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Editorial

This collection contains the proceedings of the 21st European Conference on Composite Materials (ECCM21), held in Nantes, France, July 2-5, 2024. ECCM21 is the 21st in a series of conferences organized every two years by the members of the European Society of Composite Materials (ESCM). As some of the papers in this collection show, this conference reaches far beyond the borders of Europe.

The ECCM21 conference was organized by the Nantes Université and the Ecole Centrale de Nantes, with the support of the Research Institute in Civil and Mechanical Engineering (GeM).

Nantes, the birthplace of the novelist Jules Verne, is at the heart of this edition, as are the imagination and vision that accompany the development of composite materials. They are embodied in the work of numerous participants from the academic world, but also of the many industrialists who are making a major contribution to the development of composite materials. Industry is well represented, reflecting the strong presence of composites in many application areas.

With a total of 1,064 oral and poster presentations and over 1,300 participants, the 4-day event enabled fruitful exchanges on all aspects of composites. The topics that traditionally attracted the most contributions were fracture and damage, multiscale modeling, durability, aging, process modeling and simulation and additive manufacturing.

However, the issues of energy and environmental transition, and more generally the sustainability of composite solutions, logically appear in this issue as important contextual elements guiding the work being carried out. This includes bio-sourced composites, material recycling and reuse of parts, the environmental impact of solutions, etc.

We appreciated the high level of research presented at the conference and the quality of the submissions, some of which are included in this collection. We hope that all those interested in the progress of European composites research in 2024 will find in this publication sources of inspiration and answers to their questions.

Each volume gathers contributions on specific topics:

- **Vol 1. Industrial applications**
- **Vol 2. Material science**
- **Vol 3. Material and Structural Behavior – Simulation & Testing**
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IMPROVEMENTS ON THE “CRADLE TEST” FOR THE MECHANICAL CHARACTERISATION OF PULTRUDED RODS UNDER COMPRESSION

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Abstract

One morphological factor limiting the compression potential of continuous fibre composites is the misalignment of fibres. Pultrusion constitutes a manufacturing method that can produce better fibre alignment, therefore improving compression strength. The mechanical characterisation in compression of these materials is challenging when using traditional methods. In this work, we revisit the “cradle test”, which has previously demonstrated its effectiveness to measure the compression failure strain of pultruded composite rods. One of the main drawbacks of the experiment was the lack of a method to evaluate the force acting upon the rod, the missing element required to obtain the full strain *vs.* stress response of the material. This paper addresses this challenge by proposing two novel solutions.

1. Introduction

While continuous carbon fibre reinforced polymers display an excellent performance under tension, their compressive strength is only in the order of 50-60% their tensile strength. In fact, compression is arguably one of the most complex failure mechanisms observed in composites [1]. One of the reasons behind the limited compression performance is fibre misalignment. Misaligned fibres facilitate kink band formation at lower global stress levels, explaining the reduced strength in compression. The pultrusion manufacturing method has proved its efficacy at improving fibre misalignment [2]. The tension exerted on the yarns during pultrusion leads to improvement in the alignment of individual fibres in the resulting composite rod.

The characterisation of the compression performance of these pultruded rods with traditional methods such as direct compression has some limitations. For instance, stress concentrations arise from the gripping process and the application of endcaps. When combined with the inherent anisotropy of fibre composites, these factors contribute to premature failure in the gripping region, hindering the accurate measurement of the material's true compression limit. Another limitation of direct compression testing is the complexity of the specimen preparation and its sensitivity to misalignments of the specimen’s assembly [2].

In a previous study, the authors introduced a novel experimental methodology, the “cradle test”, where the compression (top) side of a beam under four-point bending was employed to gradually introduce the desired compression loading condition onto a carbon fibre/epoxy pultruded rod [3]. Specialised optical instrumentation was employed to capture sequential macro images of the pultruded rod up to fracture. These images were used to measure the history of strains via digital image correlation. The newly introduced experiment proved to achieve compression failure within the gauge length and to measure consistent strains to failure. In this work, we present improvements on the test design and data reduction process, that include various strategies to calculate the load acting upon the specimen. This would give the full strain-stress response of any material tested following this novel methodology.

2. The cradle test

2.1. Methodology

The test consists of a PMMA beam that “cradles” a pultruded composite rod specimen, which is glued in a channel on the top side of the beam. A schematic of the specimen is shown in Figure 1. When loaded in four-point bending with a total force *P*, the pultruded rod becomes compressed. A notch in the beam makes it possible to image the deforming rod, previously coated with a speckle pattern. The images are then postprocessed via Digital Image Correlation (DIC) to obtain the strain history. In this way, not only can the strain to failure be measured, but also the failure mode is assessed by observing the fractured specimen. Further details on the test were introduced in [3].

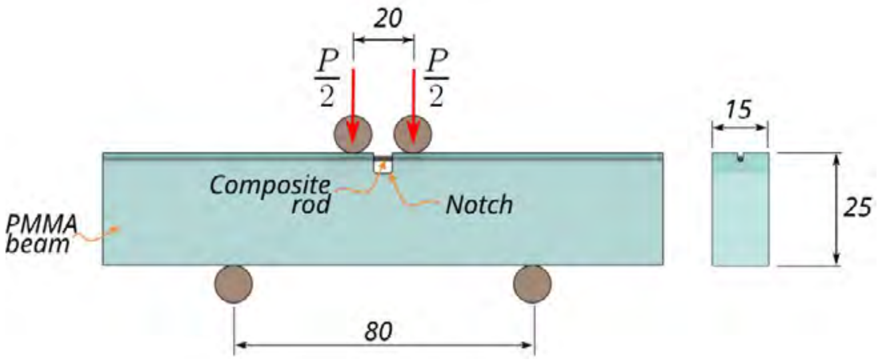

Figure 1. Schematic of the specimen. Dimmensions in mm.

2.2. Preliminary results

We conducted experiments using pultruded rods made of carbon fibre/epoxy, commercially available from Easy Composites (EC). The volume fraction, obtained from micrographic images, was approximately 45%. Figure 2 shows the strain history obtained from DIC in one representative experiment. The failure strain is taken from the frame just prior to fracture. The image at fracture indicates that the method successfully produced compression failure.

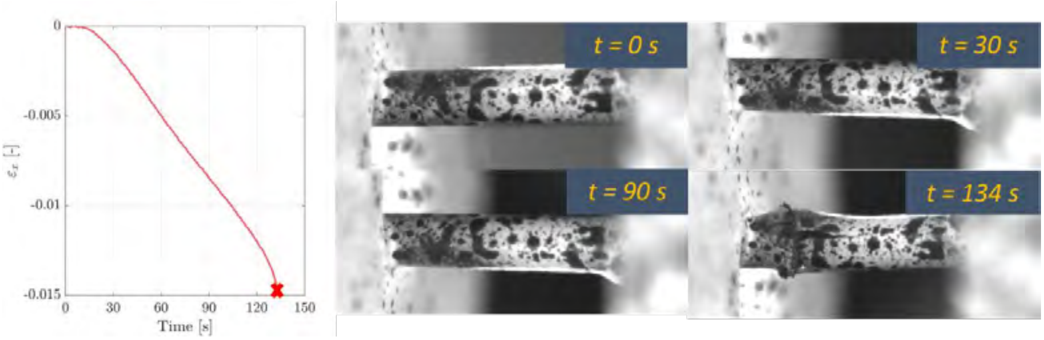

Figure 2. Strain history during the experiment and snapshots showing compression failure.

Table 1 shows the average failure strain recorded in the experiments with EC material system compared against other results previously reported in existing literature [2], [4]. The strains to failure measured with the cradle test are higher than those from the literature, suggesting that the cradle test attains a measurement closer to the absolute compression performance of the composite.

Table 1. Results obtain by the cradle test on EC material *vs*. other studies [3].

Material system	*Failure Strength* (MPa)	*Failure strain* (%)	*Stiffness* (GPa)
T300/828 [2]	1136 ± 84	0.929 ± 0.063	131 ± 7.5
IM7/828 [2]	1568 ± 75	1.127 ± 0.059	186 ± 5.9
T800/924C [4]	-	1.04	-
EC (current study)	-	1.42 ± 0.2	-

3. Improved concepts

While the strain to failure is measurable using the first version of the cradle test, the main limitation is that the full material response *i.e.* strain *vs.* stress cannot be identified with the version of the test shown above. This was the motivation for the work herein presented. Two distinct improvements are introduced below.

3.1. Modified notch

Under the assumption of the magnitude of the force across the beam vertical midplane being sufficiently similar to that of the force across the pultruded rod, we can integrate the stress field over the midplane to evaluate the force acting on the beam. This should be close to the force acting on the pultruded rod provided that horizontal forces developed at the loading and support positions remain small. The stress field can be evaluated by combining DIC surface measurements and plane stress assumptions. With this approach, the original design yields a highly non-linear profile of stresses along the mid plane, mainly because of the influence of the stress concentration (Figure 3b). The stress concentration effects combined with the inaccuracy of the DIC due to edge effects, affect the sensitivity to errors and noise of this approach. The updated version, moves the notch corners further away from the mid plane (Figure 3a), improving the linearity in the mid plane stress profile and reducing sensitivity to 'noisy' DIC measurements near the edges. In Figure 3b, the results from finite element method show that the non-linearity of the stress distribution near the notch is reduced with the new design.

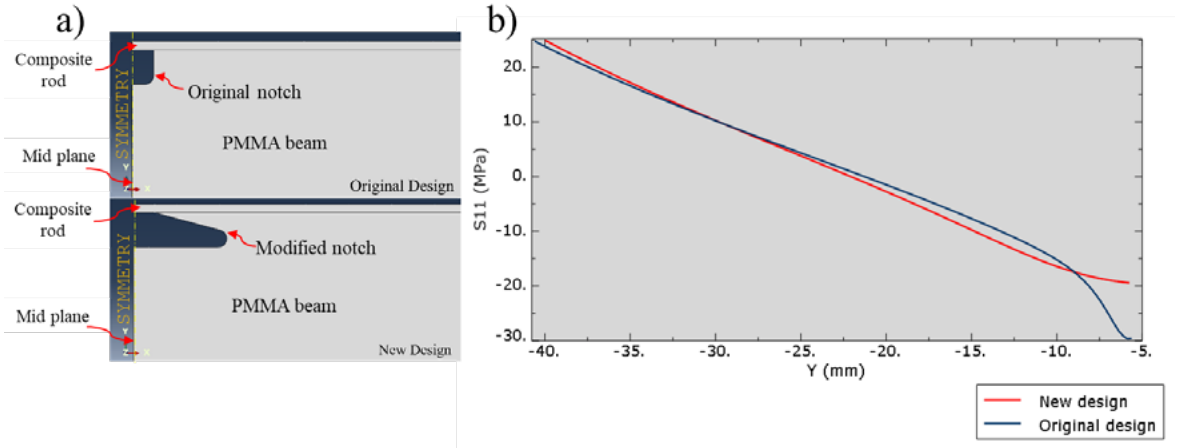

Figure 3. Modified notch: a) Schematic of the original and the new design b) FEM result of the stress distribution on the midplane of both designs.

3.2.a Double notched beam

This concept considers a PMMA beam with top and bottom notches as well as a metal sheet glued at the bottom to be used as load cell. The geometry was designed such that the horizontal component of the resultant force across the beam midplane is sufficiently small such that the load acting on the metal sheet is similar to the load acting upon the rod. The metallic sheet on the tension side would be instrumented with strain gauges to be used as a load cell. Results from finite element simulations (Figure 4b) showed that the free body forces (forces across sections) for both composite rod and metal sheet were 892 N and 887 N, respectively. The discrepancy in forces is less than 0.67%, therefore negligible. This validates the concept of using a metal sheet to measure the load on the composite rod.

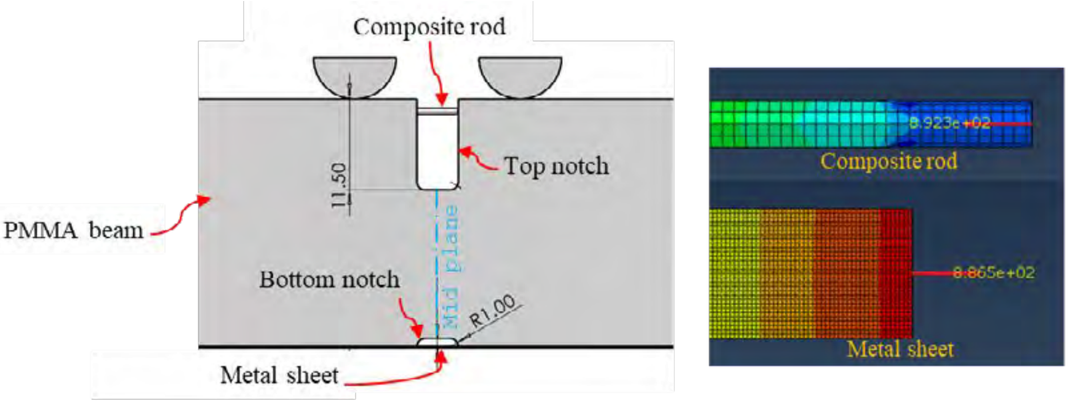

Figure 4. Double notched beam: a) Schematic of the new design. b) FEM results of the free body forces acting on the rod(top) and metallic plate(bottom)

4. Conclusions

In this paper we summarised the methodology for the “cradle test”, used to characterise the compression performance of composite pultruded rods. Among the main limitations of the experiment, we highlighted the lack of a direct method to measure the force acting on the composite rod. We proposed two different solutions to overcome this challenge. The first one is simply by modifying the geometry of the notch and then utilising the existing optical full field strain measurement methods (e.g. DIC). The second approach, requires the machining of two notches in the beam and a metal sheet (on the underside) acting as a load cell. Both methods have been validated by numerical simulations. The next steps include the manufacturing and testing of the proposed concepts.

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