A Crystallization-Enhanced Thermo-mechanically Coupled Visco-hyperelastic-plastic Model for Thermoplastics Overmolding Processes

Tiansheng Liu*[1], Xiangfeng Li[1], Majd Tabib[1], Birte Boes[1], Martin Giersberg[2], Junhe Cui[3], Hakan Çelik[2], Michele Valsecchi[4], Sanat Kumar[4], Jacob Fish[3], and Jaan-Willem Simon*†[1]

[1]University of Wuppertal – Germany
[2]IKV - Institute for Plastics Processing in Industry and Craft at RWTH Aachen University – Germany
[3]Department of Civil Engineering Engineering Mechanics, Columbia University – United States
[4]Columbia University – United States

Abstract

The overmolding process, where thermoplastic compounds are joined with continuous fiber-reinforced thermoplastic tapes, is a critical technique in industries such as automotive, aerospace and energy. While widely adopted, this process often suffers from poor interfacial adhesion, leading to premature part failure, overdesign, and reliance on trial-and-error practices. The underlying challenges stem from the interplay of multiple spatial and temporal scales, as well as from the influence of diverse process-morphology interactions which remain poorly understood. Addressing these challenges requires advanced modeling approaches to predict and optimize the performance of thermoplastic materials in industrial applications. To this end, this study is part of an NSF-DFG collaborative project focusing on thermoplastic overmolding processes. The project aims to develop advanced material models to investigate and understand the process-dependent material morphology characterized by crystallinity, resulting mechanical performance and failure behavior of tape reinforced thermoplastic parts produced, thereby optimizing design reliability.

In the current work, we develop a material model for semi-crystalline thermoplastics based on the co-rotated intermediate configuration (CIC) theory which integrates elastoplastic and viscoelastic components to capture the time-dependent, nonlinear thermo-mechanical responses of the material. It features bidirectional thermal-displacement coupling to describe self-heating effects during deformation and unidirectional coupling of crystallinity to the displacement field. Using this model, we can predict the spatiotemporal evolution of the stress state, heat generation, and temperature of overmolded thermoplastic parts under different crystallinity, loading rates and thermal conditions, thereby establishing a clear cause-and-effect relationship between process control and interfacial bond strength. This approach aims to address key challenges in manufacturing, such as insufficient bonding strength and premature failure, while unlocking the potential of UD tape reinforcements to minimize material usage and emissions, promoting more sustainable and efficient engineering practices.

*Speaker

†Corresponding author: jsimon@uni-wuppertal.de