Polymer Testing 56 (2016) 269–276

Contents lists available at ScienceDirect

Polymer Testing

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

Test Method

Through-thickness compression testing of fabric reinforced composite materials: Adapted design of novel compression stamps

M. Gude, R. Schirner*, D. Weck, E. Dohmen, M. Andrich

Technische Universität Dresden, Institute of Lightweight Engineering and Polymer Technology, 01062 Dresden, Germany

ARTICLE INFO

Article history:
Received 25 August 2016
Received in revised form
11 October 2016
Accepted 18 October 2016
Available online 24 October 2016

Keywords:
Compression
Load application
Finite element analysis (FEA)
Fabric reinforced polymer

ABSTRACT

The use of thick-walled fabric reinforced laminates in force transmission zones increased in the last years due to optimised production processes for composite structures. This enabled especially the manufacturing of thick laminates free of pores or other defects. As generally acknowledged, for a robust design and precise failure prediction of these structures reliable material property data are essential. While many test standards were analysed and modified in accordance to the specific characteristics of fibre reinforced materials, out-of-plane compression tests seem outdated. So far, some test methods are established; however, a standardised test method for compression testing in through-thickness direction of the laminate is still missing.

A novel approach for through-thickness compression testing of fabric reinforced polymers with specifically designed stiffness-adapted compression stamps is presented. Comprehensive numerical analyses of the compressive load application and the dimensioning of the compression stamps in relation to the specimen size have been performed. It is shown, that the developed through-thickness compression testing device with the adapted design of the novel compression stamps is best suitable, as higher compressive strengths of fabric reinforced polymers can be experimentally determined.

1. Introduction

Composite structures with positive or friction locking joints are often exposed to spatial stress conditions in the load application area. For example, composite fan blades of aircraft engines, composite cylinder tubes of hydraulic actuators, and composite drive shafts with sinusoidal serration show significant compression stresses in through-thickness direction of the composite [1–3].

In order to design such structures, high demands on the quality and reliability of 3D material property data call for a set of robust test devices and processes. However, in comparison with technically advanced in-plane test standards, the test methods for through-thickness (TT) compressive material behaviour do not take into account the specific biaxial/triaxial deformation behaviour of fabric reinforced composite materials. Thereby, it has not yet been adequately investigated that fabric reinforced polymer laminates show high potential for the use in high-stressed load application areas due to their compressive strengths. Therefore, the design of multidirectional fabric reinforced polymer (FRP) structures shows an increased need for reliable TT compressive properties determined by a material-adapted, robust test method.

In this respect, specimen design is of fundamental significance to achieve reliable material properties. A comprehensive overview of established TT-testing approaches is given in [4,5]. Approaches for characterising the tensile and shear behaviour of textile reinforced material can be found in [6–10], where also strain rate dependencies have been taken into account. In contrast, measuring TT-compression properties of textile reinforced composites is still a challenge.

Based on uniaxial compression tests from civil engineering, various test devices for composite compression testing have been derived, e.g. by Ferguson [11], Park [12] or Bing [13]. These studies focussed on material properties, specimen geometry or size effect. The impact of load application and of hindered transverse specimen deformations on the 3D-stress distribution within the specimen was not investigated. Additionally, a particular challenge in testing fabric reinforced composites in laminate thickness direction is the very high compressive strength of up to 1000 MPa, which requires an adapted and very robust test device. Although different testing devices have been developed, especially the influence of the load application on the stress distribution within the specimen has not been analysed in detail yet.

* Corresponding author.
E-mail address: robert.schirner@tu-dresden.de (R. Schirner).
URL: http://www.tu-dresden.de/mw/ilk

http://dx.doi.org/10.1016/j.polymertesting.2016.10.024
0142-9418/

Nomenclature

variables

A	mm^2	area
E	GPa	Young's modulus
G	GPa	shear modulus
R	MPa	strength
F	N	force
$F^{\dot{m}}$	-	fracture function
ε	%	strain
ν	-	Poisson's ratio
σ	MPa	normal stress
τ	MPa	shear stress
μ	-	friction parameter
$\dot{m}$		interaction coefficient

Indices

$i = 1,2,3$	axes of single layer
$(+)$	tension
$(-)$	compression

Without any doubt, the specimen geometry is an important issue. Different specimen geometries have been presented in earlier and recent works [4,5,11,12].

In this paper, an advanced compression test device with novel compression stamp designs for through-thickness compression testing of fabric reinforced polymers is presented. The compression stamps are characterised by a stiffness-adapted design as well as dimensions which closely match the cross section of the specimen. It is shown, that using these novel compression stamps allows the determination of higher compressive strengths of fabric reinforced polymers and therefore the developed test setup could form the basis for a new standard test method.

2. Test device for compression testing with a novel compression stamp design

The basic compression test device corresponds to the known design with two pressure plates which are attached to the upper and lower heads of a universal testing machine. To eliminate misalignments while testing and to reduce unwanted stresses and deformations within the load strand of the testing machine standard column guidances can be used [14]. In contrast to this simple column guidance proposed by Ferguson [11], the column guidance suggested here is equipped with advanced clearance-free cylindrical roller bearings to withstand high static transverse forces. Additionally, a ball joint is mounted on top of the column guidance in order to avoid torsional moments. As frictional forces within the guide units of the column guidance cannot be excluded, it is a common procedure to generate a “correction curve” by loading the test device without any specimen. This curve can be used to scale the experimentally determined stress strain curves.

The compression stamps are attached in between the lower and upper plates of the column guidance (Fig. 1). The design of the compression stamps and the resulting stress-strain behaviour of the fabric reinforced polymer specimen has been analysed in detail by using finite element analyses. The results are shown in section 3.

Different shapes of the specimen (e.g. short block, waisted block, cylinder) have been analysed by Olssen [5]. It was shown that the short block specimen is well-suited for compressive strength determination and this coincides with own preliminary works. Due to the relatively short height of the specimens, a waisted geometry with small radius leads to significant and failure-critical stress concentrations at the region of the radius close to the test section. In addition, researches by Kim et al. [15] show that the measured strengths of short block specimen are slightly higher compared to cylindrical specimen. Focussing a practicable manufacturing a square-shaped block is preferred instead of a cylindrical shaped specimen. The cylindrical shape can be manufactured by core drilling or turning, although these techniques are quite demanding due to the small specimen size. The manufacturing of the short blocks can be performed quite easy from a plain plate by using a precision cutting machine. Because of the cost-efficient and precise manufacturing of the short blocks, this specimen geometry is used for the in-depth load application analyses.

Concerning the load application, the quoted sources did not take any specific precautions except the use of grease lubricants to reduce the interfacial friction [15]. Overall, it is recommended to prepare the contact surfaces of the compression stamps and the

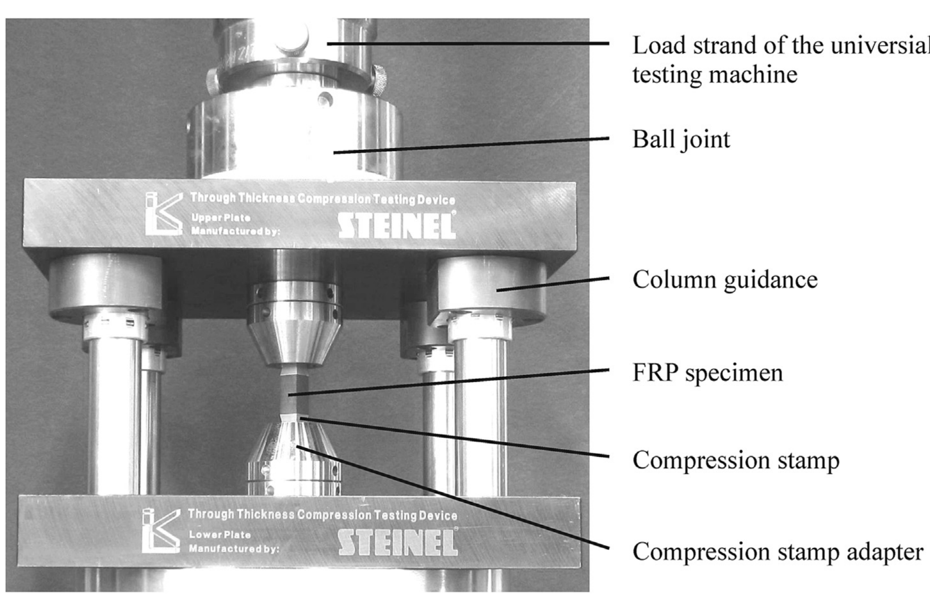

Fig. 1. Through-thickness compression test device.