LIGHTWEIGHT
Chopped fiber compression molded composite parts are lighter in weight than aluminum or titanium.

COMPLEX PART FABRICATION
Compression molding allows design and fabrication of complex shapes in single-shot molding.

OPTIMIZED LOAD PATHS
Parts can be optimized with ribs and stiffened assemblies to strengthen high-load areas.

LIGHTNING PROTECTION
Surfaces of external parts can have lightning strike foils incorporated into the surface layer.

INTEGRATED FASTENERS
Parts can be supplied with integrated fasteners and features.

OUR OBJECTIVES
- Lightweight complex parts
- High-strength structure
- Rapid part forming

Toray Advanced Composites
INTRODUCTION
Toray Advanced Composites is a world leader in composite material design and development for aerospace, satellite, high performance industrial, and consumer product industries. Toray manufactures chopped thermoset and thermoplastic carbon fiber bulk molding compounds (BMC) for compression molding with standard, intermediate, or high modulus carbon fiber reinforcements available. Toray CCS, a group within Toray Advanced Composites, specializes in the design, tooling, and fabrication of complex compression molded composite parts using BMC.

Compression molding using BMC is an enabling technology for the fabrication of complex composite parts for aerostructures, space, and satellites. Compression molding offers an alternative to machining and hand lay-up for intricate geometry components. The process also delivers cost and weight savings by allowing the fabrication of composite parts in high volumes with short cycle times. Special features such as lightning strike foils and integrated fasteners can be designed into the part. The utilization of chopped fiber BMC in compression molded parts often delivers higher strength and lighter weight than the metal parts they replace.

COMPRESSION MOLDING PART DESIGN AND FABRICATION
The Toray CCS group is a leading designer and fabricator of compression molded parts utilizing chopped fiber advanced composites—producing parts that fly today on a variety of commercial aircraft, helicopters, jet engines, nacelles, and satellite structures. Toray offers in-house design capabilities for customers, where we optimize part design to facilitate proper strengths for load paths, allow effective tool design for efficiency, and minimize costs. Our turnkey service includes tool design and part strength optimization, along with full manufacture, inspection, and secondary post molding machining.

Toray’s compression molding process uses steel tooling to mold chopped fiber advanced composites under high pressures (69 bar/1000 psi or higher). This process provides highly consolidated parts, much lighter than metal. Additionally, thermoplastic-based and thermoset-based composites allow for compression molding parts with complex shapes not otherwise possible with continuous long fiber composites.

To provide ideal stiffness, compression molded parts are optimized with integrated ribs or pad ups. Adding almost negligible weight, standard, intermediate, or high modulus carbon fibers are chopped into fiber widths of 3.2 mm/0.125”, and lengths of 12.7, 25.4, and 50.8 mm (0.5, 1, or 2”) and added for bending stiffness. Additionally, Toray can integrate fasteners, gaskets, and cut outs to parts, as well as specially designed surfaces such as lightning strike mesh or glass isolation plies.

SYNTACTIC THERMOSET MOLDING
When low dielectric strengths are desired or where very high service temperatures are required, Toray molds parts out of syntactic thermoset pastes. Syntactic molding is common in radome structures, heat shields, missiles, and aircraft. Compression molding of syntactic materials allows for simpler, more consistent complex shape manufacture of difficult to handle syntactics pastes/films.

“Aeronautics was neither an industry nor a science. It was a miracle.”

Igor Sikorsky
MATERIALS USED IN COMPRESSION MOLDING

Compression molding is a highly controlled process utilizing precise resin content-controlled uni-directional tape made with standard or intermediate modulus fibers. Resins can be thermoset or a thermoplastic (e.g., PEEK or PPS) depending on final part requirements.

Bulk molding compounds are made by chopping these UD tapes into fiber lengths ranging from 3 to 50 mm (0.25 to 2”). Longer fiber lengths generally provide higher strengths, while shorter fibers allow more complex structural details to be molded into the part. Once chopped, the material is placed into a mold, heated, and compressed under high pressure to form the part.

THE CASE FOR COMPRESSION MOLDED PARTS

Figures 1, 2, and 3 highlight the progression from a simple metal part to an optimized compression molded composite part.

Design flexibility with compression molded composites allows modification of simple geometry to create a higher performance, lighter weight part. In comparison, a similarly designed metal part would require complex machining, continuous fiber composites would be extremely difficult to fill into such complex shapes, and injection molding compounds do not have the mechanical properties to provide equal performance.
ADVANTAGES OF COMPRESSION MOLDED COMPOSITES

- Lower part labor content through:
  - Reduced kitting, lay-up, final trim, post machining, and inspection steps
  - Consolidated part count and reduced post assembly times
  - Molded in attachment features
  - High yields and ability to make multiple parts in one nested mold
  - Reduced scrap via high pressure molding processes
  - Mold controlled dimensions
  - Fast molding times

- Replace multiple simple parts into one complex part
- Lighter weight, and higher performance
- Dimensionally stable
- Non-corrosive benefits (galvanic protection, chemical resistance)

APPLICATIONS WHERE COMPRESSION MOLDED PARTS EXCEL:

Toray chopped fiber molding compounds (BMC) enable the cost-effective production of complex, extremely high-tolerance composite parts, typically to replace machined aluminum or titanium components for weight or cost reduction.

- Metal/composite parts that have changing cross-sectional thicknesses or material tailoring requirements
- Complex geometries that limit the ability to use continuous laminate composites (i.e., long process or high cost)

TOOLING FOR COMPRESSION MOLDED PARTS

Toray compression molded parts typically include a non-recurring tooling cost. Matched-metal tooling is required due to compression molding long-fiber BMC with high-fiber content which requires high pressures up to 138 bar (2000 psi) to fill complex features. It is also required that tolerances on the core and cavity halves of the tool must be tightly controlled so that entrapped air can escape while fiber and resin cannot. Based on these factors and the complexity of the part, tooling costs can range from beyond the basic cost of lamination tooling to lower than the cost of an injection molding tool.

THERMOPLASTIC PROCESS, SPEED, AND BENEFITS

While thermoset compression molding enjoys a long application history, thermoplastic compression molding is now experiencing more widespread use due to the benefits of thermoplastics compared to thermosets:

- Increased toughness (CAI increase of up to 40% more)
- Inherently meets Flame, Smoke, and Toxicity (FST) requirements without additives
- Natural resistance to solvents
- Infinite shelf life of BMCs at room temperature
- Recyclable
- Low VOC emissions
- Reformable
- Weldable
- Faster processing times
BILLET STOCK FOR PROTOTYPES

For low quantity and prototype parts it is often cost-effective to fully machine the part from a compression molded billet. This process bypasses expensive tooling costs and allows the designer to examine the form, fit, and function of a BMC molded part before committing to high rate production tooling. Billet is essentially a thick orthotropic layered laminate, which is a limitation. In the plane of the plate, properties will be close to quasi-isotropic, but through the thickness the properties are resin dominated, and therefore weak. The corresponding part machined from the plate will have similar limitations.

**BMC THERMOSET EPOXY**

<table>
<thead>
<tr>
<th>RESIN</th>
<th>DRY T&lt;sub&gt;d&lt;/sub&gt; ONSET</th>
<th>CURE TIME AND TEMPERATURE</th>
<th>KEY PRODUCT CHARACTERISTICS</th>
</tr>
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<tbody>
<tr>
<td>MS-1A</td>
<td>Epoxy 164°C (327°F)</td>
<td>15-30 minutes at 138°C (280°F) followed by post cure of 1-2 hours at 177°C (350°F)</td>
<td>Chopped fiber epoxy BMC with high modulus fiber</td>
</tr>
<tr>
<td>MS-1H</td>
<td>Epoxy 191°C (375°F)</td>
<td>15-30 minutes at 138°C (280°F) followed by post cure of 1-2 hours at 177°C (350°F)</td>
<td>Chopped fiber epoxy BMC with intermediate modulus fiber</td>
</tr>
<tr>
<td>MS-4H</td>
<td>Epoxy 191°C (375°F)</td>
<td>15-30 minutes at 138°C (280°F) followed by post cure of 1-2 hours at 177°C (350°F)</td>
<td>Chopped fiber epoxy BMC with high-strength (standard modulus) fiber</td>
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**BMC TORAY CETEX® THERMOPLASTIC**

<table>
<thead>
<tr>
<th>RESIN</th>
<th>PEAK T&lt;sub&gt;g&lt;/sub&gt;</th>
<th>PROCESSING TEMPERATURE</th>
<th>KEY PRODUCT CHARACTERISTICS</th>
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<tr>
<td>MC1100</td>
<td>PPS 90°C (194°F)</td>
<td>330°C (625°F)</td>
<td>PPS based BMC with high-strength (standard modulus) fiber</td>
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<tr>
<td>MC1200</td>
<td>PEEK 143°C (290°F)</td>
<td>385°C (725°F)</td>
<td>PEEK based BMC with high-strength (standard modulus) fiber</td>
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<tr>
<td>MC1322</td>
<td>PEKK 162°C (324°F)</td>
<td>380°C (715°F)</td>
<td>PEKK based BMC with high-strength (standard modulus) fiber</td>
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**AEROSPACE MARKET SEGMENTS**

- **AEROSTRUCTURES**
- **FORCES AND SATELLITE**
- **LAUNCHERS**
- **RADOMES**
- **AIRCRAFT INTERIORS**
- **ENGINES: HIGH TEMP**
**COMPRESSION MOLDING APPLICATIONS**

Compression molding offers both cost and weight savings by allowing complex composite parts to be fabricated in high volumes with short cycle times.

An example application that demonstrates the advantage of compression molded parts is in the Bell-Boeing V-22 Osprey. Compression molded parts have replaced honeycomb stiffened composite parts providing cost and productivity savings.

Toray can design the part, fabricate the tooling, and then move into full production to support your needs. For prototype parts or parts with limited production volumes, consider compression molded billet stock, which can be machined to shape.

A technical paper titled “Compression Molded Billet: Advantages and Usages” offers valuable information. It can be found on our website under Compression Molded Parts. [www.toraytac.com/compressionmoldedparts](http://www.toraytac.com/compressionmoldedparts)

**GENERAL DESIGN GUIDELINES**

<table>
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<tr>
<th>FEATURE</th>
<th>TOLERANCE</th>
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<tbody>
<tr>
<td>Part Weights</td>
<td>10g-5+ kg (0.25-12 lbs)</td>
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<tr>
<td>Dimension Tolerance</td>
<td>0.18 mm ± 0.007&quot;</td>
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<tr>
<td>Features Tolerance</td>
<td>0.13 mm ± 0.005&quot;</td>
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<tr>
<td>Iterative Tool Mods</td>
<td>0.08 mm ± 0.003&quot;</td>
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<tr>
<td>Wall Thickness - Minimum</td>
<td>~1.3 mm ± 0.05&quot;</td>
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<td>Draft Required</td>
<td>1-3°</td>
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<tr>
<td>Transition Radii</td>
<td>0.6-1.2 mm (0.025-0.05&quot;)</td>
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**MATERIAL PROPERTIES, TORAY BMCs, (SI UNITS)**

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<tr>
<th>PROPERTY</th>
<th>UNITS</th>
<th>MS-4H</th>
<th>MS-1H</th>
<th>MS-1A</th>
<th>MC1322**</th>
<th>MC1200***</th>
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<td>PPS</td>
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<tr>
<td>Fiber Content by vol.</td>
<td>%</td>
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<td>49%</td>
<td>52%</td>
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<td>59%</td>
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<td>Density</td>
<td>g/cc</td>
<td>1.50</td>
<td>1.50</td>
<td>1.52</td>
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<td>MPa</td>
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<td>GPa</td>
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<td>Shear Strength, F_xy</td>
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<td>177.9</td>
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<td>Flexural Strength, F_f^1/2</td>
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<td>Open-Hole Strength, F_OHC</td>
<td>MPa</td>
<td>265.4</td>
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<td>Compression After Impact, F_CAI</td>
<td>MPa</td>
<td>146.2</td>
<td>137.2</td>
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<td>Bolt Bearing Strength, F_br</td>
<td>MPa</td>
<td>859.4</td>
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</table>

* See data sheet for more information

** Laminate fabricated with 1.6mm x 12.7 mm (1/16" x 1/2") length Toray Cetex® MC1322 AS4D BMC.

*** Laminate fabricated with 25.4mm (1") length Toray Cetex® MC1200-IA BMC using xpress compression Molding Process
THERMOSET BMC PREFORMING PROCESS

The material is layered onto a flat pattern board.

The tacky material is compressed by hand while transferred to a preforming tool.

The preform is transferred to the cavity of the preheated compression molding tool.

Finished ribs.

To learn more, search for the following articles and case studies at www.toraytac.com

Top Five Questions Asked about Compression Molding
Hear answers from an expert on the most asked questions about compression molding at www.toraytac.com/literature (Articles section)

Toray Compression Molding Design Guide
To request a printed copy of this design guide, go to www.toraytac.com/processing-guides

BMC Billet Stock
Available products for cost-effective fabrication of a thick composite structure. www.toraytac.com/selector-guides (Product Highlights section)

Redesigning for Simplicity and Economy
Read about the compression molded access door for the Bell-Boeing V-22 Osprey at www.toraytac.com/literature (Articles section)
For more product information such as product data sheets, case studies, or technical papers, please use the following resources:

Search for the Toray TAC Product Selector

www.toraytac.com/bmc

Go to our online resource center for case studies and technical papers

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