Construction and Building Materials 96 (2015) 648–656

Contents lists available at ScienceDirect

Construction and Building Materials

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

# Tensile behavior of glass fiber reinforced composite at different strain rates and temperatures

Yunfu Ou, Deju Zhu *

*College of Civil Engineering, Hunan University, Changsha, Hunan 410082, China*

## HIGHLIGHTS

- Tensile strength and toughness of GFRP increase with increasing strain rate.
- Young's modulus and tensile strength of GFRP decrease with increasing temperature.
- Maximum strain of GFRP is almost constant over the temperature range of −25–50 °C.
- The failure patterns of GFRP are related to the testing conditions.
- The shape parameter ($m$) values are only dependent on strain rate, but not temperature.

## ARTICLE INFO

*Article history:*
Received 19 May 2015
Received in revised form 24 July 2015
Accepted 9 August 2015

*Keywords:*
GFRP
Mechanical properties
Statistical properties/methods
Mechanical testing

## ABSTRACT

Glass fiber reinforced composite (GFRP) samples were tested at different strain rates from quasi-static up to 160 $s^{-1}$ and temperatures from −25 to 100 °C to investigate any possible effects on their mechanical properties and failure patterns. The experimental results show that the tensile strength, maximum strain and toughness increase with increasing strain rates at room temperature, and the Young's modulus, tensile strength and toughness decrease with increasing temperatures at the strain rate of 40 $s^{-1}$. Weibull statistics were used to quantify the degree of variability in the tensile strength and obtain Weibull parameters for numerical simulations and engineering applications.



## 1. Introduction

Fiber reinforced polymer (FRP) has been in use since the 1940s but only recently has won the attention of engineers involved in the construction of civil structures [1]. The ability to tailor composites, attributes of high stiffness-to-weight and strength-to-weight ratios, fatigue resistance, corrosion resistance, and lower manufacturing costs, makes them exceedingly attractive when compared with conventional metals for use in building reinforcement [1–8]. However, the response of a structure designed with static properties, in many technological applications, might be too conservative under dynamic loading conditions due to its high strain-rate sensitivity. Moreover, once subjected to elevated or cryogenic temperatures, the mechanical properties of this kind of composites, such as the Young's modulus and strength, would experience significant changes [9–13]. Consequently, many research projects, in recent decades, have been undertaken in an attempt to better understand the effects of strain rate and temperature on these materials.

Barre et al. [14] determined the tensile dynamic behavior of glass fiber-reinforced phenolic and polyester resins in order to find the influence of strain rate on the mechanical properties of composite materials. The results revealed that dynamic elastic modulus and strength tend to increase with increasing strain rate. Shokrieh et al. [15] studied the behavior of unidirectional glass fiber reinforced polymeric composites at quasi-static and intermediate strain rates of 0.001–100 $s^{-1}$ by means of a servo-hydraulic testing apparatus equipped with a strain rate increase mechanism and pointed out that a significant increase of the tensile strength by increasing the strain rate. The tensile modulus and strain to failure are also observed to increase slightly by increasing the strain rate. Ochola et al. [16] determined the strain rate sensitivity of glass fiber reinforced polymer (GFRP) at strain rates of $10^{-3}$ and 450 $s^{-1}$. The experimental results also showed that the dynamic material strength for GFRP increases with increasing strain rates. Rotem et al. [17] investigated the effect of strain rate on the tensile properties of unidirectional glass fiber/epoxy composites and

* Corresponding author.
*E-mail address:* dzhu@hnu.edu.cn (D. Zhu).

http://dx.doi.org/10.1016/j.conbuildmat.2015.08.044
0950-0618/

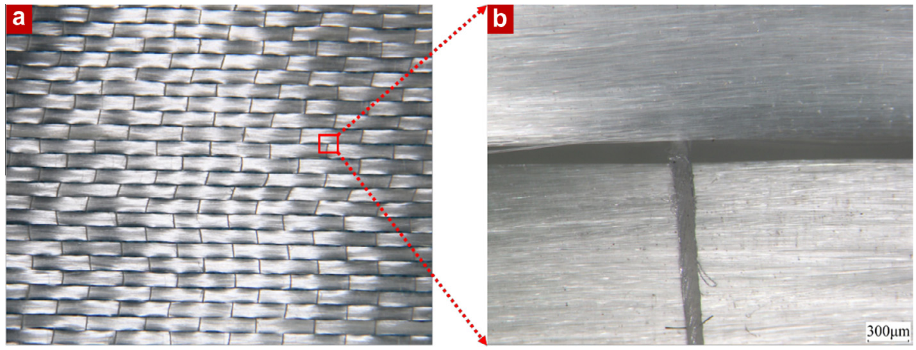


**Fig. 1.** (a) Woven structure and (b) optical microscopy image of glass unidirectional fiber fabrics.

**Table 1**
Physical and mechanical properties of GFRP components.

| Components | Tensile strength (MPa) | Young's modulus (GPa) | Elongation (%) | Density (g/cm$^3$) | *c*/*s* area of single yarn (mm$^2$) |
|---|---|---|---|---|---|
| Glass yarn | 919 | 113 | 1.5 | 2.54 | 0.473 |
| Epoxy resin | 36 | 6.1 | 1.8 | 1.7 | – |

found that the dynamic strength is three times higher than the static value and the dynamic modulus is 50% higher than the static value. However, Lifshitz et al. [18] found that the elastic modulus of angle ply glass/epoxy laminates was independent of strain rate and the dynamic failure stress was only moderately higher than the static value (20–30% higher). Melin et al. [19] investigated the dependence of the transverse tensile properties on strain rate of a high performance carbon/epoxy composite loaded in

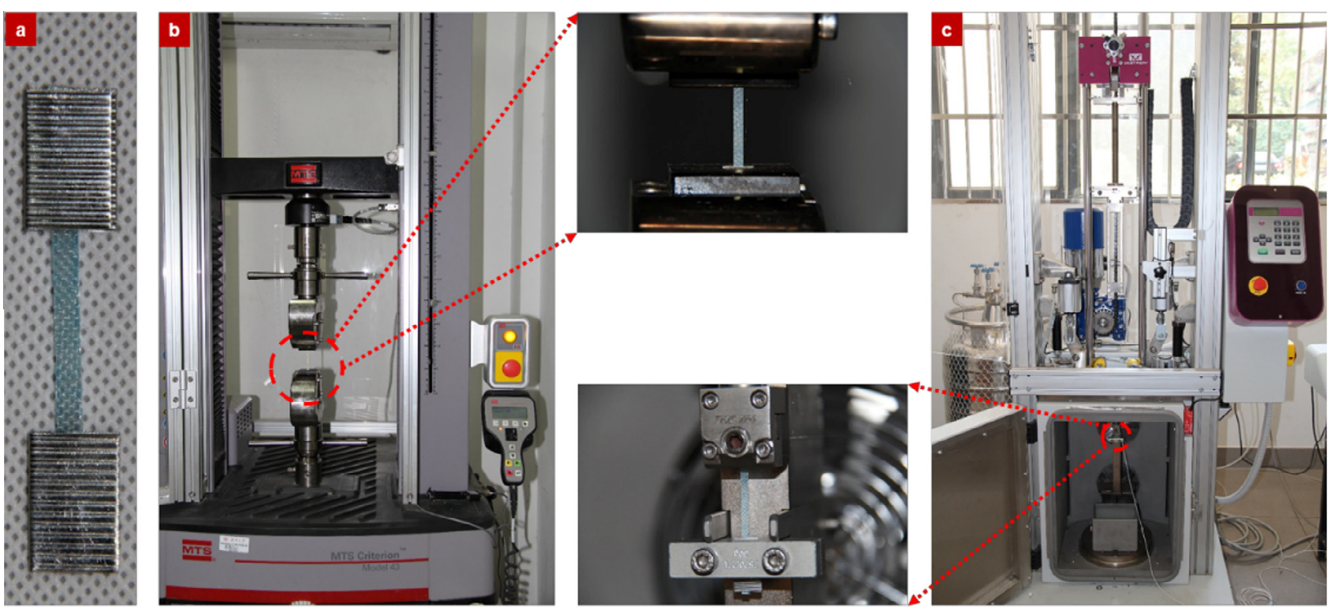


**Fig. 2.** (a) GFRP specimen; (b) MTS load frame; (c) Instron drop-weight impact system.

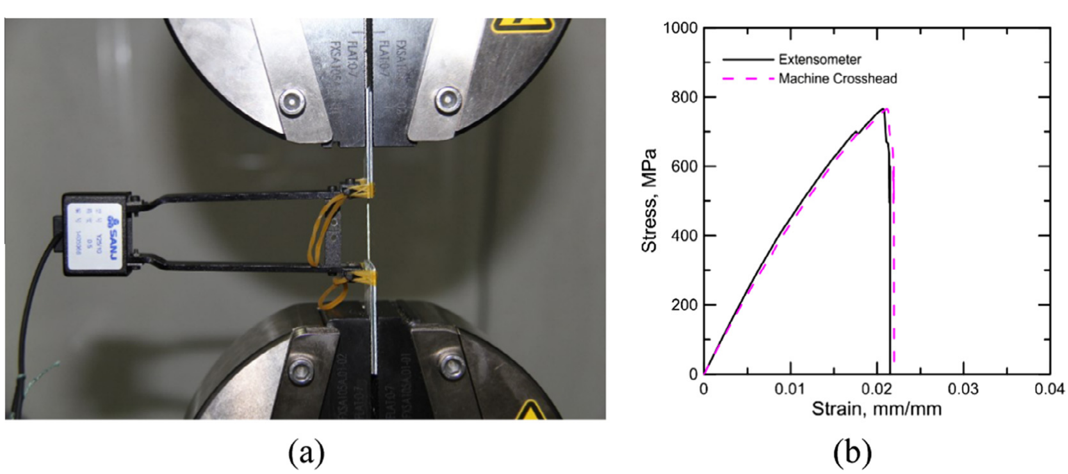


**Fig. 3.** (a) Installation of extensometer; (b) comparison of strain measurement by an extensometer and the machine crosshead.