stage ends in the early days of the applied sustained load. The first stage occurs primarily because of increases in the resin strain due to its viscous behavior, redistribution of applied stresses in the fibers, and straightening of uneven fibers [15,16]. In the second stage, the FRP materials encounter a slow creep strain increase. The second stage occurs primarily because of defects that occur in the fabrication stage of FRP materials, such as voids between the fibers or between the fibers and the resin. If the stresses in FRP materials exceed 60% of their ultimate stress (0.6 f_u), the defects grow, leading to total failure of the material in the long run. This failure is defined as the third stage or the tertiary stage of creep [15].

Several creep tests have been performed on FRP laminates, pultruded profiles, and frames [20–22]; however, few attempts have been made to investigate the creep behavior of FRP bars. It is worth to mention that testing FRP bars represents the real condition of FRP-reinforced concrete members. Moreover, differences in cross-section's geometry (configuration and area) may lead to a different confinement force applied by the outer bulk of the FRP materials on their cores, which could affect their creep behavior. In addition, due to the economic aspects, generally, the FRP laminates and profiles, are constructed using lower fiber amounts and higher fillers in comparison to FRP bars which defiantly affects the creep performance. Finally, in most cases, even in unidirectional FRP laminates and profiles, some transvers fibers are also available, the second creep stage is obtained after 42 days which can be another reason for the importance of testing FRP bars. Maksimov and Plume [20] investigated the creep behavior of several hybrid aramid-glass reinforced plastics as well as their resin matrix and fibers individually. The authors showed that the resin individually experienced a high number of creep strains under sustained loads, and after 5.7 years, the total strains exceeded the initial elastic strains by 430%–470%. Moreover, after 5.7 years, the total strain of fibers exceeded the initial elastic strains by 2.0–2.2 times. However, Maksimov and Plume reported creep resistant behavior for the mixture of resin and fibers (i.e., creep strains only about 5% of their initial strains after 5.7 years). In a study conducted by Ascione et al. [22], the creep behavior of carbon fiber reinforced polymer (CFRP) pultruded laminates were investigated. The results showed that laminates under 0.3, 0.375 and 0.45 f_u experienced 1.63, 1.66 and 1.71% creep ratios in the long run, respectively. They reported that under these stress levels the FRP laminates did not experience the third creep stage.

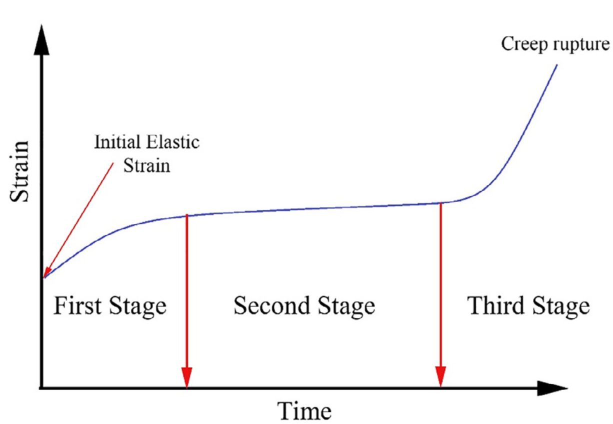

Fig. 1. Different creep stages [15].

In the case of FRP bars, Wang et al. [12] investigated the creep behavior of basalt fiber reinforced polymer (BFRP) tendons for pre-stressing applications and showed that creep behavior is related to the stress applied on the BFRP bars. The results revealed that BFRP bars experienced creep strains about 3.58% of their initial elastic strain under 0.5 f_u. However, studies on the creep behavior of different FRP bars—such as CFRP, glass fiber reinforced polymers (GFRP), or Hybrid (glass and carbon fibers) FRP bars—under different applied stresses are very limited, and a thorough investigation is needed to obtain their creep behavior before they are utilized in RC members.

Shi et al. [16] studied the creep behavior of the normal and pretension-treated basalt fiber-reinforced polymer tendons, concluding that both types can sustain 0.6 f_u and 0.7 f_u without experiencing a fracture within 42 days. The creep behavior of 9.8 mm GFRP bars were investigated by Nkurunziza et al., whereby the specimens were subjected to alkaline solution and de-ionized water for 417 days under stress levels up to 0.8 f_u [13]. The reported results showed that the maximum creep strain is less than 5% of the initial elastic strain and that the bars did not reach the third creep stage under the chosen stress levels.

Given the aforementioned findings, in this study, the creep behaviors of different FRP bars characterized by different fiber and resin types as well as bar diameters were examined under different sustained stresses. The main aim was to compare the second creep stage of carbon, glass, and hybrid carbon-glass FRP bars. The tests were carried out for 83 days to record the second creep stage. Moreover, to investigate the effects of bar characteristics, bar diameters, and applied stress levels on creep behavior, analysis of variance (ANOVA) was performed. Finally, empirical equations for the creep behavior of FRP bars at the end of the second stage (after 83 days) were developed based on the test results, using a Bayesian linear regression method. The findings of this study will increase understanding of the effects of different FRP bars' parameters and applied stress levels on the bars' creep behavior.

2. Experimental program

Several specimens were tested to investigate the effects of different FRP bars' parameters, including fiber type, resin type, bar diameter, and the applied sustained stress levels on the FRP bars' behavior in the first and second creep stages. Based on the study by Maksimov and Plume [20] the second creep stage is obtained after 42 days of creep test. However, in this study, the tests were continued up to 83 days to guarantee the observation of the second creep stage in FRP bars.

2.1. Materials

2.1.1. FRP bars

Four types of FRP bars were used in this study, Namely, sand-coated GFRP bars with epoxy resin (Type A), grooved CFRP bars with epoxy and Vinyl Ester resins (Type B and C, respectively),