Innovative Modeling and Simulation Technology Area

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Innovative Modeling and Simulation Technical Area
An Integrated Approach Is Required

- Low-cost fiber
- Fast processing resins
- User-friendly forms

Materials

- Rapid composite conversion processes
- NDE/repair
- Recycling
- Joining

Manufacturing (Vehicles, Wind, CGS)

- Cost-efficient part design
- Manufacturing simulation
- Materials database

Design and Simulation

Technology Readiness

Insertion Points

Lab Scale
Sub-scale
Full Scale
The State of Composites Manufacturing Simulation

- Unlike design simulation software, the manufacturing of polymer composite materials and structures involves multi-physics phenomena.

- Phenomena span the disciplines of polymer science, rheology, reaction kinetics, fluid mechanics of non-Newtonian liquids, heat and mass transfer, mathematical topology, anisotropic thermoelasticity, and viscoelasticity.

- Curing reactions of thermoset polymers, melting and solidification of thermoplastic polymers, flow and impregnation of viscous polymers in fibrous preforms and tows, consolidation of fiber preforms, conduction and convective heat transfer, geometric conformation of fiber preforms to curvilinear surfaces, residual deformations due to anisotropy in thermal expansion.
Innovations Needed

• Stamp forming, resin transfer molding, and injection over-molding of both continuous and discontinuous fiber systems are offering performance characteristics and cycle times.

• The recycling of factory scrap for carbon fiber composites presents significant challenges, but recent developments suggest that it should be possible to reuse scrap in value-added components in the same vehicles that produced it, thereby achieving zero landfill.
Prediction of Manufacturing Variability

- **Uncertainty quantification (UQ)** is used by the National Nuclear Security Administration to certify weapons performance in the absence of testing as governed by global treaties.

- This body of knowledge can be transferred to the composites industry to guide the development of new certification paradigms for manufacture and performance of composite materials and structures.

- UQ is an established methodology to predict the range in expected outcomes through simulation. As such, UQ can combine simulation and experiments to reflect the actual range in expected performance and thereby ensure confidence in performance with fewer experiments.
Human Talent and Tools

- Education and training of a new generation of engineers who can transform a metals-based industry to a composites-based industry is needed.

- Simulation tools that capture the multiple phenomena in composites manufacturing to achieve near-optimum manufacturing and designs are essential.

- These tools can revolutionize high performance products for energy efficiency and value in use.
Leverage Computing Power to Enhance Confidence

- Create Composites Virtual Factory HUB (cvfHUB)
- Develop platform for hosting and integration of commercial software tools for composites
- Correlate at multiple scales prediction and reality
- Integrate tools to create end-to-end process simulation
- Make tools browser-available to entire value chain solving these issues in composites manufacturing and performance
The Vision: cvfHUB

- The cvfHUB is based in the Composites Design and Manufacturing HUB (cdmHUB) and becomes the platform to support an array of simulation tools and to develop the human talent to support composites design and manufacturing simulation enterprise.

- It increases the rate of development and deployment of simulation tools and the composite simulation tool user community by an order of magnitude.

- Browser-based platform format is exercised to test its robustness.

- Commercial simulation tools are showcased.

- Engineers and scientists interact with composites community colleagues continuously and securely.

- New simulation tools are available as they are developed and deployed on the cdmHUB 24/7 in user and developer chat groups.

- Synergism yields more and unexpected results (business).
Virtual Factory

The composites virtual factory is a manufacturing simulation-based platform that will provide browser access to physics-based simulations of the elements in specific composites manufacturing processes to allow virtual construction of manufacturing processes such as compression molding, injection molding, resin transfer molding, resin infusion, pultrusion, filament winding, advanced fiber placement, autoclave lamination, textile sheet forming, stretch forming, and additive manufacturing.
Simulation across IACMI Partners and Scales

Solution Spinning Line

Carbon Fiber Technology Facility (CFTF)

Prepreg Production Pilot / Full Scale

Pilot Scale PCM
1,000 ton press

Full Scale PCM
4,000 ton press
Simulation of Manufacturing Processes

Scale up PAN-derived Carbon-Fiber production at CFTF
- Minimize energy content (and cost) of carbon fiber through innovative processing schemes with simulation
- Achieve innovations in precursor technology (PAN and non-PAN), thermal conversion technologies, and surface treatment and sizing technologies

Automotive, Wind and CGS

Resin transfer molding (RTM) and high pressure-RTM
- Reduce cycle time from 5–8 min to under 3 min
- Scale lab efforts (<2 min cycle) with fast cure resins to parts the size of a floor pan
- Characterize rheology and permeability
- Use advanced simulation to predict molding process and structural response
- Simulate rapid manufacturing of continuous fiber preforms with controlled fiber orientations

Compression molding of continuous carbon fiber-reinforced plastics (CFRP)
- Scale laboratory–demonstrated press molding of prepregs at or near the targeted 3 min part cycle for parts the size of a roof
- Simulate draping and characterize rheology
- Simulate high-speed lamination techniques and automated transfer to hot press with fast closing speeds

Insert / overmolding
- Scale structural injection molding with long (carbon) fiber–reinforced thermoplastics to overmold an insert (e.g., continuous fiber preform, composites) placed in performance-critical locations
- Use rheological characterization and advanced simulation to predict molding process and structural response
Simulation Tool Validation

• Simulation tools validated at the lab scale at Purdue
• Lab-scale manufacturing process facilities established for all IACMI processes
• Simulation tools validated for all manufacturing processes within IACMI
• Simulation tool input data developed for all IACMI materials systems and processes
• Simulation tool validated at subscale and full scale at other IACMI sites
Indiana Manufacturing Institute
WEST LAFAYETTE, Ind.—Purdue Research Foundation board of directors on February 18, 2015 approved construction of the $50 million, 62,000 ft\(^2\) IMI, where Purdue University researchers will expand research in composite materials manufacturing.

- IACMI will occupy approximately 30,000 ft\(^2\) of the IMI.
- Validation at the lab scale for all IACMI manufacturing processes will be located adjacent to simulation studios of the cvfHUB.
- Cooperating industries are invited to co-locate in the IMI.
Composites Manufacturing Simulation Workforce Development

- Industrial interns—Dassault Systemes, ESI, e-Xstream Engineering
  - Interns assigned to specific software products
- ORNL/Purdue research faculty
  - ORNL scientists as adjunct faculty
- IVY Tech Community College
  - Composites manufacturing technicians
- Purdue Polytechnic Institute
  - Composites manufacturing and repair
  - Life cycle analysis for the digital factory and recycling
- Purdue College of Engineering
  - Composites simulation
  - Process simulation validation
Technology Area Design, Modeling and Simulation

Simulation Thrust Objectives

• Develop and launch the cvfHUB
• Accelerate development of comprehensive tool sets for the composites community.
• Deploy and integrate simulation tools that capture the manufacturing phenomena under development in the other IACMI centers of excellence

Validation of the Simulation Tools Thrust Objectives

• Lab-scale validation with input property measurement
• Meso-scale validation in Ohio, Colorado, and Tennessee
• Full-scale validation in Michigan and Colorado

Recycling Thrust Objectives

• Develop streams of value-added products that can be manufactured from fibers and prepreg materials reclaimed from the factory floor.
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- Purdue’s cdmHUB and cvfHUB will put browser-based simulation in the hands of subject matter experts and Tier I–II suppliers
  - cvfHUB: Deliver a comprehensive suite of commercial simulation tools for center of excellence project teams in MI, OH, CO, TN

Integration of many major commercial simulation tools

- Convergent Manufacturing Technologies
- SwiftComp
- Dassault Systemes
- ESI
- Moldex3D
- Hyperworks
- Material and discovery studio
- Preforming draping
- Simulation cure kinetic modeling
- Automated tape laying and fiber placement
- RTM
- Nondestructive evaluation
- Curing simulation
- Molecular material studies
- Material and discovery studio
- Preforming
- Joining
- Braiding
- Design and modeling simulation
- Draping simulation
- Curing
- Molecular material studies
- Material and discovery studio

Vehicle teams
Wind teams
CGS teams

Tool training
Tool evaluator (TML)
New tool development

Commercial tools
Browser-based Secure data
Phenomena-Based Tool Development

• An **integrated simulation tool suite** can consist of the assembly of modules that treat specific phenomena.

• These phenomena are central to all composites manufacturing and performance characteristics.

• If the modular elements are assembled, all the important issues in design and manufacturing can be interrelated to provide optimum solutions.
Model Composites Manufacturing Process—High Pressure RTM

1. **Preform Stacking**
   - CATIA

2. **Heat Transfer and Exotherm in the Press**
   - COMPRO

3. **Cure Kinetics in the Mold**
   - RAVEN

4. **Effective Mechanical Properties**
   - DIGIMAT

5. **Effective Anisotropic Heat Transfer Properties**
   - DIGIMAT

6. **Resin Infusion**
   - PAM-RTM

7. **Preform Assembly: Fiber Orientation**
   - CATIA DIGIMAT

8. **Residual Stress State**
   - COMPRO

9. **Consolidation/Compaction in Mold**
   - CATIA/COMPAC

10. **Post-mold Deformation**
    - MARC/ABAQUS
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WE WELCOME INQUIRIES