

# PROCESS SIMULATION OF COMPRESSION MOLDING OF PREPREG PLATELET MOLDING SYSTEMS

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## Introduction

Prepreg platelet molding systems are formed by cutting and slitting pre-impregnated carbon fiber tape using either a thermoplastic or thermosetting matrix into rectangular platelets of prescribed length and width. These platelets are then used as a molding compound in compression molding applications without addition of extra matrix material. In this way, complex geometries with large fiber volume fraction can be produced. In contrast to typical reinforced injection molding systems which possess two scales of interest, the part scale and the fiber scale, platelet molding systems possess three scales of interest: the part scale, the platelet scale, and the fiber scale. The platelet scale is typically significantly larger than the fiber scale and substantial compared to the part scale. Thus, existing methods for flow simulation which treat orientation state as a continuous and smooth field variable are inappropriate in parts containing thin sections in which only a small number of platelets occupy a given volume. In this work, we present a simulation method in which anisotropic viscosity and the smoothed particle hydrodynamics method are used to both account for the anisotropic behavior of platelet suspensions and the required spatial variation in orientation state. This method is applied to a pin bracket and compared to CT scanned orientation results.

## Constitutive Modeling

In this work, the platelet, though an orthotropic geometry, is modeled as a nearly incompressible transversely isotropic fluid following (1) where  $\eta_{23}$  is the transverse shearing viscosity of the fiber suspension comprising the platelet,  $R_\eta$  is the anisotropy ratio,  $R_\eta = \eta_{11}/\eta_{22}$ , which relates platelet scale effects and fiber scale effects [1],  $K$  is a penalizing bulk modulus required for explicit simulations,  $A$  and  $\mathbb{A}$  are the second and fourth order orientation tensors [2],  $D$  is the deviatoric part of the rate of deformation tensor, and  $F$  is the total deformation gradient. The anisotropy ratio has been found to be related to the platelet length to thickness ratio squared [1,3]. Orientation evolution of the fiber direction,  $p$ , and platelet normal direction,  $r$ , is performed using affine motion, (2) and (3), equivalent to Jeffery's equation with the shape factor set to 1 and  $-1$  respectively [4]. While the constitutive model, (1), does not require the platelet normal direction, it is a required output of the simulation for subsequent performance analyses [5].

$$\sigma = \text{dev}(2\eta_{23}\{D + 2(R_\eta - 1)\mathbb{A}:D\}) + K\{\det F - 1\}I \quad (1)$$

$$\dot{p} = W \cdot p + (D \cdot p - D:ppp) \leftrightarrow p = F \cdot p^0 / \|F \cdot p^0\| \quad (2)$$

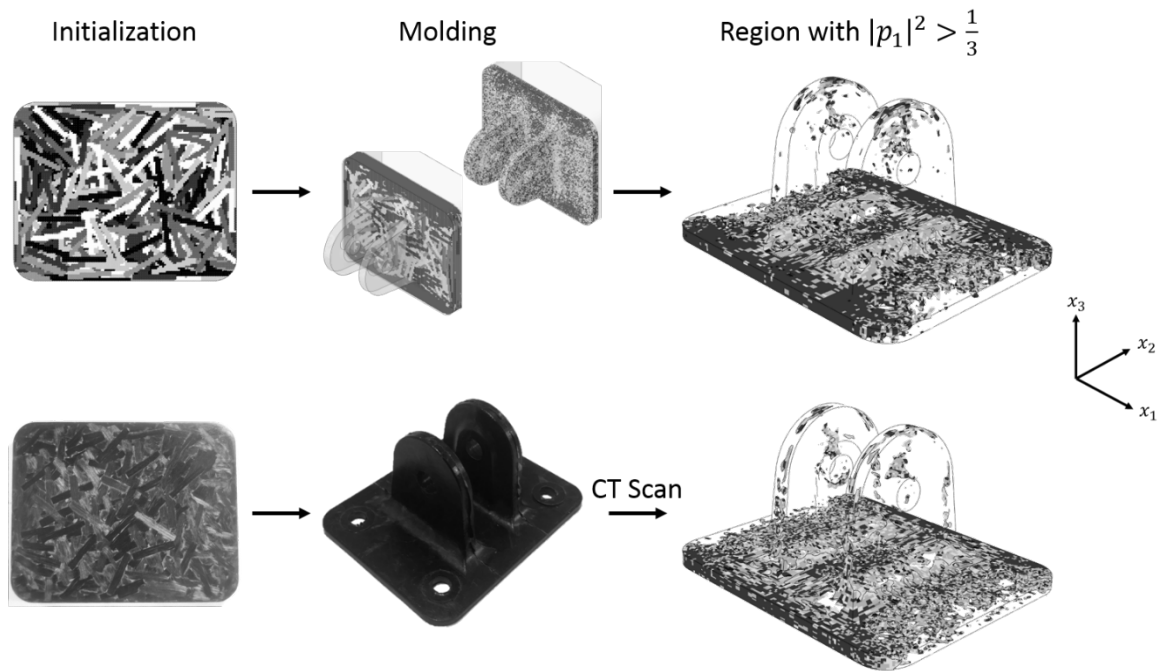
$$\dot{r} = W \cdot r - (D \cdot r - D:rrr) \leftrightarrow r = F^{-T} \cdot r^0 / \|F^{-T} \cdot r^0\| \quad (3)$$

## Finite Element Simulation Approach

The presented constitutive model is implemented in Abaqus/Explicit via the user subroutine VUMAT. In order to simulate the large deformations encountered in a flow simulation, the smoothed particle hydrodynamics (SPH) method is used. To capture the large nature of platelets as compared to parts, neighbouring sets of particles are initialized with similar orientation. The orientation for each group is generated from a uniform random in plane distribution (see Figure 1). The flow simulation is performed as isothermal with free slip boundary conditions as found to be appropriate for highly planar, highly anisotropic material [6].

## Results

We now present the results of simulating the compression molding of an example bracket compared to the results of CT scanning a physical part for the final orientation state. Benefitting from the large nature of platelets, CT scanning of an entire bracket and subsequent orientation analysis is performed [7,8]. In Figure 1, we show the process and results of the simulation procedure and experimental procedure where both the simulated orientation results and CT scan based orientation results have been mapped to an equivalent structural mesh. The results of the simulation is promising in that both the orientation state and spatial variability of orientation state are captured similarly to the physical part.



**Figure 1:** *Compression Molding (top: simulation, bottom: physical) and Comparison to CT Scan Measurement*

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## References

- [1] Favaloro AJ. Rheological Behavior and Manufacturing Simulation of Prepreg Platelet Molding Systems. Purdue University, 2017.
- [2] Advani SG, Tucker CL. The Use of Tensors to Describe and Predict Fiber Orientation in Short Fiber Composites. *J Rheol (N Y N Y)* 1987;31:751–84. doi:10.1122/1.549945.
- [3] Sommer DE. Constitutive modeling of the rheological behavior of platelet suspensions. Purdue University, 2016.
- [4] Jeffery GB. The Motion of Ellipsoidal Particles Immersed in a Viscous Fluid. *Proc R Soc A Math Phys Eng Sci* 1922;102:161–79. doi:10.1098/rspa.1922.0078.
- [5] Kravchenko SG. Failure Analysis in Platelet Molded Composite Systems. Purdue University, 2017.
- [6] Tucker CL. Flow regimes for fiber suspensions in narrow gaps. *J Nonnewton Fluid Mech* 1991;39:239–68. doi:10.1016/0377-0257(91)80017-E.
- [7] Denos BR, Kravchenko SG, Pipes RB. Progressive Failure Analysis in Platelet Based Composites Using CT-Measured Local Microstructure. *Int. SAMPE Tech. Conf.*, 2017, p. 1421–35.
- [8] Denos BR. Fiber Orientation Measurements in Platelet-Based Composites via Computed Tomography Analysis. Purdue University, 2017.