Structural Thermoplastics Roadmapping Report

University of Maine
Advanced Structures and Composites Center
Consortium for Manufacturing Innovation in Structural Thermoplastics (CMIST)

Based on the work completed at the:
(1) CMIST Roadmapping Workshop at UMaine – January 2017
(2) CMIST Roadmapping Workshop at SPE Automotive Composites Conference & Exhibition (ACCE) – September 2017

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CMIST Structural Thermoplastics

Roadmap Vision

To develop the next generation of environmentally sustainable structural thermoplastic composites that save energy and create value to end users

Develop products/processes that result in exponential thermoplastic composite market growth
The objective of the CMIST Roadmap Workshops is to develop a roadmap that addresses the following goals:

• Identify projects and project areas that address the following technical challenges in structural thermoplastic composite materials:
  • Realizing faster manufacturing cycle times;
  • Developing reliable and fast thermoplastic joining methods;
  • Transforming manufacturing methods to substitute high volatile organic compound thermosets with thermoplastics; and,
  • Characterizing thermoplastic composites for desired performance and economical manufacturing (considering cost, ‘manufacturability index’, etc.) including recycling methods.

Note: These project areas could be funded by federal agencies, by CMIST, by CMIST member companies or by other groups

• Identify the supporting infrastructure needed to accomplish these projects (e.g., websites, pilot facilities) and could be provided by federal agencies, by CMIST, by CMIST member companies or by other groups.
The scope:

• At the conclusion of the CMIST Roadmap Workshop series, the participants will have created the framework ("landscape") for the technology roadmap and will have identified and prioritized project areas.

• Development of the roadmap will continue into 2018 with input from consortium members and industry respondents.

• The final roadmap will be disseminated broadly in print and on the CMIST website in text and chart forms.

*Priority projects/project areas will be the subject of the upcoming Topic Roadmapping Workshop scheduled at the University of Maine Advanced Structures and Composites Center on November 14th and 15th, 2017.
**Opportunity Description**

(Customer benefit)

To increase and enhance existing product types through easier assembly. Decreased installation/down time. Improved OEM manufacturing.

**Market Drivers**

To make life easier for customer assembly (after market/OEM).

**Estimated Market Size and Growth rate**

TBD market research. Growth in OEM take up. Penetrate some of other split bearings.

**Key Technologies and State of Readiness**

Combination of properties in one material for inner race assembly (3). Component re-engineering (2). Manufacturing capability (3). (1) = ready, (3) = not ready.

**Strategic Fit**

V. good. 4/9 strategic initiatives. OEM partner; Value added products; Best value solution; Profitable sales growth.

**Ballpark cost to develop to Pilot**

TBD, say £150k.

**Time-scale to cash**

N/A.

**Enablers / Barriers / Risks**

Enablers:

- Commercial: Impact on existing products.
- Technical: Unable to achieve combined material properties.

Barriers:

- Commercial: Cost increase.
- Technical: Poor acceptance in market place.

Risks:

- Commercial: Impact on existing products.
- Technical: Unable to achieve combined material properties.

**Mini Business Case**

We have a high potential opportunity to:

- Differentiate company in the split bearing world.
- Present greater challenges to the solid bearing market.
- We should do it because:
  - Improved customer satisfaction.
  - Increases OEM sales.
  - Reduced Cooper manufacturing cost.

**Technology / Market intelligence gaps**

- Quantify incremental sales benefit.
- R&D material properties options for single material inner race assembly.

**Team:**

Stuart Morris Kevin Phelps

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**January 17-18 (Landscape Workshop)**

**September 6 (Landscape Refinement)**

**November 14-15 Topic Roadmapping Workshop**

**Applications & Programs selection matrix**

**Topic Roadmaps**

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Structural Thermoplastics Taxonomy

• A graphic was organized as a taxonomy and applied to structural thermoplastics, providing an overview of market intelligence based upon existing and prospective:

<table>
<thead>
<tr>
<th>Market Drivers</th>
<th>Value Streams</th>
<th>Projects/Project Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 identified</td>
<td>16 identified</td>
<td>13 identified</td>
</tr>
</tbody>
</table>

Ranked by popularity (generated by workshop attendance vote)


Definitions

Market Driver
Societal, technological, economic, political and environmental trends that are impacting the industry or will in the future. Also changes from consumers, competitors and new industry and supplier entries.

Value Stream
A product or process that is considered of value based upon its ability to improve or replace existing products or introduce new features or functions to the market.

Projects/Project Areas
The application prospective value streams and apparent market drivers in the development of new technologies and scientific approaches. This may also apply to standards, resources and capabilities developments.
### Market Drivers

<table>
<thead>
<tr>
<th>Term</th>
<th>2020</th>
<th>2020</th>
<th>Medium Term</th>
<th>2025</th>
<th>2025</th>
<th>Long Term</th>
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<tbody>
<tr>
<td>1. Improved Manufacturing Capabilities</td>
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<td>4. Materials R&amp;D and Database</td>
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### Value Streams

**Application Areas**
- Aerospace & Defense
- Automotive
- Other Transport
- Civil Infrastructure
- Architecture
- Other

**Supply Chain**
- Materials Availability
- Logistics
- Personnel
- Supplier Issues (Capacity)
- Other (IP, Legal Agreements, etc.)

### Projects/Project Areas

**Capabilities**
- Manufacturing Capability
- Manufacturing Technology
- Materials Classification
- Testing
- Software (Modeling, Simulation)
- Other

**R&D Priorities**
- Materials (Metal, Polymer, Composite)
- Materials Capabilities (Non-automated)
- Materials Characterization/Classification
- Software (Modeling/Simulation)
- Other

### Why? (Step 1)
- **Market Drivers** provide the rationale that drives the overall effort.

### What? (Step 2)
- **Value Streams**: Application and Supply Chain areas developed in response to Market Drivers.

### How? (Step 3)
- **Projects and Project Areas**: Specific Capabilities and R&D Priorities that address the technical challenges in structural thermoplastic materials (see workshop objectives).
Strategic Landscape Summary

The graphic on the following page captures the prioritized issues identified during the workshop. The relative priorities of these issues are indicated by color coding.

Darker color indicates higher importance
# Market Drivers

<table>
<thead>
<tr>
<th>Market Drivers</th>
<th>2017</th>
<th>Short Term</th>
<th>2020</th>
<th>2020</th>
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## Market Drivers

- **6. Supply and Demand Issues**
  - Improved Manufacturing Capabilities
  - Joining Products and Processes
  - Energy Life Cycle Inventory
  - Materials R&D and Database
  - Cost Issues (Production)
  - Multifunctional Materials
  - Need for OEM Specifications
  - IP Agreement Issues
  - Production Size (Capacity & Part Size)
  - Thermoplastic Finish
  - Design Flexibility

- **7. Workforce**
  - Regulations (Environmental and Health)
  - Energy Life Cycle Inventory
  - Thermoplastic Finish

- **8. Market Needs**
  - Improved Manufacturing Capabilities
  - Joining Products and Processes
  - Energy Life Cycle Inventory
  - Materials R&D and Database
  - Cost Issues (Production)
  - Multifunctional Materials
  - Need for OEM Specifications
  - IP Agreement Issues
  - Production Size (Capacity & Part Size)
  - Thermoplastic Finish
  - Design Flexibility

- **9. Legal & Regulation**
  - Regulations (Environmental and Health)
  - Energy Life Cycle Inventory
  - Thermoplastic Finish

- **10. Societal**
  - Improved Manufacturing Capabilities
  - Joining Products and Processes
  - Energy Life Cycle Inventory
  - Materials R&D and Database
  - Cost Issues (Production)
  - Multifunctional Materials
  - Need for OEM Specifications
  - IP Agreement Issues
  - Production Size (Capacity & Part Size)
  - Thermoplastic Finish
  - Design Flexibility

- **11. Other**
  - Improved Manufacturing Capabilities
  - Joining Products and Processes
  - Energy Life Cycle Inventory
  - Materials R&D and Database
  - Cost Issues (Production)
  - Multifunctional Materials
  - Need for OEM Specifications
  - IP Agreement Issues
  - Production Size (Capacity & Part Size)
  - Thermoplastic Finish
  - Design Flexibility

## Value Streams

<table>
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<th>2025</th>
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</table>

## Supply Chain

- **Materials Availability**
  - Process
  - Materials
  - Recycling

- **Logistics**
  - Process
  - Materials
  - Recycling

- **Personnel**
  - Process
  - Materials
  - Recycling

- **Supplier Issues (Capacity)**
  - Process
  - Materials
  - Recycling

- **Other (IP, Legal Agreements, etc.)**
  - Process
  - Materials
  - Recycling

## Projects/Project Areas

- **Manufacturing Capability**
  - 1. Process
  - 2. Materials
  - 3. Recycling
  - 4. Software
  - 5. Specialized Tooling
  - 6. Civil Infrastructure
  - 7. Automotive Parts
  - 8. Repair and Durability with Diagnostics
  - 9. Workforce
  - 10. Aerospace Parts
  - 11. Defense Parts
  - 12. Miscellaneous Parts
  - 13. Wind Parts
  - 14. OEM Collaboration
  - 15. Testing
  - 16. IP

- **Testing**
  - Process
  - Materials
  - Recycling

- **Software (Modeling, Simulation)**
  - Process
  - Materials
  - Recycling

- **Materials (Metal, Polymer, Composite)**
  - Process
  - Materials
  - Recycling

- **Materials Characterization/Classification**
  - Process
  - Materials
  - Recycling

- **Software (Modeling/Simulation)**
  - Process
  - Materials
  - Recycling

- **Other**
  - Process
  - Materials
  - Recycling

## R&D Priorities

- **2017**
  - 1. Process
  - 2. Materials
  - 3. Recycling
  - 4. Software
  - 5. Specialized Tooling
  - 6. Civil Infrastructure
  - 7. Automotive Parts
  - 8. Repair and Durability with Diagnostics
  - 9. Workforce
  - 10. Aerospace Parts
  - 11. Defense Parts
  - 12. Miscellaneous Parts
  - 13. Wind Parts
  - 14. OEM Collaboration
  - 15. Testing
  - 16. IP

- **2020**
  - 1. Process
  - 2. Materials
  - 3. Recycling
  - 4. Software
  - 5. Specialized Tooling
  - 6. Civil Infrastructure
  - 7. Automotive Parts
  - 8. Repair and Durability with Diagnostics
  - 9. Workforce
  - 10. Aerospace Parts
  - 11. Defense Parts
  - 12. Miscellaneous Parts
  - 13. Wind Parts
  - 14. OEM Collaboration
  - 15. Testing
  - 16. IP

- **2025**
  - 1. Process
  - 2. Materials
  - 3. Recycling
  - 4. Software
  - 5. Specialized Tooling
  - 6. Civil Infrastructure
  - 7. Automotive Parts
  - 8. Repair and Durability with Diagnostics
  - 9. Workforce
  - 10. Aerospace Parts
  - 11. Defense Parts
  - 12. Miscellaneous Parts
  - 13. Wind Parts
  - 14. OEM Collaboration
  - 15. Testing
  - 16. IP

- **2030**
  - 1. Process
  - 2. Materials
  - 3. Recycling
  - 4. Software
  - 5. Specialized Tooling
  - 6. Civil Infrastructure
  - 7. Automotive Parts
  - 8. Repair and Durability with Diagnostics
  - 9. Workforce
  - 10. Aerospace Parts
  - 11. Defense Parts
  - 12. Miscellaneous Parts
  - 13. Wind Parts
  - 14. OEM Collaboration
  - 15. Testing
  - 16. IP
## Priority Market Drivers (by rank)

<table>
<thead>
<tr>
<th>No.</th>
<th>Market Driver</th>
<th>Votes</th>
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<tbody>
<tr>
<td>1</td>
<td>Improved Manufacturing Capabilities (Making Parts Cheaper, Faster and More Reliable)</td>
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<tr>
<td>2</td>
<td>Software and Analysis</td>
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<td>3</td>
<td>Recycling and Circular Economy Sustainability</td>
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<td>Materials R&amp;D and Database</td>
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<td>Supply and Demand Issues</td>
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<td>Joining Products and Processes</td>
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<td>Cost Issues (Production)</td>
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<td>Supplier and Supply Chain Validation</td>
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<td>11</td>
<td>Need for OEM Specifications</td>
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<td>19</td>
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<tr>
<td>20</td>
<td>Consumer Acceptance of New Products and Technologies</td>
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</tbody>
</table>

Based on the Market Driver priority ranks generated at the January 2017 CMIST Workshop, located at UMaine. Feedback incorporated from the September 2017 CMIST Workshop, located at the SPE Automotive Composites Conference & Exhibition (ACCE).
Top Priority Market Drivers

Improved Manufacturing Capabilities (Making Parts Cheaper, Faster, More Reliable)

The end goal for manufacturers is to create parts with desirable traits or properties including low cost, high strength, light weight and low cycle time. Improved manufacturing capabilities, once capital equipment costs and process engineering challenges are met, are considered a strength of structural thermoplastics.

Software Analysis

The need for software is evident in the development of realistic models for material properties, new parts designed by analysis, simulated thermoforming processes for LFRT, as well as predictive software to limit redundant efforts that result in gaining knowledge through multiple platforms. Software analysis platforms offer an opportunity for structural thermoplastics.

Recycling and Circular Economy Sustainability

In cradle-to-cradle production, all material inputs and outputs are seen as either technical or biological components. Technical components can be recycled or reused with no loss of quality whereas biological components are composted or consumed. By contrast, cradle-to-grave refers to a company taking responsibility for the disposal of goods it has produced, but not necessarily putting products’ constituent components back into service. Realizing the potential for sustainability using structural thermoplastics is a significant market opportunity. Efforts to reduce material waste offer recycling as a clear solution. The limited infrastructure or incentives for material recycling reduces participation by established part manufacturers. Inherent thermoplastic recyclability is indicative of a market strength that will be validated through end of life part analysis. The recycling model for thermoplastics has the potential to mimic the success of the aluminum recycling business.
Materials R&D and Database

Numerous databases exist for materials scientists and engineers, but these databases lack specific material properties needed for virgin and recycled structural thermoplastic composites. Determination of required material properties to list in a single, non-proprietary database is an opportunity to accelerate the development of standardized test methods for structural thermoplastics.

Repair

Repair prevents unnecessary replacement of composite parts to better avoid the cradle- to-grave scenario. Repair also serves to utilize and recommission otherwise out-of-service parts. Structural thermoplastics possess many mechanisms for repair, allowing for repair through thermal, chemical and mechanical pathways. Multiple modes of repair are indicative of a material market strength but the opportunity exists to develop new and better controlled processes for repair of LFRTPs.

Supply and Demand Issues

Manufacturers have a limited supply chain environment with long lead times and few suppliers. These supply and demand issues are a market weakness to be managed and improved. As demand for structural thermoplastics grows the supply chain will mature. This includes a clear line of sight for raw materials availability and manufacturing supply origins.

Joining Products and Processes

Part processing, post-processing and repair phases of manufacture all rely on controlled, rapid methods for the joining of structural thermoplastics. Current joining methods range from welding to adhesive bonding, all of which must be optimized for individual polymer:polymer bonding. Developments to improve adhesive selections is expected to introduce the opportunity to bind structural thermoplastics to themselves, other thermoplastics and dissimilar materials, such as metals or ceramics.
Multifunctional Materials

New age materials, designated as multifunctional or smart, are capable of reacting to changes in the environment. Structural thermoplastics and adaptive sensor technology provide clear signal pathways to accommodate new innovations in multifunctional materials. State of the art material capabilities, such as self-healing or self-sensing bring forth new opportunities to be capitalized on an industry-wide basis.

Cost Issues (Production)

High costs associated with prototyping and high volume part production are driving the need for more efficient options. These costs encompass processing infrastructure, energy requirements and raw material expenses. Structural thermoplastics are on the frontier of delivering competitive end part prices in low and high volume production. Structural thermoplastics exhibit this strength characterized by the ability to produce parts through rapid, automated processes which will drive production costs down.

Supplier and Supply Chain Validation

In cradle-to-cradle production, all material inputs and outputs are seen as either technical or biological components. Technical components can be recycled or reused with no loss of quality whereas biological components are composted or consumed. By contrast, cradle-to-grave refers to a company taking responsibility for the disposal of goods it has produced, but not necessarily putting products’ constituent components back into service. Realizing the potential for sustainability using structural thermoplastics is a significant market opportunity. Efforts to reduce material waste offer recycling as a clear solution. The limited infrastructure or incentives for material recycling reduces participation by established part manufacturers. Inherent thermoplastic recyclability is indicative of a market strength that will be validated through end of life part analysis. The recycling model for thermoplastics has the potential to mimic the success of the aluminum recycling business.
Need for OEM Specifications

The lack of OEM material specifications for mechanical performance, processing temperatures and chemical resistance is a weakness of structural thermoplastics. Other industry accepted materials are highly standardized for both design and testing by a variety of reputable organizations including the International Organization for Standardization (ISO), American Association of State Highway and Transportation Officials (AASHTO), the Society for Automotive Engineering (SAE) and the American Society for Testing and Materials (ASTM). Initial introduction of structural thermoplastic specifications by OEMs is paramount to the development of international standards and achieving market adoption.

Energy Life Cycle Inventory

Structural thermoplastics are an emergent material. Thermoplastics exhibit promise in improving current structural composite life cycle energy usage. Collation or production of energy data for structural thermoplastics from a material production, part production and end of life recycling standpoint is a market weakness to be addressed.

Production Size (Capacity & Part Size)

Technology advances operate on a continuous pattern of low and high societal and economic demand cycles which currently favor thermoplastics. State of the art defense, aerospace and automotive production demands may be satisfied when processing with structural thermoplastics. Opportunities exist for high volume, rapid production across industry and unique and field-deployable parts manufacturing and recycling for military applications. Large thermoplastic parts for automotive, aerospace or wind applications present some challenges in scaled molding or heated press manufacturing techniques. Opportunities exist to further develop scalable processes such as thermoplastic infusion resins and large scale continuous processes such as pultrusion or roll/belt forming.
**Priority Market Drivers**

**Thermoplastic Finish**

Consumer trends show the aesthetics of part surface finish to be interrelated to market acceptance. Finish is a current weakness of structural thermoplastics. Enhanced finishing methods brings forth an opportunity for a single molding and finishing operation.

**Regulations (Environmental & Health)**

Thermoplastic production chemistry represents a significant improvement when compared to thermoset production chemistry. Production chemistry is a driving factor in regulatory and environmental concerns. Current thermoset systems are trademarked by highly volatile organic compounds, creating regulatory pressure and an opportunity for market adoption of thermoplastics. Thermoplastic lightweighting represents a potential emerging solution to increased emissions regulations.

**Workforce**

Material adoption is heavily influenced by the level of exposure throughout all technical tiers, from equipment operator to technician and engineer to PhD. Education and training programs for structural thermoplastics must be designed and deployed at all levels. A knowledgeable workforce will impact both structural thermoplastic quality control and the availability of skilled labor, indicating an opportunity for market growth.
IP Agreement Issues

The collaboration of specialty thermoplastic entities including thermoplastic resin manufacturers, reinforcing fiber manufacturers, government agencies and academic professionals is currently hampered by intellectual property (IP) and patent agreements. Generation of IP is the ideal outcome from both individual and collaborative research and developments. To encourage collaboration within the structural thermoplastics industry, shared IP agreements must be drafted for use on future innovations. This will assist to mitigate any threats to industry partnerships and stimulate future innovation.

Design Flexibility

Structural thermoplastics offer the opportunity for design and optimization flexibility due to the range of efficient manufacturing processes used in thermoplastic production. There are a range of very efficient processes, such as pultrusion, injection molding and vacuum thermo-forming, which can be combined with more tailored manufacturing processes, such as 3D printing of filled or unfilled thermoplastic, or high pressure heat forming of long fiber engineered composite panels. Multiple processes can be combined to form very efficient parts taking advantage of more than one process. For example, a long fiber pressure heat formed part could then be injection molded around it’s perimeter to form a net shape part that does not need to be trimmed, or a pultrusion could be heat welded to a vacuum formed panel to provide strength or stiffness in a particular area, or a fine detail could be 3D printed onto a panel to add a feature in one area. The combination of the best aspects of various automated manufacturing techniques enable highly engineered parts to be made in an efficient and repeatable manner.
Resources and Support

Developments in technology are accomplished through an interconnected support system. The success of this support structure is dependent on a diverse pool of resources. Examples of resources are local and federal government agencies, large industrial partners, private and public universities and community colleges. The collaboration of entities accelerates the rate of structural thermoplastic applications realized within respective industry sectors. Remodeling resources and support for structural thermoplastics mitigates a market weakness.

Consumer Acceptance of New Products and Technologies

Consumer markets are unified in that they are highly variable due to the influence of consumer acceptance and popularity. Structural thermoplastics are materials that have potential for implementation in a variety of applicable industries and are therefore influenced by a wide range of consumers. There is a threat to the use of structural thermoplastics in that risk aversion to cultural change must be considered for all future developments. Successful consideration and mitigation of this threat has the ability to incur exponential prosperity and market growth for a particular structural thermoplastic product or technology.
# Definitions: Opportunity & Feasibility

## Opportunity Factors

<table>
<thead>
<tr>
<th>DIMENSION</th>
<th>FACTOR</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOLUME</td>
<td>Market size</td>
<td>Size of potential market, or number of potential adopters, reasonably available to us</td>
</tr>
<tr>
<td></td>
<td>Our sales potential in a given time</td>
<td>Sales volume or number of adoptions anticipated in a defined time (e.g., 5 years)</td>
</tr>
<tr>
<td></td>
<td>Synergy opportunities</td>
<td>Possible additional benefits to other projects or activities, or the possibility of new opportunities in combination</td>
</tr>
<tr>
<td></td>
<td>Customer benefit</td>
<td>Immediate benefit to customers (internal or external) or potential adopters</td>
</tr>
<tr>
<td></td>
<td>Competitive intensity in Market</td>
<td>Number or significance of the competition</td>
</tr>
<tr>
<td>MARGIN</td>
<td>Increased margin, or benefit per unit</td>
<td>Improvement in product margin (e.g., cost reduction or price premium) compared to existing products; or benefit to us per adoption</td>
</tr>
<tr>
<td></td>
<td>Business cost reduction or simplification</td>
<td>Facilitates cost reduction or simplification of business processes</td>
</tr>
<tr>
<td></td>
<td>Industry/market readiness</td>
<td>How easy will it be for customers or adopters to take up the product? Do they have to change their behavior or processes?</td>
</tr>
<tr>
<td>PLATFORM</td>
<td>Market growth</td>
<td>Anticipated growth rate of market</td>
</tr>
<tr>
<td>FOR FUTURE</td>
<td>Future potential</td>
<td>Product is a platform for future products or could open new markets in future</td>
</tr>
<tr>
<td>BENEFIT</td>
<td>Learning potential</td>
<td>Will improve the knowledge or competence of the business</td>
</tr>
<tr>
<td>INTANGIBLES</td>
<td>Impact on Brand Image</td>
<td>Effect on brand image or staff morale</td>
</tr>
<tr>
<td></td>
<td>Impact on key customer relations</td>
<td>Importance for relations with key customers</td>
</tr>
</tbody>
</table>

## Feasibility Factors

<table>
<thead>
<tr>
<th>DIMENSION</th>
<th>FACTOR</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHARACTERISTICS</td>
<td>Product differentiation</td>
<td>How well the product is differentiated from those of major competitors</td>
</tr>
<tr>
<td>OF THE PRODUCT</td>
<td>Sustainability of competitive advantage</td>
<td>Our ability to sustain our competitive position (e.g., IPR, brand strength etc)</td>
</tr>
<tr>
<td></td>
<td>Technical challenge</td>
<td>How confident are we that the proposed product is technically feasible?</td>
</tr>
<tr>
<td>CAPABILITY</td>
<td>Market knowledge</td>
<td>Our understanding of size and requirements of the market</td>
</tr>
<tr>
<td>SUPPORTING</td>
<td>Technical capability</td>
<td>Do we have the required technical competence to design the product?</td>
</tr>
<tr>
<td>BUSINESS</td>
<td>Fit to sales and/or distribution</td>
<td>Fit to our sales competences and/or distribution chain</td>
</tr>
<tr>
<td>PROCESSES</td>
<td>Fit to manufacturing and/or supply chain</td>
<td>Ability to manufacture or supply the product</td>
</tr>
<tr>
<td></td>
<td>Finance</td>
<td>Availability of finance for the project</td>
</tr>
<tr>
<td>ORGANIZATIONAL</td>
<td>Strategic fit</td>
<td>How well does the proposal fit our company strategy?</td>
</tr>
<tr>
<td>BACKING</td>
<td>Organizational backing</td>
<td>Level of staff or management backing at an appropriate level</td>
</tr>
</tbody>
</table>

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Selection Criteria for Voting on Value Streams and Projects/Project Areas

Based on the defining factors of opportunity and feasibility, the factors highlighted in red were determined to be most applicable for structural thermoplastics.

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Future Potential</td>
<td>Technical Capability</td>
</tr>
<tr>
<td>Customer Benefit</td>
<td>Fit to Manufacturing and/or Supply Chain</td>
</tr>
<tr>
<td>Increased Margin or Benefit per Unit</td>
<td>Technical Challenge</td>
</tr>
<tr>
<td>Synergy Opportunities</td>
<td>Sustainability of Competitive Advantage</td>
</tr>
<tr>
<td>Business cost reduction or simplification</td>
<td>Product Differentiation</td>
</tr>
<tr>
<td>Market Growth</td>
<td>Market Knowledge</td>
</tr>
<tr>
<td>Market Size</td>
<td>Strategic Fit</td>
</tr>
<tr>
<td>Industry/Market Readiness</td>
<td>Organizational Backing</td>
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<tr>
<td>Our Sales Potential in a Given Time</td>
<td>Fit to Sales and/or Distribution</td>
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<td>Learning Potential</td>
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<tr>
<td>Impact on Brand Image</td>
<td></td>
</tr>
<tr>
<td>Competitive Intensity in Market</td>
<td></td>
</tr>
</tbody>
</table>

*Based on the most popular factors of opportunity and feasibility for use roadmapping of structural thermoplastic composite materials. The Selection Criteria for Opportunity and Feasibility were determined at the January CMIST Workshop.*
Based on the average Value Stream priority ranks generated at the January 2017 CMIST Workshop, located at UMaine and the September 2017 CMIST Workshop, located at the SPE Automotive Composites Conference & Exhibition (ACCE). ACCE Participants votes were distinguished by the opportunity and feasibility selection criteria defined in the January Workshop.
Top Priority Value Streams

Process

Processes that enable manufacturers to reduce cycle time and improve geometric tolerances for both raw materials and finished products comprised of structural thermoplastics are essential to the acceptance and standardization of composites. These processing improvements will allow such materials to permeate a magnitude of industrial and consumer markets. Automation for reliable gap control, tightly tolerated unidirectional tapes, continuous fiber 3D printing, nondestructive joining methods and 5D printing will all contribute to scalable, fast cycle times in applications across all industries.

Materials

In order to effectively harness the improved performance properties of structural thermoplastics, acceptance by industry driving markets must be accomplished. Such markets include mass transit, aerospace, and automotive. To satisfy current manufacturing needs material suppliers must be able to produce a structural thermoplastic that is characterized by an optimum combination of physical properties. Industry currently seeks a structural thermoplastic defined by low melt temperature and high glass transition temperature or low viscosity and high strength or low density and impact resistance. Opportunities also exist for the exploration of material and process combinations or hybridizations and cost efficient additives for UV resistance in cases where a value added material may be produced.

Recycling

Structural thermoplastics are inherently recyclable. This property invites the development of recyclable or reusable wind and Marine Hydrokinetic (MHK) blades, as well as boat hulls. Processing developments include separation technology for heterogenous thermoplastic resin matrices and fiber reinforcement and single-stream plastics processing. Competitive recycled materials must compete with virgin materials, overall offering added value from the crude materials. Modes of consumer input and recycling data access will assist development success. Recycling material market trends and index availability throughout the US, similar to in the EU and Japan, are also a consideration of interest.
Software

Software and necessary input values are required to accurately simulate and predict the formation and performance characteristics of structural thermoplastic raw materials, consolidated tailored blanks and end-use products. The software should be a user-friendly and simple platform to promote adoption by all industries. The software must be designed to predict the occurrence of spring-in and warping in thermoformed parts through the utilization of input data and standard composite design principles.

Specialized Tooling

Tooling constructed from structural thermoplastics offers improved performance, enhanced tool surface aesthetics and unparalleled time and money savings when clients are in need of a custom tool. A conformable material for coating metal tools should be exploited for use at forming temperatures, satisfying the needs of high temperature polymer processing, such as PEEK and PEKK.

Civil Infrastructure

Structural components form the foundation of civil infrastructure. These components, such as I-beams, large pipes, metal culverts, rebar and pipe and tank systems, are characterized by simple geometric profiles. The adoption of structural thermoplastics for use in these applications offers improved durability and substantial cost savings when applied to already accepted construction, installation and repair procedures. Structural thermoplastics may also be applied to existing damaged infrastructure, for instance utilize a thermoplastic plate to reinforce a steel I-beam. This could reduce the effects of deterioration, cracking and porosity and extending the life span of previously built civil infrastructure.
Automotive Parts

The use of structural thermoplastics for the production of automotive parts will be substantially assisted by the publication of a design guide containing production scale information, structural thermoplastics composite materials recommendations for use, performance ratings, and mechanical, thermal and chemical property information. This manual should be user-friendly for OEMs and avoid customization and complexity. The facilitation of a work group without competitive barriers will accelerate this guide's development, standards development and OEM education. The production costs associated with structural automotive materials, such as carbon fiber, must be diminished to become a cost competitive alternative material. Initial product developments to prove cost and weight reduction could be back pillows, seat backs and headliners.

Repair and Durability with Diagnostics

Durability is highly influential when analyzing, understanding and quoting an expected structural thermoplastic product’s service life. Durability must also be understood with regard to all environmental conditions. In situ monitoring of structural thermoplastic parts should be developed and applied. This is expected to improve the industry understanding of composite action and durability, specifically in remote locations. Techniques for repair should also be developed and standardized for applications such as aircraft repair, pioneer projects may include materials and processes that enhance already existing technologies. Long term developments should focus on the creation of self-diagnosing and self-healing thermoplastic materials for use in structural applications where repair is unattainable.
Priority Value Streams

Workforce

Improvements to product quality, lead times and the ability to construct complex geometries are, in part, accomplished through education of the structural thermoplastics workforce. Establishment of training programs for the distribution of automated manufacturing, as well as structural thermoplastics and general composites and polymer knowledge will result in an improved and educated supply chain. Workforce education should be addressed by introducing community college programs in composites, increasing polymer and composite university course offerings and implementing technician training courses, particularly for those trained in the machining of traditional materials, such as steel.

Aerospace Parts

The aerospace industry seeks improved innovation which may be achieved through the adoption of structural thermoplastics. Lightweighting of parts and assemblies assists to reduce overall mechanical energy requirements of any aircraft. To successfully exceed the performance of traditional materials used in aerospace applications, structural thermoplastics must have the ability to withstand massive amounts of impact and pressure. These condition needs must be satisfied and optimized before pursuing elements of cost efficacy and environmental sustainability through the implementation of reuse or recycling, which also exist for development.

Defense Parts

Parts to assist the defense industry may achieve improved ballistic performance when constructed with structural thermoplastic materials, with applications from personalized body armor to improved portable shelters. Resistance to high temperatures with limited performance compromise has the power to benefit defense operations in areas of high temp working environments, or those where ballistic energy absorption must be engineered into the portable shelter design.
Priority Value Streams

Miscellaneous Parts
Solar panels that are constructed from aluminum will benefit from lightweighting when manufactured with structural thermoplastics. Many structural components in use are in need of replacement, structural thermoplastics can be used to replace modular flooring in field deployable structures and earth anchors for aircraft applications. Long term developments should focus on engineering biodegradability as a physical property of structural thermoplastics, for containers and other applications.

Wind Parts
End-of-life recyclability is highly advantageous when dealing with plastic components, such as wind blades, that are manufactured at large-scale lengths. This characteristic is achieved when using structural thermoplastic components, which is projected to become exponentially important as blade manufacturers produce hundreds of thousands of tons of composite material per year. The application of structural thermoplastics in such designs will also directly reduce cycle time, as thermoplastic blades can be removed from a mold before reaching ambient temperature. Extreme corrosion resistance also positions structural thermoplastics as a material capable for use in applications exposed to environmental elements, such as rain and sun exposure.

OEM Collaboration
An integrated system that brings together industrial suppliers and manufactures, standards organizations and OEMs should be considered. The establishment of such a value chain consortium will allow for the identification of unmet OEM needs in terms of material developments, improved manufacturing processes and limiting performance or design concerns. The objective of this consortium will be to develop material, processing and part solutions that will directly benefit OEMs.
Testing

The standardization of structural thermoplastic composite materials is necessary to obtain manufacturer and consumer approval. Physical and performance properties that exceed that of traditional materials, for instance aluminum must be made public knowledge. Specific energy absorption, generic creep and fatigue data sets must all be generated for use in the standardization of structural thermoplastics. All testing procedures should be determined for varied resin and fiber compositions in the structural thermoplastic composite materials.

Intellectual Property

Successful structural thermoplastic developments, both product and process, result in the generation of intellectual property (IP). To increase IP generation and assist market growth, flexible and acceptable IP sharing situations that combine ownership and supply chain data accessibility should be considered. Physical and performance characteristics of structural thermoplastics must be aligned and shared through the publication of a coherent and comprehensive technical guide, similar to the metal phase diagram. The intent here is to establish an OEM accepted method for the material classification and life cycle analysis, inclusive of structural thermoplastics and recycled fibers, while avoiding the use of vernacular that is not familiar across all industries, such as “uv [ultraviolet] packaging” or “sizing,” overall increasing supply chain communication.
Based on the Project/Project Area priority ranks generated at the January 2017 CMIST Workshop, located at UMaine.

These Projects and Project Areas will be the further developed at the CMIST Topic Roadmapping Workshop on November 14th and 15th, 2017 at the University of Maine.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Projects and Project Areas</th>
<th>Votes (Opportunity)</th>
<th>Votes (Feasibility)</th>
<th>Total Votes</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Process</td>
<td>21</td>
<td>17</td>
<td>38</td>
</tr>
<tr>
<td>2</td>
<td>Characterization and Testing</td>
<td>18</td>
<td>16</td>
<td>34</td>
</tr>
<tr>
<td>3</td>
<td>Materials to Improve Process</td>
<td>14</td>
<td>16</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>Modeling Software</td>
<td>12</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>Materials - New Functions</td>
<td>12</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>Recycle - Material</td>
<td>14</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>Workforce</td>
<td>9</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td>Repair</td>
<td>11</td>
<td>8</td>
<td>19</td>
</tr>
<tr>
<td>9</td>
<td>Regulations and Acceptance Criteria</td>
<td>7</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>10</td>
<td>Recycle - Process</td>
<td>8</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>Tools</td>
<td>7</td>
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<td>14</td>
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<tr>
<td>12</td>
<td>Design</td>
<td>5</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>13</td>
<td>Inspection and Monitoring</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>
Top Priority Projects/Project Areas

Process
The standardization of processes applicable for structural thermoplastics is a development that will assist market growth. The reduction of waste, reduced cycle time and high speed processing including field forming and material enhancements for blast resistance are all areas for improvement. Processes may include sample preparation, materials testing, performance modeling and finite element analysis (FEA), thermoplastic pultrusion for complex geometries, 3D printing, field forming with stock materials (i.e. plates), accelerated continuously reinforced engineering thermoplastic composites processing, polypropylene and nylon stamp forming, and autoclave processing methods.

Characterization and Testing
Characterization of structural thermoplastic materials will require a diverse battery of standardized testing for many raw polymers, fibers and composite materials. The overall project may benefit from the production of a standardized material characterization method. This undertaking will best begin by compiling currently available material properties data into a publicly accessible database. Additional developments for materials characterization are friction measurements to determine best tool material selections and material property measurements during processing to use as inputs for simulation software. Performance over time for infrastructure structural thermoplastic materials under conditions of flexure and vibration as well as the development and testing of structural thermoplastics blast panels with regard to constructability and connection points (i.e. welding, adhesion and mechanical fastening).
Materials to Improve Process

Structural thermoplastic material developments mark the first step to process improvement. Continuous fiber filaments for 3D printing, controlled crystallization of hi-temp polymers to improve parts with a reduction of voids and shrinkages for aerospace and defense applications, improved polymer flow, expansion of polymers for carbon fiber reinforced thermoplastics are all be developments of interest. Existing materials, processes and equipment may also be modified to rapidly achieve such material enhancements.

Modeling Software

Modeling and simulation software must be understood to produce structural thermoplastic manufacturing results before material processing, with accuracy, precision and efficiency. Existent finite element analysis (FEA) software will benefit from the standardization of input values for thermoplastic composites, allowing designers to simulate deformation in formed parts. Additional theoretical modeling and simulation will benefit from the identification of structural thermoplastics ballistic properties, hybrid bodies and materials properties, crystalline polymer structures as a function of cooling rate and improved software communications for automated processing.

Materials – New Functions

Material developments that will positively influence structural thermoplastics and are expected bring about improved material functions should be considered. A supply chain cost understanding model will assist the decision of which high temp polymers are of the highest interest, as this is expected to improve material availability. Important material developments include structural methacrylate adhesive for asymmetric and multi-material assemblies, low viscosity and high temperature polymers with nano-dispersion for lighting strike protection, high chemical, temperature and force resistant structural thermoplastics, paints and finishing for low cost thermoplastic parts and multi-material hybridizations containing composites, metals and woods for optimized designs.
Recycle – Material

Materials for recycling require property analysis at both the pre- and post-recycling stages. These values must be used to determine a material classification for reuse guide and validate the necessary test methods to understand the reclaimed material performance and processability. Determination of compatible materials for core, part and filler applications must be determined for the structural thermoplastic resins, for instance high performance filler polymers for automotive applications.

Workforce

A workforce that supplies and molds a particular industry improves with the establishment and utilization of outside training and education resources accessibility. This theory may be applied to those working with structural thermoplastics in a practical and incentivizing manner. Highschool, public and private universities, community colleges and technician courses must be accessible to consider thermoplastics for the best material acceptance. It is also important to consider the education of structural thermoplastic composite materials for performance and design concepts, inclusive of comparisons to accepted metallic materials.

Repair

Improved repair mechanisms and necessary tooling and bonding agents, including bonding, welding and mechanical fastening, should be considered to extend part lifespan in many industries, such as aircraft structural repairs and field repair methods.
Regulations and Acceptance Criteria

Effective structural thermoplastics education programs will assist the most effective and mutually beneficial lobbying of government bodies in the promotion of structural thermoplastics acceptance and recommendation for use. Regulatory issues should be mapped on an individual basis to determine the process for regulatory acceptance by entities such as the Interstate Commerce Commission (ICC). One issue that exists to be further understood through testing and research is the association of nanoparticles in structural thermoplastic composites, which should be optimized for safety to obtain regulatory acceptance.

Recycle – Process

The process of recycling structural thermoplastics for repurposed materials use will be best assisted with the development of a standardized method for materials reclamation. Such reclaimed materials may be produced as sheets or panels or another form that is a capable input for the fabrication of parts from recycled fibers and resins. This process must be economical and able to be commercialized, but also be capable of assisting field recycling applications with the use of simple equipment.

Tools

Specialized tooling for manufacturing with structural thermoplastics must be able to withstand high temperatures and be conformable. Thermoplastics may be either applied to existing metal tooling or used to rapidly construct a mold using 3D printing of structural thermoplastics. Integral heating elements may also be considered for optimization for use with a structural thermoplastic mold.
Priority Projects/Project Areas

Design

Structural thermoplastics would benefit from heightened market acceptance, which could be achieved with the production of a widely accepted and industry specific design criteria and guidelines. The fundamentals for these reference manuals will be backed by performance and property values obtained from earlier standardization developments.

Inspection and Monitoring

Efficient manufacturing methods for structural thermoplastics requires modes of quality assurance by end-part inspection and monitoring. Methods for monitoring should mitigate waste, such as non-destructive, in-line testing and include structural thermoplastics materials developments to achieve multifunctional materials that are capable of self-diagnosis. Potential polymers for this would include PA, PEEK, PEKK and PPS for aerospace, energy and defense applications.
We look forward to seeing you at the November CMIST Topic Roadmapping Workshop!

CMIST
THE UNIVERSITY OF MAINE

Topic Roadmapping Workshop Agenda
November 14th and 15th, 2017

Location: University of Maine, Advanced Structures and Composites Center
35 Flagstaff Rd, Orono, ME 04469

Time: Nov. 14th 8:00AM-5:00PM & Nov. 15th 9:00AM-2:00PM EST

Tuesday, November 14th, 2017 8:00AM – 5:00PM

8:00 – 8:30 AM  Check In – coffee and tea provided
8:30 – 9:45 AM  Introduction – CMIST Objectives and Post-Workshop Results
9:45 – 10:00 AM  Break
10:00 – 10:30 AM  Topic Roadmapping Overview
10:30 – 11:00 AM  Tape Lay-Up Demo
11:00 – 12:00 PM  Lunch
12:00 – 1:00 PM  Thermoforming Cell Demo
1:00 – 3:00 PM  Team Topic Roadmapping – Session 1
3:00 – 4:30 PM  Plenary and Discussion
4:30 PM  Wrap-Up and close

TBA  CMIST evening networking activity

Wednesday, November 15th, 2017 9:00AM – 2:00PM

8:30 – 9:00 AM  Check In – coffee and tea provided
9:00 – 9:30 AM  Recap of Day 1
9:30 – 11:00 AM  Team Topic Roadmapping – Session 2
11:00 – 12:00 PM  Lunch
12:00 – 1:00 PM  Plenary and Discussion
1:00 – 2:00 PM  Wrap-Up

Join the Consortium for Manufacturing Innovation in Structural Thermoplastics (CMIST) at the upcoming topic roadmapping workshop. The Consortium has organized a workshop to connect industry members and academic professionals of the multi-tier structural thermoplastics industry. This workshop will be directed toward the development of future structural thermoplastic research initiatives, each organized to satisfy the market needs and value streams of current and prospective industries utilizing composites. This workshop will be the final opportunity to participate in the creation of a National 2015-2030 Roadmap for Structural Thermoplastics, scheduled to be released in 2018.

Help CMIST to address the following Structural Thermoplastics challenges:

1. Realizing faster manufacturing cycle times;
2. Developing reliable and fast thermoplastic joining methods;
3. Transforming manufacturing methods to substitute high volatile organic compound thermosets with thermoplastics and;

Image courtesy of the Society of Plastics Engineers.

Click HERE to Register!