

Review

Strain rate studies of pultruded glass fibre reinforced polymer material properties: A literature review

Shaohua Zhang, Colin C. Caprani^{*}, Amin Heidarpour

Department of Civil Engineering, Monash University, Melbourne, Australia

HIGHLIGHTS

- Pultruded glass fibre-reinforced polymer (GFRP) has become more widely used recently.
- The effect of strain rate on the material properties of pultruded GFRP is reviewed.
- Experimental studies and techniques for each property are critically reviewed.
- Existing constitutive models disagree when considering the strain rate effect on pultruded GFRP.
- More research is needed on pultruded GFRP properties at intermediate strain rates.

ARTICLE INFO

Article history:

Received 7 June 2017

Received in revised form 13 March 2018

Accepted 14 March 2018

Keywords:

Glass fibre reinforced polymer (GFRP)

Pultrusion

Elastic material properties

Strain rates

Fibre orientation

Constitutive material model

ABSTRACT

Glass fibre-reinforced polymer (GFRP) has been increasingly applied in civil engineering for high-performance durable structural members. Over the last decade or so, pultruded GFRP has become much more widely used due its cost-effective ease of manufacturing. In this paper, the effect of strain rate on the material properties of pultruded GFRP, including elastic modulus, in-plane shear modulus and Poisson's ratio, is reviewed. Experimental studies of each property considering fibre orientation and the applied experimental techniques are critically reviewed. Reference is made to similar studies for laminated FRP. The existing constitutive models are also reviewed and it is shown that disagreement exists when considering the strain rate effect on pultruded GFRP. From this review of both experimental and modelling research, it is concluded that a focus on the dynamic material properties of pultruded GFRP at intermediate strain rates is needed if the behaviour of GFRP structures during earthquake and other sources of vibration excitation is to be fully understood.

© 2018 Elsevier Ltd. All rights reserved.

Contents

1. Introduction	985
2. The basic properties of GFRP	985
2.1. GFRP constituents	985
2.1.1. Glass fibre	986
2.1.2. Polymer resin	986
2.2. Manufacturing process and applications of pultruded GFRP	986
2.3. Factors affecting GFRP material properties	986
2.4. Elastic constants of pultruded GFRP	987
3. Experimental studies for GFRP material properties	987
3.1. Material test equipment	987
3.1.1. Loading apparatus	987
3.1.2. Measurement devices	988
3.2. Elastic moduli	988

^{*} Corresponding author.E-mail address: colin.caprani@monash.edu (C.C. Caprani).

3.2.1.	Overview	988
3.2.2.	Laminated GFRP	990
3.2.3.	Pultruded GFRP	991
3.2.4.	Discussion	992
3.3.	In-plane shear modulus	992
3.3.1.	Overview	992
3.3.2.	In-plane shear modulus theory	993
3.3.3.	In-plane shear modulus test methods	993
3.3.4.	Discussion	996
3.4.	Poisson's ratio	996
4.	Constitutive material modelling of GFRP properties	996
4.1.	Overview	996
4.2.	Elastic/viscoelastic material model	996
4.3.	Elastic/viscoelastic material model	999
4.4.	Micromechanical material model	1000
4.5.	Discussion	1001
5.	Conclusions	1001
	References	1002

1. Introduction

Civil engineering structures are subject to loading rates ranging from very slow (quasi-static) to extremely fast (such as impact or blast). Clearly, it is vital to understand the behaviour of structural materials when undergoing different strain rates (shown in Fig. 1) to accurately predict overall structural response, thereby ensuring public safety. Construction materials present different levels of sensitivity to strain rate, changing the strength and stiffness properties. Even a small sensitivity to strain rate can lead to very different global structural behaviour [130]. For example, the materials used in reinforced concrete structures are strain-rate dependent, but differences in their properties become significant when the strain rate changes by more than one order. For concrete, it is generally concluded that compressive strength, elastic modulus, and Poisson's ratio exhibit an increase at higher strain rate [28]. The yield point of steel also shows a similar increasing trend [34]. Further, material deformation and failure modes have been shown to be dependent on different loading conditions [21]. These factors should make clear the importance of understanding the effect of strain rate on predicting global structural response.

In recent decades, fibre reinforced polymer (FRP) composites have been increasingly applied in civil engineering. FRP materials have relatively high stiffness and strength, are generally lightweight, and have good corrosion and water resistance [16]. They can be formed into a wide variety of shapes and their lightweight nature makes them easy to handle during transport and construction. These benefits make them attractive for replacing conventional-material structural members in certain circumstances, or act as a strengthening material [166]. Composite polymer materials have two constituents; fibre and matrix. The properties of FRP are strongly dependent on the properties of its constituent materials, including strain rate sensitivity [130]. This greatly complicates the prediction of the mechanical behaviour of FRP under various strain rates. As will be seen, this complexity means there is yet a lack of understanding of the effect of strain

rate on FRP, which is inhibiting progress in the use and application of FRP structures [33].

FRP material properties, such as those reported by manufacturers, are commonly based on the results of quasi-static (very low strain rate) tests [94]. These properties are applied as basic inputs in FRP constitutive material models or numerical analysis. In considering the strain rate effect, numerous investigations have been carried out for carbon fibre-reinforced polymer (CFRP) or glass fibre-reinforced polymer (GFRP) in laminated form (e.g. [4,43,70,95,97,108,110,128]). Conversely, as will be shown, little research is available on the material properties of pultruded FRP structural profiles across the whole range of strain rates. This is especially so at intermediate strain rates which correspond to the structural response such as earthquake or vibration [28,125,167]. Consequently, this paper reviews the existing literature on the influence of strain rate on the material properties of pultruded FRP, including elastic modulus, in-plane shear modulus, and Poisson's ratio. For context, relevant aspects of similar studies conducted for laminated FRP are also included. Following presentation of the manufacture of the material, this paper focuses on the experimental work undertaken thus far, and concludes in examining the constitutive models proposed for consideration of the strain rate effects in FRP. A wide range of strain rates have been covered from creep to high strain rates. This work identifies the knowledge gap in both the experimental and constitutive modelling aspects of pultruded FRP material properties, and makes recommendations for future progress.

2. The basic properties of GFRP

2.1. GFRP constituents

GFRP composite material consists of glass fibres acting as reinforcement embedded within a polymer resin (also called the matrix). A filler material may also exist between the fibre and

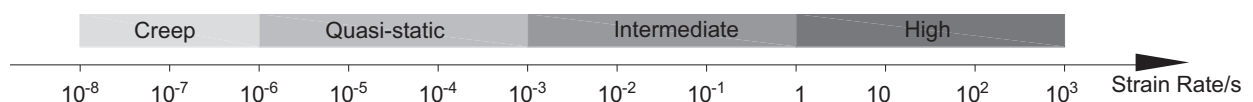


Fig. 1. Magnitude of strain rate range (after Bischoff and Perry [28]).

Download English Version:

<https://daneshyari.com/en/article/6713829>

Download Persian Version:

<https://daneshyari.com/article/6713829>

[Daneshyari.com](https://daneshyari.com)