NUMERICAL INVESTIGATION ON CRUCIFORM COMPOSITE SHAPE FOR THE BIAXIAL CHARACTERIZATION TEST

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Abstract

Composite materials are nowadays widely used in the industrial field. To mechanically characterize these materials, an in-plane biaxial test can be performed on cruciform specimen instead of using multiple classical tests. One of the major problems that limits the use of the biaxial test is the shape of the cruciform specimen. Depending on the mechanical behavior to characterize (elastic, hardening, yield criterion, limit strains…), very different specimen shapes have been proposed in the last few decades mainly for the study of metallic alloys. Results presented here lie within a more scope which is the rupture behavior characterization of composite materials subjected to complex loadings (linear and non-linear strain paths at different strain rates). The objective of this study is to define the dimensions of a constant thickness in-plane cross specimen made from glass fiber reinforced polymer (GFRP) plate. In this paper, three different shapes already presented in the literature are chosen and adapted to propose a new concept of composite specimen with aluminum tabs. The potential of these three specimens is evaluated by means of a numerical finite element investigation. The best specimen shape with the maximum stresses and strains in the central zone of the specimen is then selected.

1. Introduction

Due to their high specific mechanical properties, composite materials have been extensively used in engineering applications such as aerospace, automotive and civil structures. One of the most difficulties that make the study of composites not straightforward is that they exhibit a strong anisotropic mechanical behavior when they are subjected to complex loading conditions [1]. To accurately characterize the mechanical behavior of composite materials under such complex loadings, the in-plane biaxial test could be an interesting way in order to avoid conventional multiple uniaxial tests.

Some authors introduced different biaxial testing methods [2-4]. Biaxial tests can be classified into two main categories (i) tests using single loading systems (e.g. biaxial flexure testing, bulge test, off-axis test…) where the biaxial stress state depends on the specimen geometry or the loading fixture, and (ii) tests using two or multiple loading systems (e.g. tests on tubular specimen, in-plane biaxial on cruciform specimen…) where biaxial stress state is specified by the applied load magnitude.

According to different requirements (stress homogeneity, ability to cover a wide range of stress state...), the two most used methods are the tests on tubular specimens and the in-plane biaxial test on cruciform shapes.

Considering the biaxial test on a cruciform specimen, different studies were made to propose an optimized cruciform shape according to some requirements [5, 6]. One of these requirements is the stress concentration in the central zone of the specimen (i.e. failure in the gage section). Authors usually vary the form and reduce the thickness of the central zone of the specimen in order to achieve this requirement.

This paper is divided into two main parts. The first one is a numerical investigation in order to select an optimal cruciform specimen for the biaxial characterization. The specimen shapes are inspired from the literature. In this comparison, aluminum alloy AA5086 is used for the tabs and the composite is a GFRP plate. A thickness reduction is made in the aluminum tabs in order to have a stress concentration in the central zone. These tabs are glued on both sides of the composite plate. The idea of using aluminum tabs is to avoid the milling of the composites. The second part is a comparative study of the performance of two aluminum alloys AA5086 and AA2017 for the tabs using the optimal form found in the first part.

2. Numerical Investigation

From the literature, different shapes have been proposed for the biaxial tensile test. Most of these shapes consider a milling in the composites in order to reduce the thickness of the central zone. In this study, the cruciform specimen is composed of three main parts, two aluminum tabs (with a thickness reduction and hole in the center) placed on each side of the constant thickness composite GFRP. A finite element analysis using ABAQUS commercial software is made on three different shapes related to the literature in order to select the appropriate form.

2.1. Material Properties

Table 1 shows the in-plane glass/epoxy composite properties implemented in the numerical simulation of the in-plane biaxial test (out- of-plane properties are not considered). Considering the thickness, the composite plate is a four ply $[90/0]_s$ with a total constant thickness of 0.48 mm (ply thickness of 0.12 mm).

Table 1. GFRP Material Properties.

Material	E_1 (GPa)	E_2 (GPa)	G_{12} (GPa)	υ_{12}
GFRP	46	13	7	0.26

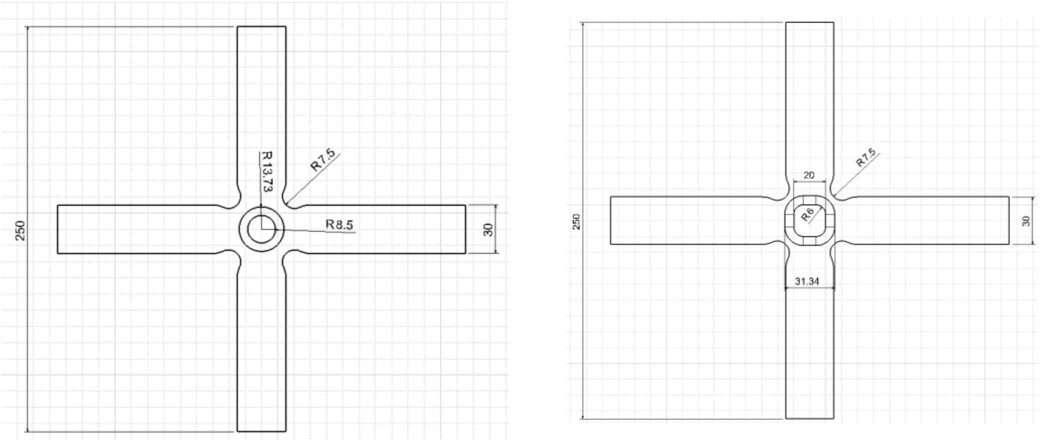
For the aluminum tabs, the two different aluminum alloys used in this paper are AA5086 and AA2017, both aluminum types are considered isotropic with the same Young modulus of $E = 70$ GPa and Poisson ratio $\upsilon = 0.3$. The thickness of the aluminum tabs is 3mm each. The difference between both types is the initial yield stress and the hardening curve. Table 2 shows the yield and ultimate stresses for both used aluminum alloys.

Table 2. Yield and ultimate stresses for aluminum alloy AA5086 and AA2017.

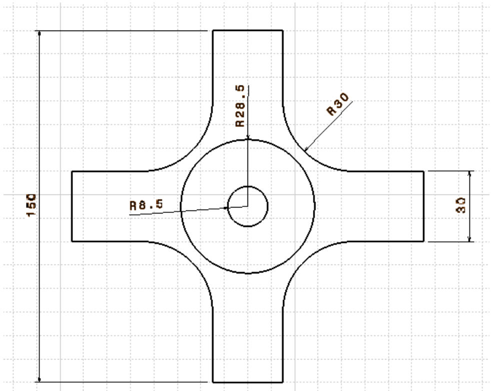
Aluminum	Yield Stress (MPa)	Ultimate Stress (MPa)
AA5086	126	400
AA2017	300	574

2.2. Specimen Shape

Three different shapes inspired from the literature were analyzed in this study. These three specimens have a thickness reduction in the central zone. The difference between these specimens is mainly the form of the gage section and the fillet between the arms (Figure 1). In figure 1, specimen A and specimen B have the same corner fillet between arms but different central form (Specimen A has a circular one while B has a square central zone). Specimen C has also a circular central zone but with a different fillet corner. In this comparison, only AA5086 is used for the tabs in order to compare the performance of the three specimens with the same material properties.

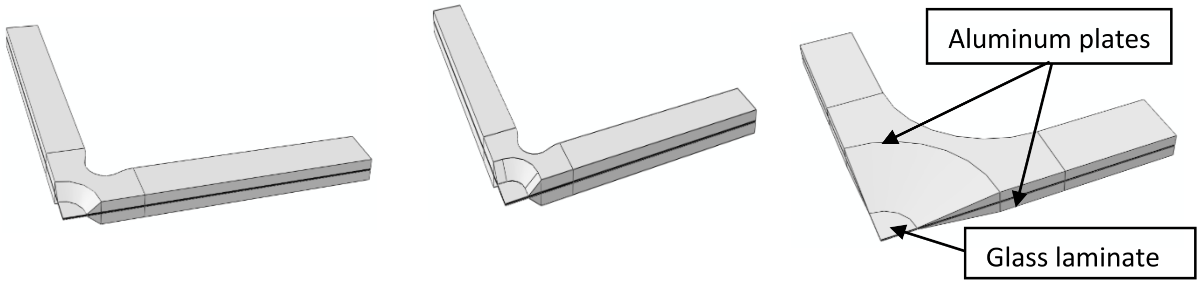


Specimen A Specimen B



Specimen C

Figure 1. Three different shapes proposed for the finite element analysis: Specimen A[5] (top left), B[7] (top right), C [8,9] (bottom).



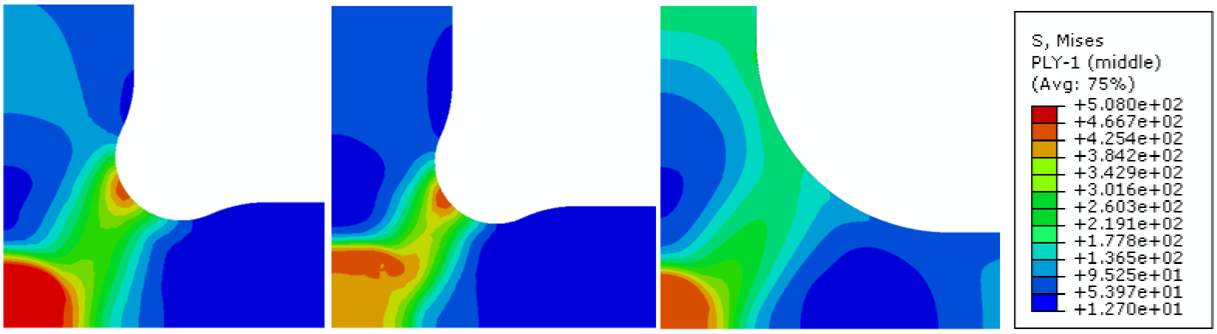
Specimen A Specimen B Specimen C

Figure 2. One-quarter of each specimen implemented for the finite element analysis.

3. Results and Discussion

The two key elements used in the comparison in order to find the optimal form are the Von Mises stresses and the equivalent elastic strains (Eq. 1). A displacement is applied on each arm of the specimen. A symmetry in both x and y directions is set as a boundary condition. A linear hexahedron C3D8R type mesh has been used for the calculation with a refined mesh in the central zone. Because of the symmetry, only one-quarter of the specimen is modeled (figure 2). All the results are shown for the 1st ply in the composite plate (for a stress level of 500 MPa). For the interface between the tabs and the composite plate, a tie constraint has been used. Figures 3 and 4 show the stress and the equivalent strain distribution for the three specimens, respectively. Regarding the central zone form, the circular zone shows a more homogeneous stress distribution compared to the square form. Moreover, the adapted corner fillet in both specimens A and B leads to a stress and strain concentration in the corner between the arms of the specimen while this concentration disappear in the smooth fillet of the specimen C. As a conclusion, this specimen has been chosen as the optimal one.

$$\varepsilon_{eq} = \frac{1}{\sqrt{2}(1+\upsilon)}\sqrt{(\varepsilon_1-\varepsilon_2)^2+(\varepsilon_1-\varepsilon_3)^2+(\varepsilon_2-\varepsilon_3)^2} \tag{1}$$



A B C

Figure 3. Stress distribution in the 1st ply of the three specimens.

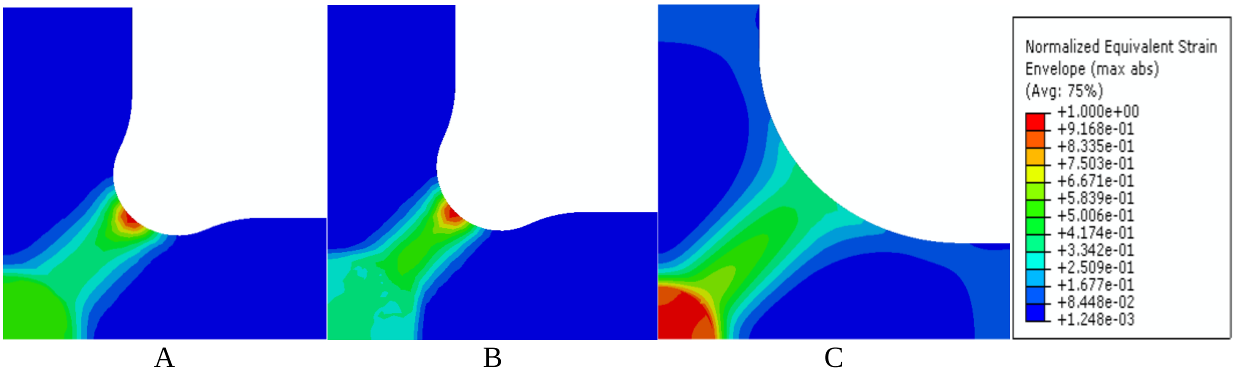


Figure 4. Equivalent strain distribution in the 1st ply of the three specimens.

Considering the aluminum tabs, a numerical study has been made on the specimen C using the two types of aluminum alloy as tabs. Figures 5 and 6 shows the stress and equivalent strain distribution in the 1st ply of the composite plate using both aluminum tabs AA5086 and AA2017. The results show a nearly similar distribution of both stress and equivalent strain.

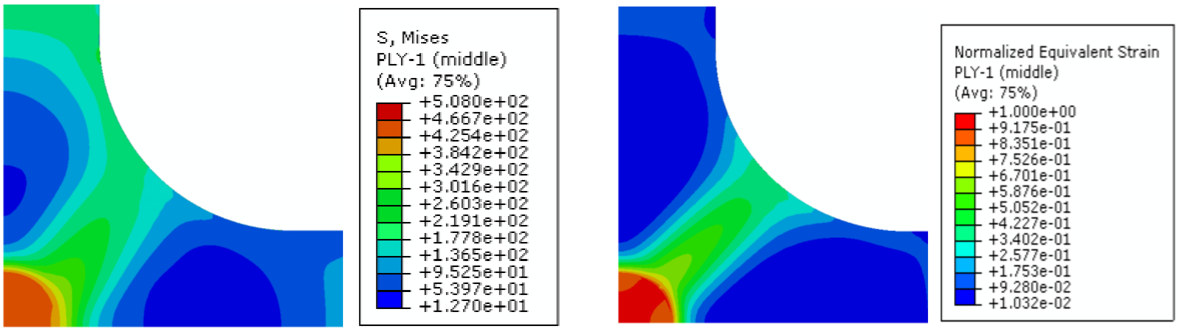


Figure 5. Stress and Normalized equivalent strain in the 1st ply of the specimen C using AA5086

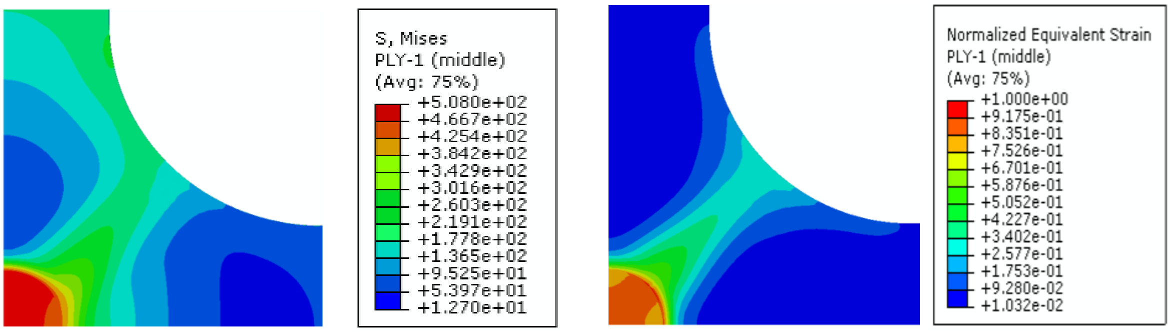


Figure 6. Stress and Normalized equivalent strain in the 1st ply of the specimen C using AA2017

For a clear view of the results, a linear path has been taken between two points on the specimen: point 1 which is the central point in the specimen and point 2 which is the point on the corner between the arms (Figure 7). Figure 8 shows the variation of both stress and equivalent strain on the linear path (the linear path is normalized between point 1 (0) and point 2 (1)). The results show that the highest stress appears in the central zone (nearly 470 MPa) compared to the lowest value in the corner (nearly 160 MPa), also a homogeneous stress state is observed in this central area. This figure shows the similarity of the variation of the normalized equivalent strain for both aluminum tabs.

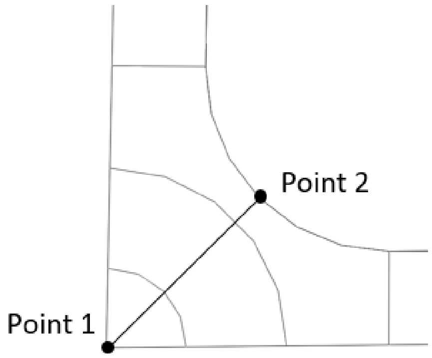


Figure 7. The linear path between points 1 and 2.

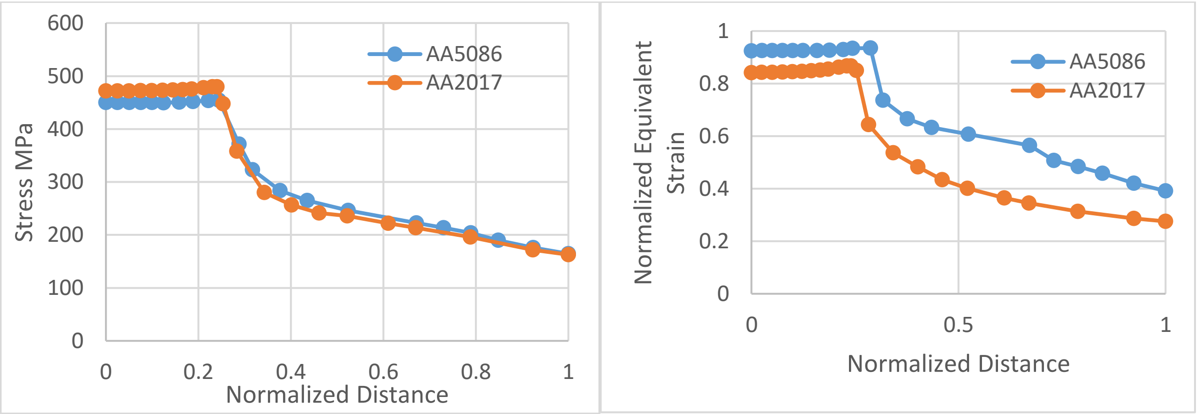
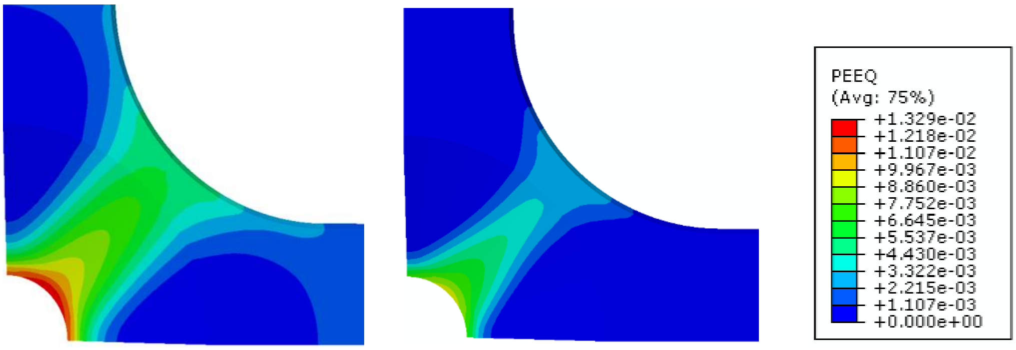


Figure 8. Variation of stress (left) and equivalent strain (right) with respect to the normalized distance between points 1 and 2.

Figure 9 shows the equivalent plastic strain distribution (PEEQ) for both grades of aluminum alloy. It is clear that AA2017, which has a higher initial yield stress, leads to very low plastic strains compared to AA5086. These differences in the maximum strain level reached by the two types of aluminium grades can lead to different behaviors of the adhesive joint (not modeled here) between the aluminium tabs and the composite plate. The higher plastic strains observed with the AA5086 tabs will lead to a higher shear stress in the adhesive joint which could induce a debonding of the tabs and the composite plate. Moreover, another important parameter to observe is the tensile forces required by the biaxial tensile machine. For a maximum stress of 500MPa in the specimen, AA2017 tabs and AA5086 tabs need respectively tensile forces of 53.5kN and 29kN in each direction for an equibiaxial test.



AA5086 AA2017

Figure 9. Equivalent plastic strain distribution in aluminum tabs.

4. Conclusion and Perspective

A finite element analysis has been successfully performed in this paper in order to select one biaxial specimen shape for the characterization of glass fiber reinforced composite using aluminum alloy as tabs. The specimen with the circular central zone and smooth corner fillet between the arms has been selected based on the stress and equivalent strain localizations observed in the central zone . Moreover, a comparison has been made between two aluminum types for the tabs. The comparison shows that AA2017 gives results similar to the one got using AA5086 for the stress and strain field distributions (with maximum values in the central zone) while the use of AA2017 tabs allows to avoid the high plastic strains which could lead to the debonding of the tabs and the composite. For the future work, a more realistic numerical study will be made by modeling the cohesive joint and an experimental validation of the proposed specimen will be performed.

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