Bias-extension test of woven fabrics: an advanced analysis through X-ray microtomography and Digital Volume Correlation

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Abstract

Thanks to both their good specific mechanical properties and deformability, woven fabrics are widely used in fiber-reinforced composites and have attracted increasing attention in several industrial domains, including aeronautics, automotive, and sport. The processing routes of woven fabric-reinforced composites usually involve a draping stage during which woven fabrics are subjected to severe deformation mechanisms. Therefore, understanding the deformation of woven fabrics has been the subject of numerous studies. Within this context, the bias-extension test has been commonly used to characterize the mechanical response of woven fabrics (1), and more particularly their in-plane shear deformation response which is the predominant deformation mode. Usually, the in-plane shear response of fabrics is quantified in the central zone of stretched rectangular samples. However, because of their multiscale architectures, woven fabrics also exhibit complex macroscale deformation phenomena with shear strain localization with finite band-width between the central zones and its adjacent regions. Modelling these effects has led to the development of enriched theories such as second gradients theories (2). In addition, other important deformation mechanisms that occur during bias-extension tests, such as in-plane surface changes and out-of-plane deformations have been rarely studied.

Therefore, to better analyze the in-plane and out-of-plane deformation mechanisms of woven fabrics, a specially-designed setup was installed in a laboratory X-ray microtomograph (3) to perform a bias extension test on a twill sample made of basalt yarns. The obtained time series of 3D images were analyzed with a dedicated Digital Volume Correlation (DVC) procedure, enabling 3D kinematic fields to be obtained (4-5), as well as the measurements of relevant strain invariants (6) during the test. The results obtained in this study highlighted that the studied twill exhibited an important 3D consolidation that involved a coupling between

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a significant out-of-plane auxetic deformation which was compensated by a higher in-plane surface densification. In addition, smooth transition zones were observed between the central sheared zone and its adjacent regions. The width of the latter extended to 2-3 period lengths of the twill, highlighting the role of its mesostructure. By extracting some interesting gradients of the strain invariants from the 3D strain fields, this study also demonstrated that the combination of X-ray tomography and DVC could be an interesting experimental investigation method to build and validate macroscopic models with enriched kinematic fields.

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