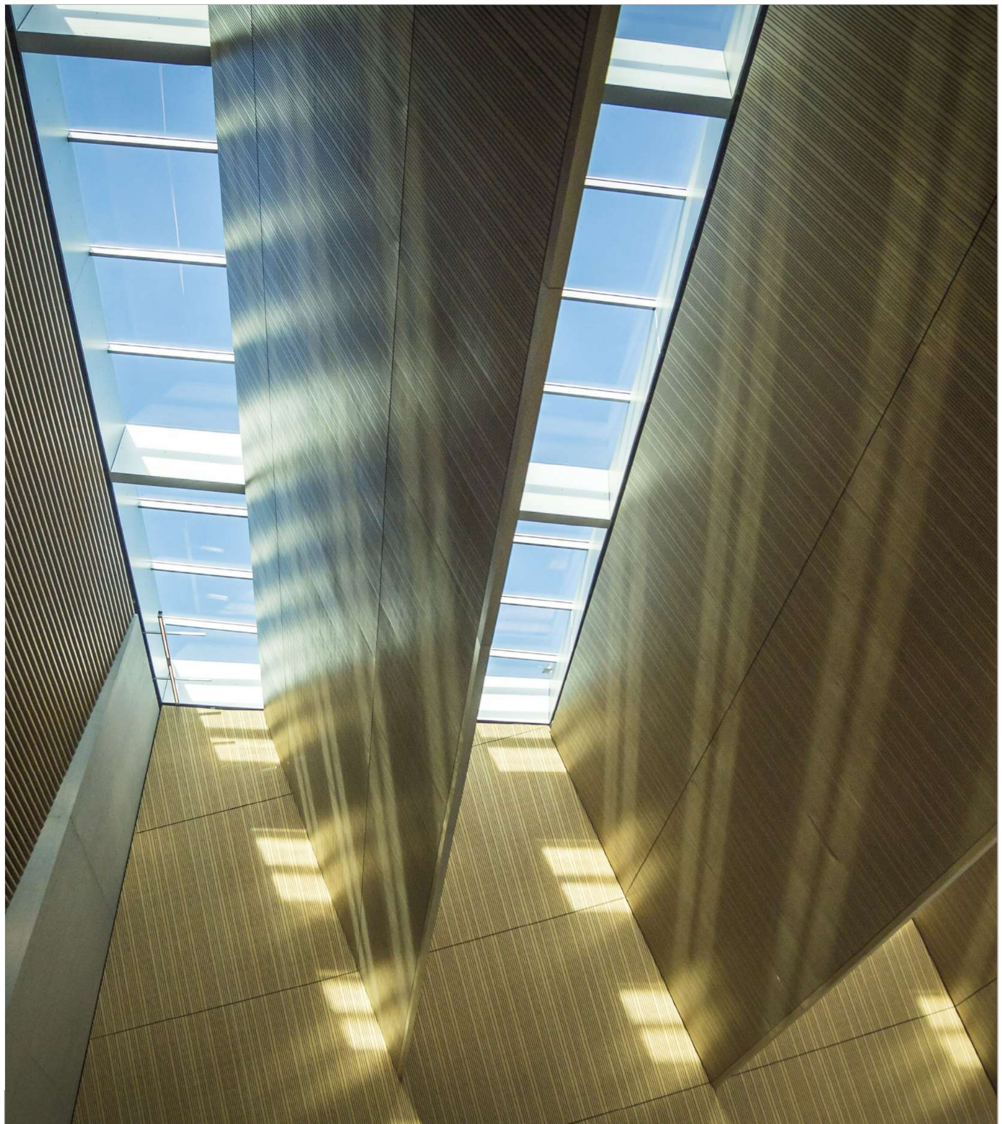
ECCM 20

26–30 JUNE 2022

LAUSANNE SWITZERLAND



Proceedings of the 20th European Conference on Composite Materials

COMPOSITES MEET SUSTAINABILITY

Vol 3 – Characterization

Editors : Anastasios P. Vassilopoulos, Véronique Michaud

Organized by :

EPFL

Under the patronage of :

CCLAB Composite Construction Laboratory

LPAC Laboratory for Processing of Advanced Composites

ESCM EUROPEAN SOCIETY FOR COMPOSITE MATERIALS

Proceedings of the 20th
European Conference on Composite Materials
ECCM20
26-30 June 2022,
EPFL Lausanne Switzerland

Edited By :

Prof. Anastasios P. Vassilopoulos, CCLab/EPFL
Prof. Véronique Michaud, LPAC/EPFL

Oragnized by:

Composite Construction Laboratory (CCLab)
Laboratory for Processing of Advanced Composites (LPAC)
Ecole Polytechnique Fédérale de Lausanne (EPFL)

ECCM 20
26-30 JUNE 2022
LAUSANNE SWITZERLAND

ISBN: 978-2-9701614-0-0

DOI: http://dx.doi.org/10.5075/epfl-298799_978-2-9701614-0-0

Published by :

Composite Construction Laboratory (CCLab)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
BP 2225 (Bâtiment BP), Station 16
1015, Lausanne, Switzerland

https://cclab.epfl.ch

Laboratory for Processing of Advanced Composites (LPAC)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
MXG 139 (Bâtiment MXG), Station 12
1015, Lausanne, Switzerland

https://lpac.epfl.ch

Cover:

Swiss Tech Convention Center
© Edouard Venceslau - CompuWeb SA

Cover Design:

Composite Construction Laboratory (CCLab)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
Lausanne, Switzerland

Disclaimer:

The ECCM20 organizing committee and the Editors of these proceedings assume no responsibility or liability for the content, statements and opinions expressed by the authors in their corresponding publication.

Editorial

This collection gathers all the articles that were submitted and presented at the 20th European Conference on Composite Materials (ECCM20) which took place in Lausanne, Switzerland, June 26-30, 2022.

ECCM20 is the 20th edition of a conference series having its roots back in time, organized each two years by members of the European Society of Composite Materials (ESCM).

The ECCM20 event was organized by the Composite Construction laboratory (CCLab) and the Laboratory for Processing of Advanced Composites (LPAC) of the Ecole Polytechnique Fédérale de Lausanne (EPFL).

The Conference Theme this year was "Composites meet Sustainability". As a result, even if all topics related to composite processing, properties and applications have been covered, sustainability aspects were highlighted with specific lectures, roundtables and sessions on a range of topics, from bio-based composites to energy efficiency in materials production and use phases, as well as end-of-life scenarios and recycling.

More than 1000 participants shared their recent research results and participated to fruitful discussions during the five conference days, while they contributed more than 850 papers which form the six volumes of the conference proceedings. Each volume gathers contributions on specific topics:

Vol 1 – Materials

Vol 2 – Manufacturing

Vol 3 – Characterization

Vol 4 – Modeling and Prediction

Vol 5 – Applications and Structures

Vol 6 – Life Cycle Assessment

We enjoyed the event; we had the chance to meet each other in person again, shake hands, hold friendly talks and maintain our long-lasting collaborations. We appreciated the high level of the research presented at the conference and the quality of the submissions that are now collected in these six volumes. We hope that everyone interested in the status of the European Composites' research in 2022 will be fascinated by this publication.

The Conference Chairs

Anastasios P. Vassilopoulos, Véronique Michaud

ECCM 20
26-30 JUNE 2022
LAUSANNE SWITZERLAND

Hosting Organizations

Composite Construction Laboratory (CCLab)
Laboratory for Processing of Advanced Composites (LPAC)
Ecole Polytechnique Fédérale de Lausanne (EPFL)

Venue

Swiss Tech Convention Center (https://www.stcc.ch)

Conference Chairs

Chair : Prof. Anastasios P. Vassilopoulos, EPFL, Switzerland
Co-Chair: Prof Véronique Michaud, EPFL, Switzerland

International Scientific Committee

Prof. Malin Åkermo SE
Dr. Emmanuel Baranger FR
Prof. Christophe Binetruy FR
Prof. Pedro Camanho PT
Prof. Konstantinos Dassios GR
Prof. Brian Falzon UK
Prof. Kristofer Gamstedt SE
Prof. Sotiris Grammatikos NO
Prof. Christian Hochard FR
Prof. Marcin Kozlowski PL
Prof. Stepan Lomov BE
Dr. David May DE
Prof. Stephen Ogin UK
Prof. Gerald Pinter AT
Prof. Silvestre Pinho UK
Prof. Yentl Swolfs BE
Dr. Julie Teuwen NL
Dr. Panayota Tsotra CH
Prof. Wim van Paepegem BE
Prof. Dimitrios Zarouchas NL
Dr. Andrey Aniskevich LV
Prof. Christian Berggreen DK
Dr. Nicolas Boyard FR
Prof. Valter Carvelli IT
Prof. Klaus Drechsler DE
Prof. Bodo Fiedler DE
Dr. Nathalie Godin FR
Prof. Roland Hinterholzl AT
Prof. Ian Kinloch UK
Dr. Thomas Kruse DE
Prof. Theodoros Loutas GR
Prof. Veronique Michaud CH
Prof. Alessandro Pegoretti IT
Prof. Joao Ramoa Correia PT
Prof. Jose Sena-Cruz PT
Prof. Antonio T. Marques PT
Prof. Thanasis Triantafillou GR
Prof. Albert Turon ES
Prof. Anastasios P. Vassilopoulos CH
Prof. Martin Fagerström SE
Dr. Alexandros Antoniou DE
Prof. Lars Berglund SE
Prof. Michal Budzik DK
Prof. Lucas Da Silva PT
Dr. Andreas Endruweit UK
Prof. Mariaenrica Frigione IT
Dr. Larissa Gorbatikh BE
Dr. Martin Hirsekorn FR
Prof. Vassilis Kostopoulos GR
Prof. Jacques Lamon FR
Prof. Staffan Lundstrom SE
Prof. Peter Mitschang DE
Dr. Soraia Pimenta UK
Prof. Paul Robinson UK
Dr. Olesja Starkova LT
Prof. Sofia Teixeira de Freitas NL
Dr. Stavros Tsantzalis GR
Prof. Danny van Hemelrijck BE
Prof. Michele Zappalorto IT
Dr. Miroslav Cerny CZ

Local Organizing Committee

Prof. Anastasios P. Vassilopoulos, EPFL
Prof. Véronique Michaud, EPFL
Angélique Crettenand and Mirjam Kiener, Lausanne Tourisme
And all those who helped, colleagues who reviewed abstracts and chaired sessions, and CCLab and LPAC students and collaborators who worked hard to make this conference a success.

Sponsors

SHIMADZU Excellence in Science

Bristol Composites Institute

JEC GROUP

suprem

Surface Measurement Systems
World Leader in Sorption Science

INSTRON

9T LABS

Anton Paar

DIA-STRON
DELIVERING MEASUREMENT SOLUTIONS

AELER

HRC

ICCM 23 BELFAST 2023

TEIJIN

Functional Composite Materials

materials
an Open Access Journal by MDPI

ELSEVIER

frontiers
ECCM Research Topic on Advanced Manufacturing of Composites
Open for submissions

Supporting partners

JEC

CertBond
COST Action CA18120

EsSENce

Switzerland Tourism.

SWISS

SBB CFF FFS

sampe Switzerland

CU COMPOSITES UNITED SWITZERLAND

canton de vaud

Lausanne

Contents

DESIGN OF A BENDING EXPERIMENT FOR MECHANICAL CHARACTERISATION OF PULTRUDED RODS UNDER COMPRESSION

Gustavo, Quino[a], Paul, Robinson[b], Richard S., Trask[a]

a: Bristol Composites Institute, Faculty of Engineering, University of Bristol, BS8 1TL, UK
b: Department of Aeronautics, Imperial College London, SW7 2AZ, UK

Abstract: *Carbon fibre pultruded rods are used in structural applications across a wide range of industries due to their lightweight, corrosion/fatigue resistance and outstanding properties in the axial direction. While there is available literature on the mechanical characterisation of pultruded rods under tension and bending, very little has been reported about their compression response. The characterisation of the mechanical performance of pultruded rods under uniaxial direct compression is challenging due to the high sensitivity to alignment, stress concentrations in the gripping zone, and the complexity of specimen manufacturing, especially when the rods can be of small diameter (~1mm).*

Existing literature reports the use of the compression side of a beam under bending to test materials with high axial stiffness and strength such as carbon fibre laminates. In this work, we show the applicability of such idea on pultruded rods. We report on the design of a novel bending experiment to characterise the compression behaviour of pultruded rods, ensuring low strain gradient and consistent failure within the gauge section.

Keywords: compression; pultruded rod; CFRP; mechanical test

1. Introduction

Continuous fibre non-crimped composite materials usually display their maximum strength and modulus in the direction of the fibre, in particular, under tensile loads. However, in compression, due to various factors such as fibre waviness and pre-existing defects, instabilities such as micro buckling, lead to premature failure, and a poorer compression performance [1-4]. Literature reports compressive strengths in the fibre direction below 60% the tensile strength [1].

Composite pultruded rods tend to exhibit a better fibre alignment than laminates; therefore, they stand as an alternative to improve the compression performance of fibre composites [2]. However, measuring the improved compression performance poses a challenge from the experimental point of view. Materials with high axial stiffness like composites tend to fail in the gripping areas due to stress concentrations caused by system applying the load.

Direct compression experiments have been previously reported in literature. For example, Soutis [2] and Clarke [3] made use of direct compression to measure the strength and strain to failure of carbon fibre pultruded rods. Both studies reported that failure would sometimes take place in the vicinity of the loading endcaps, due to stress concentrations. In addition, sample preparation was costly and time consuming, and the system would be highly sensitive to the final alignment of the assembly.

  doi:10.5075/epfl-298799_978-2-9701614-0-0

An alternative method to introduce compression in a specimen is via bending. In a beam subjected to bending, one side would be in tension while the opposite side would be loaded in compression. This approach has been used in composite laminates and sandwich beams [5]. In this work, we extend that approach to design a novel four-point bending test to conduct compression tests in pultruded rods that can provide with consistent failure within the gauge section.

2. Experiment design

2.1 Material and specimen concept

The concept is shown in Figure 1a. It consists of a pultruded rod glued on top a channelled beam under bending. The beam is loaded symmetrically in four-point bending mode with a total force P. The span length is L and distance between loading pins of D (Figure 1b). The rod will be loaded in compression due to bending of the assembly, while the bottom side of the beam will be in tension. The beam also has a through thickness cut to allow direct view of the composite pultruded rod.

The material considered for this design exercise was a 0.8mm diameter carbon fibre pultruded rod, commercially available from Easy Composites (Easy Composites Ltd, UK). The beam was made of Poly (methyl methacrylate) (PMMA).

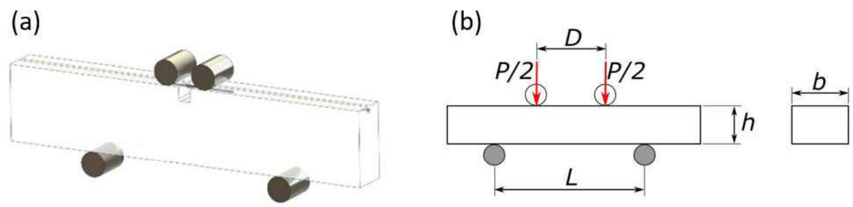


Figure 1. Beam: a) Concept; b) Geometric parameters.

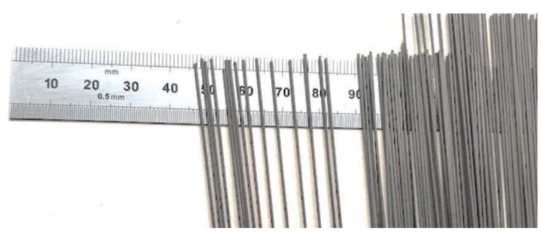


Figure 2. CFRP Pultruded rods used in the study.

2.2 Design criteria

The following 6 design criteria/guidelines were followed for the design of the experiment.

a. Beam theory

From beam theory, a beam under symmetric four-point bending will have a maximum flexural stress σ_f of:

$$\sigma_f = \frac{PL}{2bh^2}\left(1-\frac{D}{L}\right) \qquad (1)$$

Keeping the total load P constant, a smaller ratio $\frac{D}{L}$ will be required to obtain a higher maximum flexural stress. A ratio D/L=1/4 was chosen for this design exercise.

b. Buckling of rod free length

The exposed free length of the pultruded rod is at risk of buckling as it can be considered a slender structure. Analytically, the critical length for Eulerian buckling was calculated to be 7.4 mm, for the extreme case of pinned ends. A free length of 5mm was selected.

c. Total load

The total load *P* required to introduce a compressive stress in the pultruded rod high enough to trigger compressive failure, should be within the limits of available testing equipment.

d. Beam structural integrity

The beam material should not fail in tension or compression before the pultruded rod has reached a stress equal to its compressive strength.

e. Bending percent in the rod

Under direct compression of a rectangular laminate specimen, the standard ASTM D6641 recommends the use of 2 strain gauges. Even though the specimens do not buckle, opposite sides of the coupons will exhibit different strains due to a certain degree of bending. The strain measured with the two strain gauges ε_1 and ε_2 define the bending percent B_y as in Eq. (2). According to the standard, the bending percent is acceptable when it is under 10%.

$$B_y = \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + \varepsilon_2} \times 100\% \quad (2)$$

Similarly, in our proposed experiment, the strains in opposite ends of the specimen will not be the same. Fig. 3 shows the detail of the exposed free length of the pultruded rod. Following the definition of bending percent, the strain ε_1 was measured in the "orange" dot, while ε_2 was measured in the "green" point, in the axial direction in both cases.

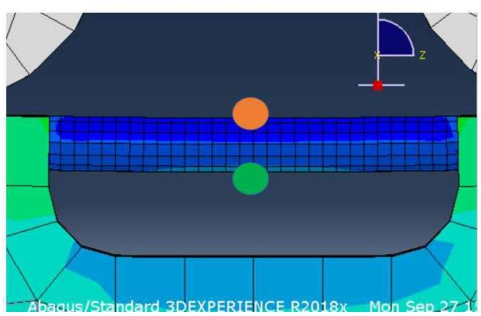


Figure 3. Detail of the exposed free length of the pultruded rod. The "orange" side will be at a higher compressive strain than the "green side"

f. Maximum stresses in rod

The final design should yield a maximum stress within the gauge length of the pultruded rod.

Criteria *c, d, e,* and *f* were verified via the virtual experiment described in the next section.

2.4 Geometry optimisation and virtual experiment

A virtual experiment (see Fig. 4) was setup using Abaqus 2017 (Dassault Systèmes Simulia Corp, USA). The rods and beam were meshed with linear brick solid elements C3D8R. The behaviour of the composite pultruded rod and the beam were assumed linear elastic. The loading pins and roller supports were modelled as rigid parts. The material properties assigned to all parts in the FE model are summarised in Table 1.

Table 1: Material properties used for the PMMA beam and the CFRP rod within the FE model.

	$E, E_{11}(GPa)$	$E_{22}(GPa)$	$\nu\ (\nu_{12})$	$G_{12}(GPa)$	$G_{23}(GPa)$
PMMA	3.2		0.33		
CFRP	174	8.34	0.31	4.55	2.6
Loading pins/ Roller supports	Rigid				

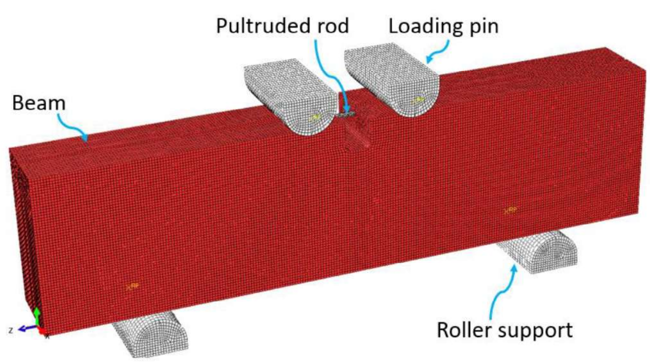


Figure 4. Meshed model of the experiment.

The geometry of the beam was optimised to minimise the bend percent on the pultruded rod specimen defined in Eq. 2. A manual iteration of the various geometric parameters h, D, L was conducted to ensure that the resulting B_y is within the acceptable range. The results of the various values of bending percent for 3 different combinations of geometric parameters, with the rod loaded at the same compressive stress of 1.2 GPa are shown in Table 2.

Table 2: Iteration of geometric parameters.

Iteration	$h\ (mm)$	$D\ (mm)$	$L\ (mm)$	$B_y(\%)$
1	20	20	60	10.8
2	20	20	80	11.1
3	30	20	80	3.0

The values of $h = 30mm, D = 20mm, L = 80mm$ was chosen for the final design. For that case, the axial stresses along 40 mm of the central section of the pultruded rod (Fig. 5a) is displayed in Fig. 5b. It is observed that the higher stresses are within the gauge section. The simulation results also showed strains under 2% in the PMMA beam, ensuring that it will not fail during the test.

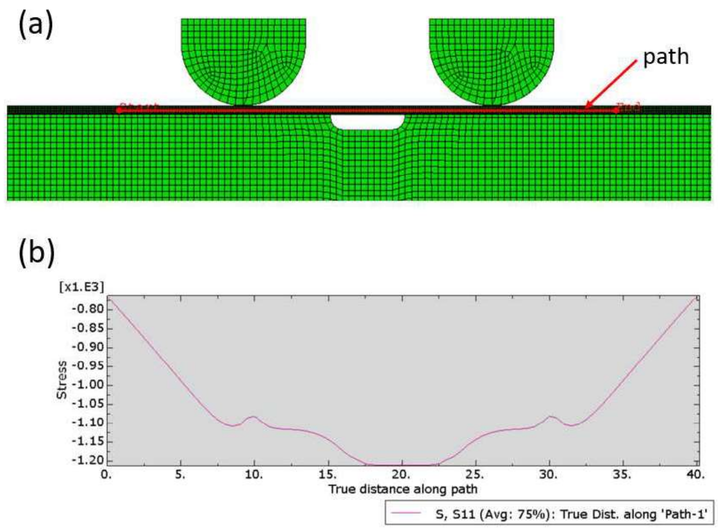


Figure 5. Axial stress along the centreline of the rod: a) Centreline path, b) Axial stress along path.

3. Experimental

The experiment was conducted in quasi-static regime in the servo-hydraulic machine Instron 8872. The load was acquired with a 25 kN load cell. The pultruded rod was prepared with black speckle over a white background to obtain the history of strains via digital image correlation.

Fig. 6 shows a snapshot of the free length of the pultruded rod specimen, right after fracture. The fracture took place within the gauge length suggesting that the design process successfully minimised stress concentration at the ends.

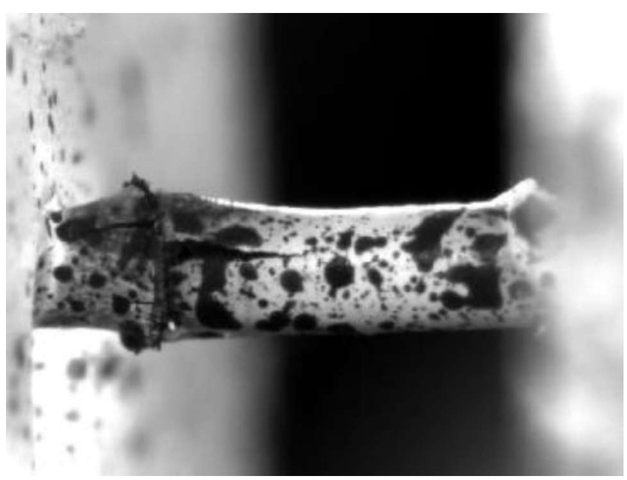


Figure 6. Compressive failure of the pultruded rod.

4. Conclusions and future work

The proposed methodology provides with compression fracture within the gauge length and stands as an advantageous alternative to direct compression due to the simpler specimen preparation, and the reduction of stress concentrations. The method will be used for a complete series of specimens of various composite rod systems obtained by pultrusion.

Acknowledgements

The authors would like to acknowledge the funding provided by UK Engineering and Physical Sciences Research Council (EPSRC) programme Grant EP/T011653/1 NextCOMP, Next Generation Fibre-Reinforced Composites: a Full Scale Redesign for Compression.

5. References

1. Fleck, N.A. 1997. “Compressive Failure of Fiber Composites.” In Advances in Applied Mechanics, 33:43–117.
2. Soutis, C. 2000. “Compression Testing of Pultruded Carbon Fibre-Epoxy Cylindrical Rods.” Journal of Materials Science 34: 3441–46.
3. Clarke, A. B. 1998. “Mechanical Properties and Process Conversion of a Novel Form of Unidirectional Carbon Fibre/Epoxy Rod.” University of Bristol.
4. Thomson, D., Quino G., Cui H., Pellegrino A., Erice B., and Petrinic N.. 2020. “Strain-Rate and off-Axis Loading Effects on the Fibre Compression Strength of CFRP Laminates: Experiments and Constitutive Modelling.” Composites Science and Technology 195 (July): 108210.
5. ASTM. 2002. “Standard Test Method for Compressive Properties of Unidirectional Polymer Matrix Composite Materials Using a Sandwich Beam.” Annual Book of ASTM Standards 08 (Reapproved): 1–9.

  doi:10.5075/epfl-298799_978-2-9701614-0-0