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Anisotropic Stiffness Degradation in Biaxial Tensile Testing of SMC

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Biaxial tensile tests allow the investigation of damage evolution in sheet molding compound under biaxial stress states. This is of particular interest due to the different damage phenomena in composite materials. A key challenge is to find a suitable specimen design, because typical cruciform specimens fail in the arms before damage occurs in the area of interest which is the area of the biaxial stress state in the center area of the specimen. A specimen was found which enables the observation of anisotropic stiffness degradation which is one phenomenon of damage. In this proceedings the results of the experiments are presented.

1 Introduction

Sheet molding compound (SMC) as a discontinuous fiber reinforced composite combines high strength and stiffness and a low density with an economical production and is, thus, an ideal lightweight material. The detailed understanding of the mechanical behavior of SMC presents, however, a challenge to composite material science. The focus of the present work lies on biaxial tensile testing of SMC. Biaxial stress and strain states cover a wide range of application loads. The detailed characterization of damage also under multiaxial stress states, is indispensable for the understanding of the damage phenomena and serve to validate damage models. The cruciform specimen design is the basic prerequisite for suitable experiments. In the past many attempts have been made to find an appropriate specimen design. Several authors proposed specimen designs varying the cut type, the slits type and the reduced center area type [1]. ISO 16842 [2] provides a standardized cruciform specimen but applies only for sheet metals. For example [3] and [4] conducted research to find specimen shapes for fiber reinforced polymers. In [5] and [6] different specimen designs are investigated and compared with respect to different optimality criteria, where the most important criterion is the highest strain in the area of interest which is a measure for the likelyhood to observe damage in this area. The best performing specimen is reinforced by unidirectional carbon reinforced tapes on both sides of the arms. Details about the design and the manufacturing can be found in [5], [7] and [8]. The present work shows investigations with this specimen where anisotropic stiffness degradation is observable.

2 Material and experimental methods

The investigated material is sheet molding compound (SMC) with an unsaturated polyester polyurethane hybrid (UPPH) as matrix with 23 vol% glass fibers of 25 mm length. The experiments are performed by a biaxial testing device by Zwick which consits of four electro mechanical actuators that are arranged perpendicular to each other. Each actuator is independently controllable. A digital image correlation system by GOM, called ARAMIS 3D 4M, measures the strain field on the specimen. The testing procedure is based on a cyclic increase of uniaxial tension load in $\boldsymbol{e}_1$-direction. Between each loading step a constant uniaxial tension load in the $\boldsymbol{e}_2$-direction is aplied. This allows to measure the stiffness degradation in and perpendicular to the main loading direction. A schematic force time path of the testing procedure is shown in Figure 1. To evaluate the stiffness degradation there are two important measures. The area averaged strain over the area of interest A^{I}, the center area with the biaxial stress state, is defined by

$$\bar{\varepsilon}^{\mathrm{I}}_{ij} = \frac{1}{A^{\mathrm{I}}} \int_{A^{\mathrm{I}}} \varepsilon_{ij}\left(\boldsymbol{x}\right) \, \mathrm{d}A. \tag{1}$$

As the calculation of the stress is not straight forward, the force difference ΔF_i over the strain difference $\Delta\bar{\varepsilon}^{\mathrm{I}}_{(i)(i)}$ is taken as the measure for the stiffness s_i in $\boldsymbol{e}_i$-direction

$$s_i = \frac{\Delta F_i}{\Delta\bar{\varepsilon}^{\mathrm{I}}_{(i)(i)}}. \tag{2}$$

The values are taken at the beginning of each cycle after long waiting times to have the same conditions regarding viscoelastic effects (see violet marks in Figure 1).

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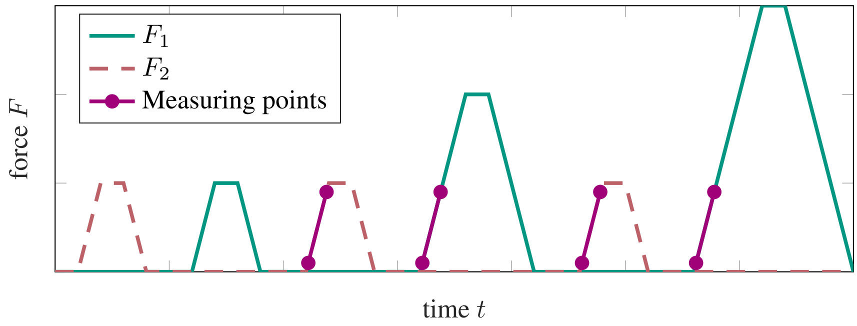

Fig. 1: Schematic force path for the experimental procedure

3 Results

Figure 2 shows the stiffness over the maximum reached strain $\bar{\varepsilon}_{11}^{\mathrm{I}}$ over the whole loading history (i.e., the maximum strain in the cycle before) until the instant of measurement. For comparability the values for the stiffness are normalized to the initial value. The anisotropic stiffness degradation is clearly visible. The stiffness in the main loading direction decreases to 0.9 % of the initial stiffness, the stiffness in non-loading direction to about 0.97 %.

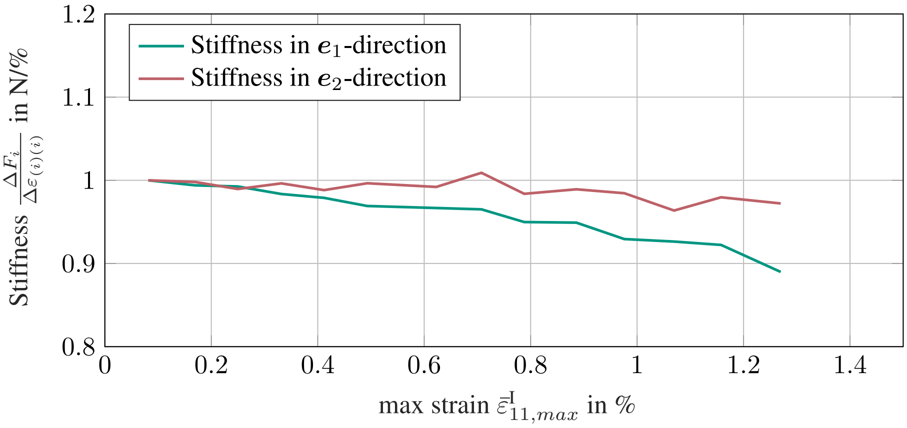

Fig. 2: Stiffness over the maximum reached strain in the area of interest

4 Conclusion

With the cruciform specimen for biaxial tensile testing developed in [5], anisotropic stiffness degradation as one phenomenon of anisotropic damage is observable. This result confirms the suitability of this specimen to identify anisotropic damage. To evaluate the stiffness degradation quantitatively in a statistically representative way a higher number of experiments will be performed.

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References

[1] Y. Ohtake, S. Rokugawa, and H. Masumoto, Key Eng. Mater. **164–165**, 151–154 (1999).
[2] International Organization for Standardization, ISO 16842 **ISO 16842** (2014).
[3] A. Smits, D. Van Hemelrijck, T. P. Philippidis, and A. Cardon, Compos. Sci. Technol. **66**, 7–8 (2006).
[4] M. C. Serna Moreno, J. L. Martínez Vicente, and J. J. López Cela, Compos. Struct **103**, 27–33 (2013).
[5] M. Schemmann, J. Lang, A. Helfrich, T. Seelig, and T. Böhlke, J. Compos. Sci. **2**, 12 (2018).
[6] J. Lang, M. Schemmann, T. Seelig, and T. Böhlke Proceedings 18th Conf. Exp. Mech. **2(8)**, 411 (2018).
[7] D. Bücheler, Ph.D. Thesis, Karlsruhe Institute of Technology (2017).
[8] M. Hohberg, L. Kärger, D. Bücheler, and F. Henning, Int. Polym. Process. **32,5**, 659–668 (2017).

