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A thermo-viscoelastic approach for the characterization and modeling of the bending behavior of thermoplastic composites

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Abstract

Currently, there is no established and cost-effective method for the bending characterization of continuous fiber reinforced thermoplastic composites. Isothermal mechanical testing techniques are time and labor-intensive and deliver information only about distinct points of the temperature-dependent property curves. In this study, Dynamic Mechanical Analysis (DMA) as well as novel rheometer-based bending experiments were performed to assess temperature-dependent and viscoelastic behavior. On the basis of the experimental results a new method was defined and validated for the efficient characterization of temperature-dependent elastic bending behavior via DMA. Furthermore a linear viscoelastic material model was derived from DMA experiments by means of time-temperature superposition. As the material behavior proved to be of a highly viscoelastic nature, a method was developed to calibrate a material model, the parallel rheological framework, implemented in Abaqus.

Keywords: A. Thermoplastic resin, B. Thermomechanical, C. Finite element analysis (FEA), E. Forming

1. Introduction

The automotive industry is endeavoring to reduce the curb weights of the vehicles using lower density materials and employing lightweight design techniques to meet the stringent safety requirements while reducing emissions. A great number of non- and semi-structural components have already been replaced by lighter materials, mostly with light metals and unreinforced or fiber-reinforced plastics. Continuous fiber-reinforced plastics exhibit excellent mechanical properties and are capable of substituting metals in structural applications. The aerospace industry has been using these materials for decades, but the automotive segment is significantly more cost-sensitive [1]. Furthermore, international legislations require new vehicles to be recyclable to a given weight percentage. Thermoset resin systems do not possess a re-melting capability and are therefore difficult to recycle. Thermoplastic composites solve this problem and simultaneously offer relatively fast cycle times compared to thermoset systems, making them very interesting for the automotive industry. Since a trial and error based development is insufficient and costly, virtual prototyping is vital to enable their industrial implementation and cost-effective development. The thermoforming process along with several subversions is the most commonly used manufacturing technique to form continuous fiber-reinforced thermoplastic sheets into complex geometries. The thermoforming process is governed by the temperature change of the blank; the organic sheet is first heated above the matrix' melting temperature, then placed into the mold and formed with relatively low forces. While and after forming, the sheet rapidly loses heat due to radiation, convection and primarily heat transfer to the tempered molds. Eventually it consolidates and the part is ready for demolding. The changing temperature alters the mechanical properties during the forming process. Thus, as pointed out by preceding studies, thermal and mechanical analyses need to be fully coupled in the forming simulation of a thermoforming process [2, 3].

As shown in several studies [2, 4–6], the outcome of numerical simulations depends significantly on the mechanical properties taken into account, hence, properties need to be thoroughly characterized, along with their temperature and other dependencies.

Boisse et al. [4] studied the separated influence of tensile stiffnesses, in-plane shear and out-of-plane bending stiffnesses on the forming of a simple geometry and proved the importance of all three properties. The draping over double curved geometries requires in-plane shear deformations [2, 4] and as the shear stiffness increases with increasing shear angle, wrinkles start to form. The onset and development of wrinkle formation is a global phenomenon that depends on all of the stiffnesses of the material, however the size and shape of wrinkles is predominantly determined by the out-of-plane bending stiffness [2, 4, 5, 7–9]. Several studies [9, 10] have demonstrated the importance of bending stiffness in the simulation of a forming process. Since wrinkling is one of the most frequently occurring failures during draping, the problem needs to be addressed.

As pointed out, that material properties need to be understood and characterized in order to be able to conduct simulations with reasonable outcomes. The simulation scale and the material model determine the involved list of parameters. In a previ-

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