White Paper

Material Characterization & Qualification – Chopped
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Objective: Predict chopped composite properties based on effective particles and matrix material properties including material non-linearity and several manufacturing, geometrical and material defects. The predicted material model is validated against test.

Approach: A computational method (**Figure 1**) is introduced for the virtual simulation of performance of chopped fibers in polymer composites. The proposed methodology judiciously combines composites Nano, micro, and macro -mechanics formulation. This new approach did lead to the development of a specialized Multi-Scale Material Characterization of chopped fiber composite system comprising of: **a)** Eshelby and Mori Tanaka failure theory, **b)** micro-macro mechanics, and damage failure theory, **c)** orientation stiffness calculation; and **d)** optimizer as part of the durability analysis software GENOA. The micro and macro -mechanics are used in the Optimization process to "reverse engineer" the fiber orientation through thickness (de-homogenization approach), ply and matrix non-linear behavior, using flow, cross flow ASTM D638 coupon tensile (stress-strain) tests. Next a comparative analysis of the derived optimized orientation versus thickness distribution is determined. The validation is illustrated on three independent classes of chopped fibers composites including: **1)** Elastomer (Fiberglass + Neoprene; **2)** Thermoplastic (Fiberglass + Polypropylene, None + Poly Amide-6, and Fiberglass + PolyButylene Terephthelate); and **3)** Thermoset (Carbon + Urethane, and Carbon + Epoxy). MCQ-Chopped is designed to predict chopped composite properties based on effective particles (e.g., chopped fibers) and matrix material properties. It also includes: **1)** assumption of uniform orientation through the width and length of the representative volume element (flat coupon), **2)** particles that can be aligned, in-plane random, and completely random in orientation in three-dimensional space, **3)** particles can also be user specified based on test observation or output from analysis using other software packages (e.g., Moldflow, Moldex 3D, etc.,). MCQ-Chopped allows characterizing chopped fiber reinforced composite material properties as a function of several manufacturing, geometric, and material variables. Chopped fiber reinforced composite coupon test data in literature show lots of scatter mainly due to limited test and scatter in the manufacturing, geometric and material property variables. Material Uncertainty analysis allows estimating mean chopped fiber reinforced composite material properties for particles aligned, 2D random and 3D random situation in the matrix and for user specified orientations. MCQ-Chopped is capable of predicting chopped composite properties considering particle-matrix Interphase, uniform or non-uniform dispersion or particles, particle waviness, agglomeration and multiple types of particles.

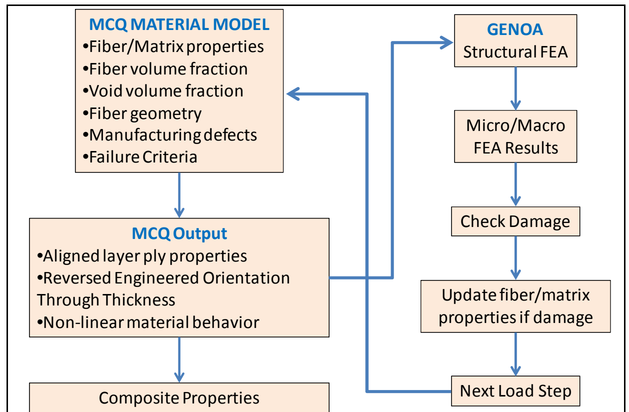

Figure 1 Chopped Fiber Methodology: GENOA/MCQ Multi-Scale Modeling Non-Linear Approach

MCQ-Chopped Data Bank and capabilities: Several classes of **thermoplastic**, **elastomer** and **thermoset** properties are available that have been validated with MCQ-Chopped analytical prediction (**Figure 2**). MCQ-Chopped typical inputs and capabilities (different modules) are shown in **Figure 3**. MCQ-Chopped modules also include parametric carpet plot (effective material property prediction for several different orientation % distribution of plies through-the-thickness). MCQ-Chopped also offers **de-homogenization approach** that models the composite constituents (fiber, matrix, and interface/interphase), chopped fiber orientation using several mathematical scales: a) nano mechanics (If needed) that includes effect of defects such as fiber waviness, resin rich, agglomeration, interphase, void shape/size; b) micro-mechanics that includes damage mechanics failure mechanisms such as translaminar and interlaminar; and c) ply/macro mechanics that includes ply level failure and interaction amongst them. This approach becomes necessary when the traditional FEM based **homogenization unit cell** fails to predict the appropriate response by not including each ply and their orientation.

Material	Fiber/Polymer	Specimen View	Manufacturing	Task/Software Used
Thermoset/Thermoplastic Chopped Fiber Composites				
1. CR-GF15	Fiberglass + Neoprene (**Elastomer**)	Short Fiber Distribution	Two Roll Mill	Material Characterization (MCQ)
2. PP-LGF20	Fiberglass + Polypropylene (**Thermoplastic**)	Long Fiber Distribution	Injection Molding	Material Characterization (MCQ)
3. PBT-GF30	Fiberglass + PolyButylene Terephthelate (**Thermoplastic**)	Short Fiber Distribution	Injection Molding	Material Characterization (MCQ)
4. Urethane 420 IMR-T300	Carbon + Urethane (**Thermoset**)	Discontinuous Long Fiber	Prepreg	Material Characterization (MCQ)
5. 8852-AS4	Carbon + Epoxy (**Thermoset**)	Discontinuous Long Fiber	Prepreg (SMC)	Material Characterization (MCQ)

Figure 2: Class of Polymers and Short/Long fiberglass & carbon Fiber Composites

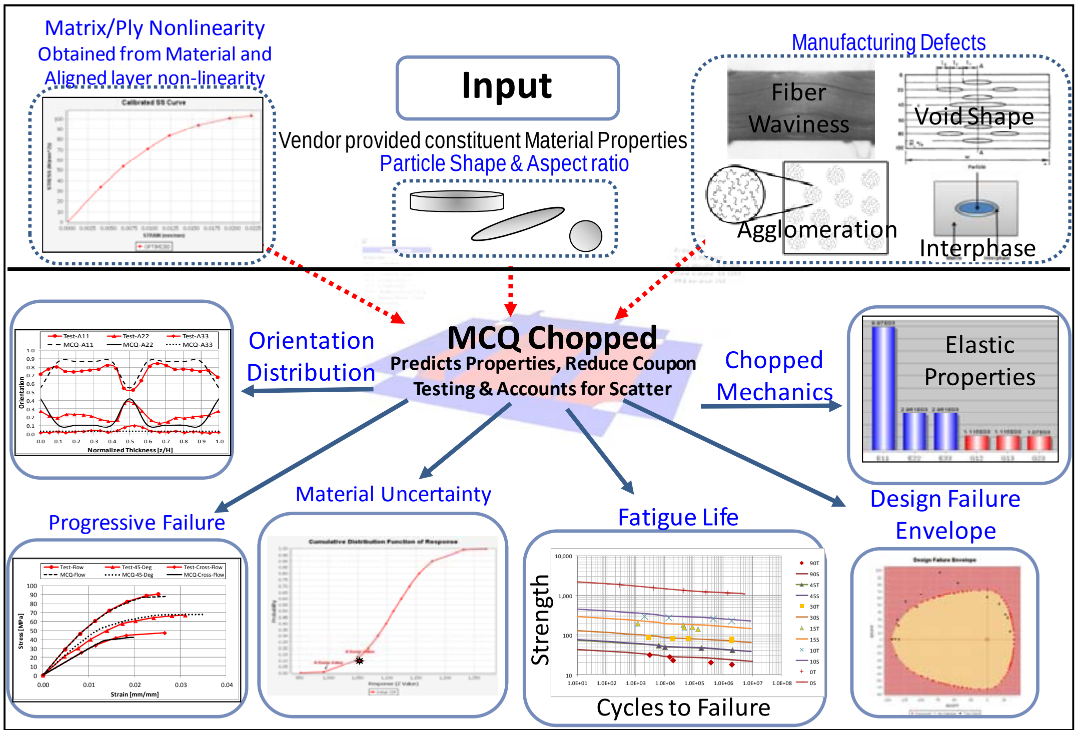

Figure 3: MCQ-Chopped typical input and capabilities

Test Validation: Predicted progressive failure analysis based stress-strain curve vs. test and predicted orientation tensor vs. test for thermoplastic material are shown in **Figure 4** and **Figure 5**. Three-point bending progressive failure analysis using MCQ-Chopped material model and Load-Displacement (L-D) curve from Test & Finite Element Simulation (GENOA/ABAQUS) are shown in **Figure 6** and **Figure 7**.

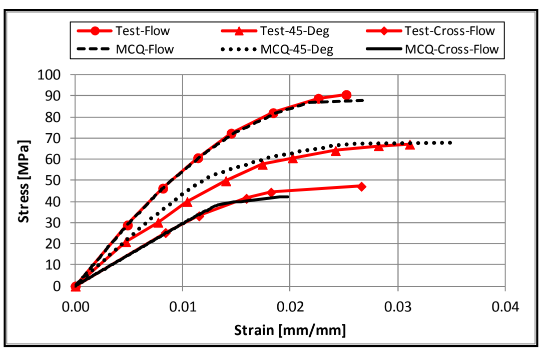

Figure 4: Simulated Stress-Strain Vs. Test (PBT-GF20) [1]

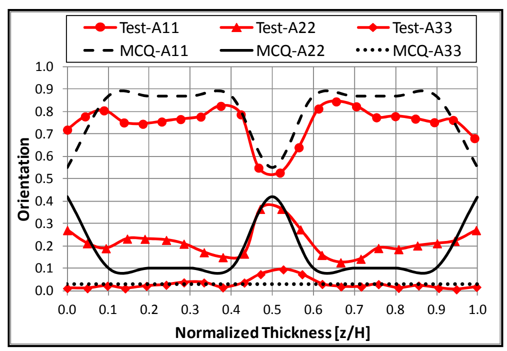

Figure 5: Orientation Distribution Vs. Test (PBT-GF20) [1]

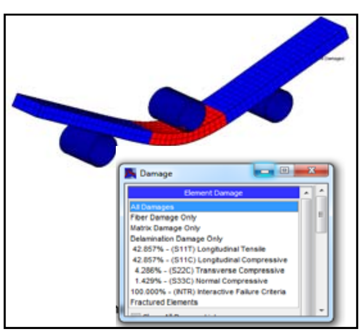

Figure 6: Three point Bending Coupon Analysis [2]

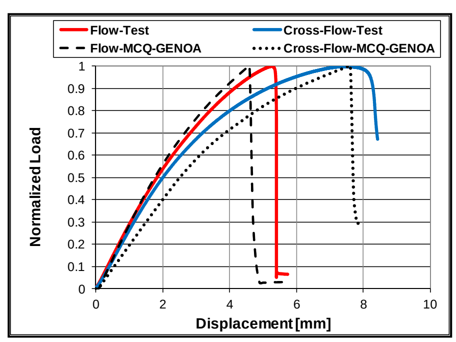

Figure 7: Simulated L-D curve vs. Test [2]

Reference:

1. Abumeri, G. H., Lee, M., (2006). A Computational Simulation System for Predicting Performance of Chopped Fibers Reinforced Polymer Composites. ERMR-2006-Elastomer-Reno.

2. H.K. Baid, F. Abdi, M. C. Lee, Uday Vaidya, Chopped Fiber Composite Progressive Failure Model under Service Loading. SAMPE 2015, Baltimore MD, May 18-21, 2015.