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Xiaofei Song, Federica Daghia, Christophe Cluzel, Yannick Elie. INFLUENCE OF BOUNDARY CONDITIONS ON THE FAILURE BEHAVIOR OF T-JOINT-SHAPED OVERMOLDED COMPOSITE STRUCTURE. 21st European Conference on Composite Materials, Jul 2024, Nantes, France. 10.60691/yj56-np80 . hal-04670208

HAL Id: hal-04670208

<https://hal.science/hal-04670208v1>

Submitted on 11 Aug 2024

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INFLUENCE OF BOUNDARY CONDITIONS ON THE FAILURE BEHAVIOR OF T JOINT SHAPE OVERMOLDED COMPOSITE STRUCTURE

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Keywords: overmolding, failure, tensile test, isostatic setup, boundary condition

Abstract

CETIM has introduced a novel composite manufacturing technique known as the Quilted Stratum Process (QSP). This method involves thermoforming thermoplastic composite components using long fiber laminate sheets made of different composite patches, followed by the overmolding of structural elements using injection molding reinforced with short fibers. In general, to characterize the interface between the long fiber and short fiber zones, tensile tests are performed for the T-joint-shaped structures made by this process. Nevertheless, the behavior depends on the precision of the imposed boundary conditions. In this work, an isostatic setup was used to study the influence of the boundary conditions on the performance of the T joint structures.

1. Introduction

Overmolding is a widely adopted manufacturing technique in multiple industries in which a material, typically a thermoplastic, is molded over a pre-existing substrate. An essential point of attention in the design of the parts is the behavior of the interface between the substrate and the overmolding, where delamination is more likely to occur. The study of the adhesion between the composite laminate and the overmolding material has consistently been a focal point, spanning various material scenarios, for example thermoplastic overmolding on thermoplastic substrate [1][2], or thermoplastic overmolding on metal substrate [3].

For the structure that is considered, both the laminate and the overmold are made of Carbon-Polyetherketoneketone (C-PEKK). More specifically, the laminate substrate consists of long-fiber woven plies while the overmolding part contains short fibers only. This work is a continuation of previous studies, which involved numerical simulations by means of a cohesive zone model [4] and delamination characterization tests [5], with the aim of parametric identification and approach validation.

Tensile tests on T joints are commonly performed to evaluate the mechanical behavior of these structures. However, during a tensile test, the lower part (laminate) can be subjected to an uncontrolled state of bending largely depending on the accuracy of the imposed boundary conditions. Moreover, misalignment in loading conditions can lead to unforeseen fractures. First simulations show that extra bending needs to be added to be consistent with tensile test results conducted previously, which proves that boundary conditions can easily be inadequately controlled. Additionally, numerical results

demonstrate a significant decrease in failure load when the loading axis is misaligned. As a consequence, an isostatic setup is pertinent regarding the need for correct evaluation of the mechanical performance of the T joint shape structure.

In this work, a novel isostatic test setup is designed and tensile tests are carried out to investigate the influence of the boundary conditions, bending in particular, and the geometry of the joint on the behavior of this kind of structure. Two types of joints are studied: a simple T joint and a T joint with added chamfer. In terms of boundary conditions, the distance between the bending support and the edge of the joint is set to 1-5 mm to allow more or less bending in the laminate.

2. Materials and methods

2.1. The isostatic tensile test setup

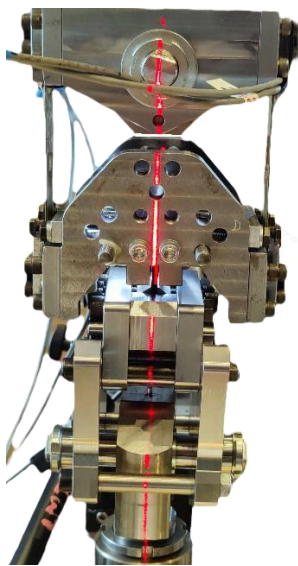


Figure 1. Isostatic setup

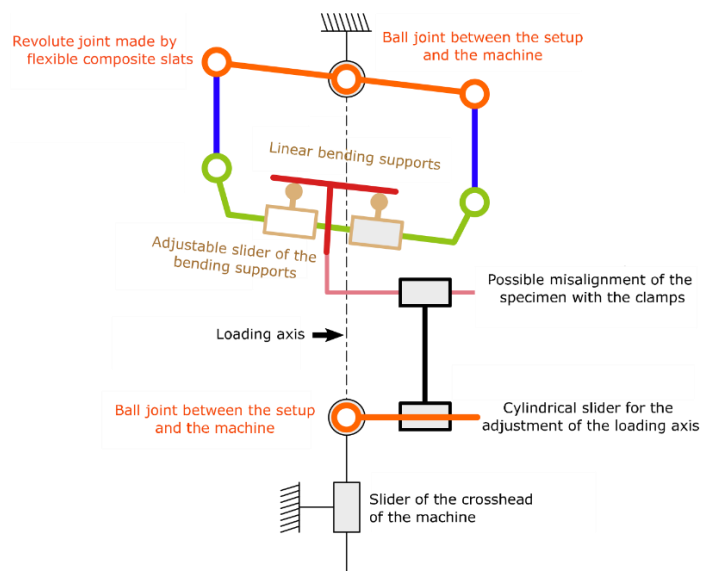


Figure 2. Kinematic diagram of the setup

The isostatic setup is shown in Figure 1 and Figure 2 presents its corresponding kinematic diagram. Compared to classical tensile test configurations, two rolling-element bearings are employed to form two ball joints instead of the rigid connections to the rest of the machine. Therefore, the setup becomes isostatic and the loading axes can be controlled without unintentionally adding extra moment. Strain gages were added on both sides of the composite slats to check if the setup is well balanced (left and right). A camera was used to extract the deformation of the specimen via Digital Image Correlation (DIC), since the crosshead displacement measured by the machine includes the deformation of the whole setup, notably the composite slats. The load measurement is carried out by the standard machine load cell.

2.2 Test configurations

In terms of specimens, two types of joints are studied: a straight T joint (Table 1 left (a)) and a T joint with added chamfer (Table 1 left (b)). The original T joint structure is shown in Figure 3. The length along the injection is approximately 42 mm. Two specimens, each with 20 mm width (Figure 4), were extracted from every T joint. To better guarantee the uniformity of the stress distribution of the interface, the leftover length of the laminate in the y direction (without the overmolded part) was removed.

Different boundary conditions were applied to study the influence of the bending of the laminate on the failure behavior of the structure. They are illustrated in Table 1 (right): one condition without bending

(b) and two conditions allowing more and less bending of the laminate (c1) (c5). As for condition (b), firstly, a plasma treatment was performed on the base laminate of the specimen in order to break chemical bonds to promote adhesion. Then, a piece of steel, approximately 13 mm thick, was affixed beneath the laminate using an epoxy glue. The conditions c_i ($i \in [1,5]$) indicate that the fixture is positioned i mm from the edge of the foot of the overmolded shape. It implies that the moment experienced by the joint edge remains the same for both the straight and the chamfer joints, while the lever arm to the plane of symmetry of the specimen is distinct.



Figure 3. Original T joint structure as produced, before recut



Figure 4. 20 mm-wide T joint used for testing, after recut

Table 1. Definition of variables for the tests on half of a specimen

Definition of joint shapes		Definition of boundary conditions	
<p>(Straight)</p>	<p>(Chamfer)</p>	<p>(b)</p>	<p>(c1)</p>
		<p>(c5)</p>	

3. Results

3.1 Cracking mechanisms

Prior to the testing, X ray CT scans showed the presence of voids in the laminate (Figure 5). These voids were in all probability induced by the thermoforming/overmolding process and were not originally present in the laminate preform. It implies that the part of the laminate that is located directly under the overmolding can be a weak zone. Various cracking mechanisms were observed in the laminate of all the specimens during testing and prior to ultimate failure. They can be classified into 2 categories (Figure 6):

- I. With boundary condition (b), formation of cracks in the laminate, close to the interface between the steel and the laminate, indicating a good adhesion on the interfaces of steel/laminate and laminate/overmolding. Potential weak zones exist inside the laminate.
- II. Development of cracks within the laminate, particularly close to the interface with the overmolded part, suggesting potential weak zones inside the laminate.

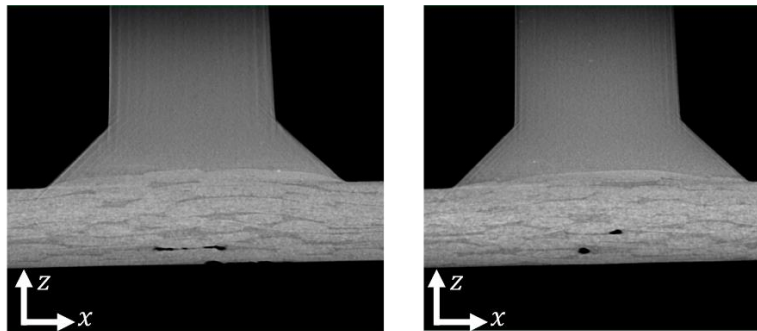
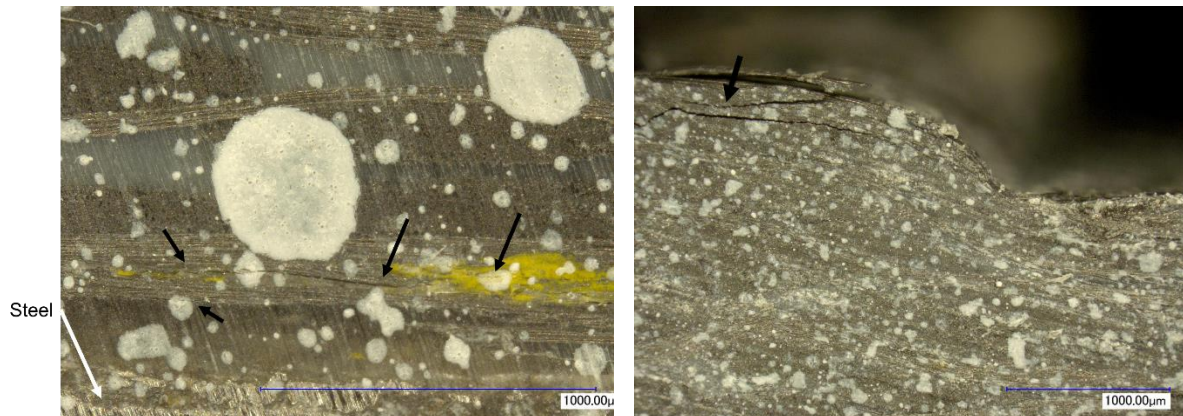


Figure 5. Voids in the laminate



(a) Type I observed in the laminate

(b) Type II observed close to the top of the laminate

Figure 6. Different cracking mechanisms

These crackings occurred during tests did not lead directly to the failure but rather contributed to the change of failure mechanisms. In particular, in the configuration without bending (b), once cracks were formed close to the steel/laminate interface, the laminate, or at least a part of it, could be subjected to bending, similar to other (ci)-type boundary conditions.

3.2 Scatter of the specimens

The X ray CT scans carried out on original T joints before recutting and the tests showed that the height at which the laminate material bulges in the stiffener shape varies (Figure 7), depending on the distance to the injection point. It was confirmed during testing: two specimens cut from the same T joints presented different behaviors. In addition, the temperature of the mold is unknown due to the continuous production of the T joints. Therefore, it is relatively probable that the specimens nominally identical (same position on the plate, same cut position from the original T joint) are not exactly the same.

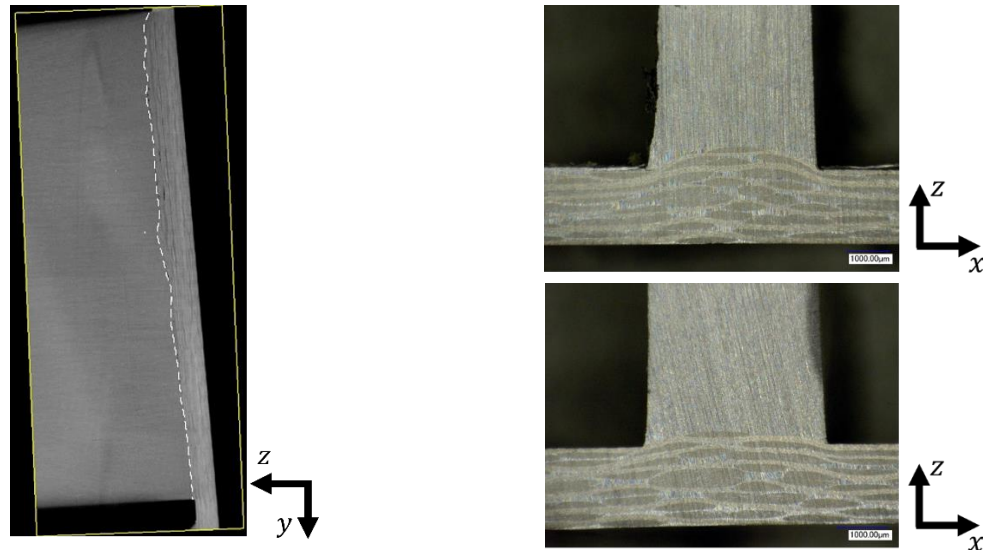


Figure 7. Variable height of the laminate/overmolded part interface along the injection length

3.3 Typical force vs. displacement curve

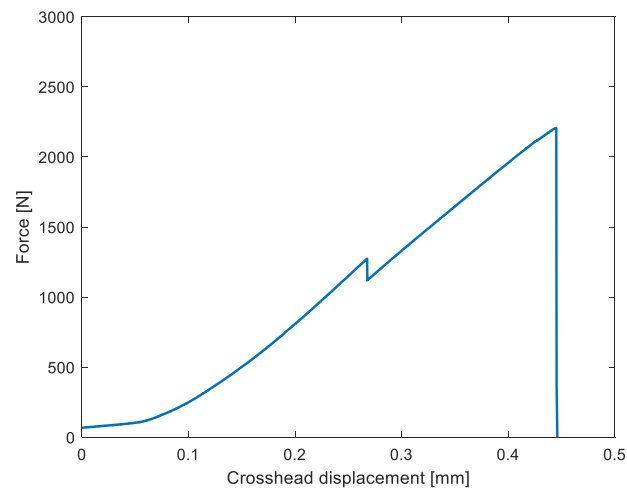


Figure 8. Typical force vs. displacement curve with load drop

Figure 8 illustrates a typical force vs. displacement curve with load drop within condition (b). According to the photos taken for DIC during testing, the load drop corresponds to the onset of the crack in the laminate. This phenomenon is not present in the (ci) type cases where bending is unconstrained. Concerning the displacement, DIC confirmed the deformation of the overmolded part is consistent with that of the simulation. In the next part, the results in terms of force will be compared with the simulations.

3.4 Comparison of Force per Unit Length (FUL)

In the numerical simulations, the interface between the laminate and the overmolding was represented by means of a cohesive zone model, but no crack in the laminate or bulging laminate geometry was simulated in the area under the overmolding. Since previous simulations were carried out with a 2D model, the maximum force (at ultimate failure) measured by the tensile test machine was converted to FUL by dividing it by the width of the T joint (in the y direction) to facilitate the comparison (Figures 9 and 10).

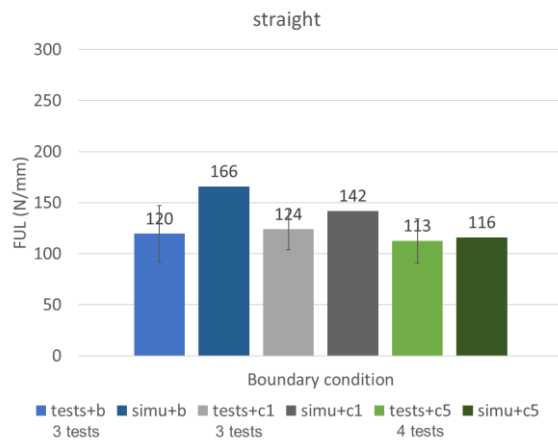


Figure 9. FUL of the straight joint

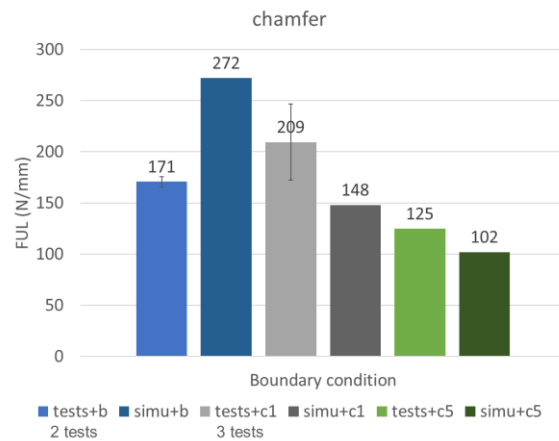


Figure 10. FUL of the chamfer joint

First of all, a significant difference can be observed between the simulations and the tests under condition (b). As was explained in Section 3.1, this is associated with the cracking in the laminate, which lead to a change of boundary condition. This phenomenon is also identifiable during the testing: a noise could be heard and a load drop appeared systematically at the same time. Moreover, the interface presents voids that were created during the injection process. The condition (b) forces the load transfer to go through the lower part of laminate that is potentially a weak zone, as was mentioned in Section 3.1, which could justify the low FUL compared to other configurations with bending. Secondly, the STD of the tests can be interpreted by the scatter of the specimens mentioned in Section 3.2. Longer cracks that did not result in failure are visible among the specimens with higher failure force. From the point of view of joint shape design, adding a chamfer does contribute to achieving a better performance. Nevertheless, it seems to be less efficient when more bending occurs.

4. Conclusions and perspectives

In this work, an isostatic setup was used to investigate the influence of boundary conditions on the behavior of T joints in tensile tests. The setup allowed to control the loading axis while not adding extra moment inadvertently. It was shown that by removing the bending, the performance of the structure was not as efficient as predicted by simulations due to cracking in the base laminate prior to final failure. The behavior of the specimen can be highly affected by its position along the injection length of the original T joint. Additional tests are underway to study the influence of the misalignment of the loading.

Acknowledgments

This work was motivated and supported by CETIM within CompInnov OpenLab.

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