Construction and Building Materials 187 (2018) 220–230

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

An investigation of the viscoelastic creep behaviour of basalt fibre reinforced timber elements

Conan O'Ceallaigh [a], Karol Sikora [b], Daniel McPolin [c], Annette M. Harte [a,*]

[a] College of Engineering & Informatics & Ryan Institute, National University of Ireland Galway, University Rd., Galway, Ireland
[b] Department of Civil Engineering, Xi'an Jiaotong-Liverpool University, Suzhou Dushu Lake Higher Education Town, Jiangsu Province 215123, PR China
[c] School of Planning, Architecture and Civil Engineering, Queen's University Belfast, University Road, Belfast BT7 1NN, UK

HIGHLIGHTS

- Viscoelastic creep deflection of BFRP reinforced timber beams measured over a 75-week period.
- No significant reduction in relative viscoelastic deflection due to FRP reinforcement.
- Beneficial reduction in strain on the tension face due to reinforcement.
- Eurocode 5 Service Class 1 creep modification factors may be suitable for FRP reinforced beams.

ARTICLE INFO

Article history:
Received 21 March 2018
Received in revised form 6 July 2018
Accepted 25 July 2018

Keywords:
BFRP
Engineered wood products
Reinforced timber
Sitka spruce
Viscoelastic creep

ABSTRACT

An investigation was carried out to examine the effect of flexural reinforcement on the long-term behaviour of timber beams. Creep tests, utilising statistically matched groups, were performed under Service Class 1 conditions on reinforced and unreinforced beams loaded to a common maximum compressive stress of 8 MPa. As flexural reinforcement resulted in a reduction in the timber tensile stresses, the viscoelastic tensile strains in the reinforced members were found to be significantly lower than in the unreinforced beams. It was found that the viscoelastic relative creep deflection was governed by the stress level in the timber and the reinforcement had an insignificant effect. It is concluded that current creep modification factors in Eurocode 5 may be suitable for the design of reinforced timber elements under Service Class 1 conditions.

1. Introduction

Structural timber products have been shown to have benefitted with regard to stiffness and ultimate load capacity when reinforced with FRP (Fibre Reinforced Polymer) materials of a superior stiffness. The short-term behaviour of these reinforced elements is relatively well understood. The addition of reinforcement can delay tension failure in timber flexural elements and utilise the additional capacity of the timber in the compression zone resulting in much more consistent behaviour as well as a significant increase in flexural stiffness [1–9]. However, the long-term or creep behaviour of such members has received less attention. Accurate prediction of the long-term performance of timber elements is of crucial importance to structural engineers when designing timber structures as timber is particularly susceptible to large creep deformations when stressed for long periods of time.

Creep effects in timber elements can be divided into two main categories, namely, viscoelastic creep and mechano-sorptive creep. The viscoelastic creep component is defined as the deformation with time at constant stress and under constant environmental conditions, which is typical of indoor conditions. Under variable environmental conditions, additional mechano-sorptive creep and swelling/shrinkage behaviour occurs. The mechano-sorptive creep effect has been shown to dramatically accelerate the rate of creep in a loaded timber element and is defined as a deformation due to the interaction between stress and moisture content change due to variable environmental conditions [10–13]. Eurocode 5 [14] provides modification factors which allow design engineers to account for both viscoelastic and mechano-sorptive creep behaviour of solid timber members and engineered wood products. Currently, there are no guidelines on how to account for the influence of reinforcement on the creep response of reinforced timber elements. The reasons for this are partly due to a lack of

* Corresponding author.
E-mail addresses: conan.oceallaigh@nuigalway.ie (C. O'Ceallaigh), karol.sikora@xjtlu.edu.cn (K. Sikora), d.mcpolin@qub.ac.uk (D. McPolin), annette.harte@nuigalway.ie (A.M. Harte).

https://doi.org/10.1016/j.conbuildmat.2018.07.193
0950-0618/

knowledge, particularly related to the long-term performance of such reinforcement systems. To date only a small number of studies have investigated creep behaviour in reinforced timber and further work in this area is required to enable the development of harmonised design rules for structural engineering applications. This paper focuses on establishing the influence of reinforcement on the viscoelastic creep of reinforced timber beams.

1.1. Viscoelastic creep behaviour of timber

For many structural applications, the most important mechanical property of timber is its resistance to deflection, including both elastic and creep deflection. The contribution of creep deflection to the total deflection is generally much more significant in the case of timber structures to those made of steel or concrete. The creep behaviour of timber also more complex as it is a function not only of timber but also environmental conditions, which change the moisture content of the material. When stressed in a constant climate condition, a timber element undergoes an instantaneous elastic deflection followed by viscoelastic creep behaviour with time. Under this constant climate condition, the level of viscoelastic creep depends on the stress level, temperature and moisture content of the timber. Senft & Suddarth [15] examined small specimens ($41.3 \times 50.8 \times 203.2$ mm^3) of Sitka spruce (Picea sitchensis) under compression load at stress levels of 10, 20, 40 and 60% of ultimate strength for load durations up to twenty days. The moisture content remained constant throughout to exclude the mechano-sorptive effect and focus solely on viscoelastic creep. They found that the viscoelastic creep behaviour increases with increasing stress levels and significantly, they found that creep deformation can occur at stress levels as low as 10% of ultimate strength. It was also reported that, at higher stress levels (>55%), specimens are susceptible to creep rupture resulting in failure [15,16]. Similarly, an increase in temperature has been shown to result in higher viscoelastic creep deformations. Davidson [17] performed creep tests on three different species at a series of constant temperatures. It was shown that the rate of creep increased slightly with increasing temperature from 20 °C to 50 °C. The magnitude of viscoelastic creep has been also shown to depend on the moisture content of the timber [10,11,18]. In a study by Hering and Niemz [19], the viscoelastic behaviour of European beech timber elements subjected to four-point bending was investigated and the longitudinal creep compliance at three different moisture contents (8.14%, 15.48% and 23.2%) was examined. Each timber specimen was loaded to approximately 25% of the ultimate bending strength for a period of approximately 200 hr and the viscoelastic creep behaviour was found to increase linearly with increasing moisture content.

Another study designed to examine if the rate of creep eventually decreases towards a creep limit was performed by Hunt [20]. Experimental creep tests on solid timber elements were carried out in a carefully controlled environment over a 13-week period. Creep functions were matched to these experimental test results and to creep test results by Gressel [21] over a much longer period of time (8 years). The curves were extrapolated to estimate the viscoelastic creep after 50 years under sustained load. No evidence was found to suggest a viscoelastic creep limit exists in timber when stressed in a constant climate condition. This demonstrates the potential for timber elements to deform throughout their service life and demonstrates the importance of understanding its behaviour.

1.2. Viscoelastic creep behaviour in reinforced timber

When timber elements are reinforced, the behaviour of the elements can be greatly altered. The short-term or instantaneous elastic behaviour of reinforced elements has been investigated by many authors and significant improvements in stiffness and ultimate moment carrying capacity have been demonstrated [1,3,7–9,22]. More ductile behaviour can be achieved when modest proportions of reinforcement are utilised in strategic locations. Reinforcing the tension zone of timber elements can delay tension failure and utilise the additional capacity of the timber in the compression zone. A limited number of studies have focused on the long-term or viscoelastic creep behaviour of FRP reinforced timber elements. Plevris and Triantafillou [23] performed long-term creep tests on carbon fibre reinforced polymer (CFRP) reinforced beams under three-point bending. There was a relatively small sample size of three beams, one unreinforced control beam and two reinforced beams with two different area reinforcement ratios of 1.18% and 1.65%, respectively. The tests were carried out under constant climate conditions and similar loads were applied to each beam. This resulted in different stress levels in the timber. It was determined from the experimental results, that the creep behaviour of the FRP-reinforced timber elements was primarily dominated by stress within the timber.

In a study by Yahyaei-Moayyed and Taheri [24], the creep performance of southern yellow pine (SYP) and Douglas fir (DF) timber beams reinforced with aramid fibre reinforced polymer (AFRP) was examined. These creep tests were carried out in an uncontrolled climate over a period of 800 h and it is noted that the applied loads (P) were not the same for the unreinforced and reinforced beams. When comparing one SYP unreinforced (P = 4.85 kN) with one SYP reinforced beam (P = 4.40 kN) there appeared to be a reduction in creep deflection, but it was not clear if this reduction was due to different stress levels within the timber or the presence of the AFRP reinforcement. The reduced load on the reinforced beam led to a lower stress level within the timber when compared to the unreinforced beam making comparisons difficult. Interestingly when one unreinforced DF beam (P = 5.60 kN) and one reinforced DF beam (P = 5.76 kN) were compared, there was a slightly higher load on the reinforced beam and a similar creep deflection was observed. The timber stress levels in both the unreinforced and reinforced beams were more comparable in this case. There was also an influence of the uncontrolled climate condition in this study and possible swelling/shrinkage or mechano-sorptive creep deformations as a result of the minor fluctuations in moisture content.

Davids et al. [25] performed long-term creep tests on six unreinforced and six reinforced 7 m long Douglas fir and western hemlock glulam beams in a sheltered environment with controlled temperature and uncontrolled relative humidity. A proportion of the beams were reinforced with glass fibre reinforced polymer (GFRP) plate with two percentage area reinforcement ratios, namely, 1.1% and 3.3%. While the laboratory tests demonstrated the effectiveness of the GFRP reinforcement in reducing the elastic deformation between the unreinforced beams and the reinforced beams, a difference between the creep deformation of the unreinforced elements and the GFRP reinforced elements is only seen at the higher reinforcement level. It is noted by Davids et al. [25] that the effectiveness of FRP reinforcement on reducing creep cannot be inferred from the test data due to the different load and associated stress levels in the timber in addition to the uncontrolled relative humidity during the test.

The creep behaviour of a loaded timber element has been shown to be heavily influenced by the stress level within the timber. When reinforced, the flexural stiffness of the timber beam is altered and stress distribution through the cross-section is affected. In an effort to reduce the difference in stress distribution between unreinforced and reinforced beams, beams should be loaded to a common maximum stress, similar to that performed by Kliger et al. [22] who carried out mechano-sorptive creep tests on beams loaded to a common maximum compressive stress.