COMPRESSION MOLDING & BULK MOLDING COMPOUNDS

Advanced Composite Materials Selector Guide

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

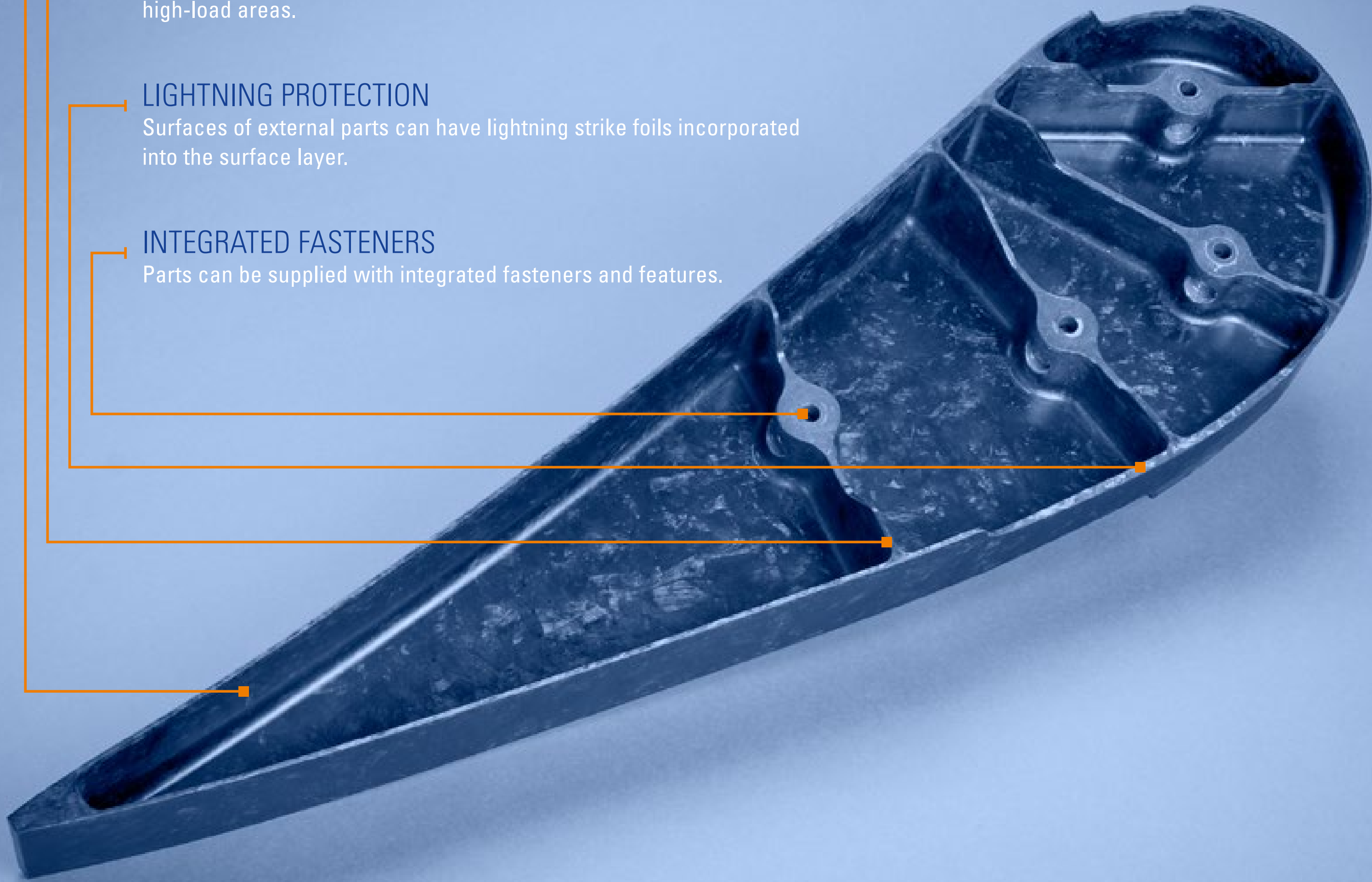
Parts can be optimized with ribs and stiffened assemblies to strengthen high-load areas.

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

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.

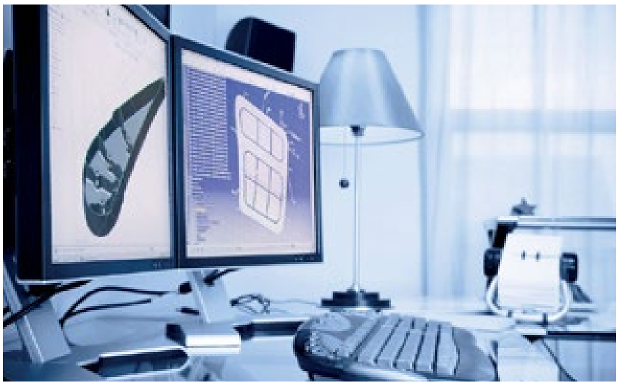
Compression molding using BMC is an enabling technology for the fabrication of complex composite parts for aerostructures, space, and satellites. Compression molding offers an alternative to machining and hand lay-up for intricate geometry components. The process also delivers cost and weight savings 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.

Bulk molding compound

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.

Figure 1. A simple metal bracket.

Figure 2. Replicates the design with composites, molded thicker overall at the same weight, added support near holes, and rounded edges.

Figure 3. Optimizes design, adding increased stiffness with molded ribs in higher load areas, reducing weight through narrow channel design.

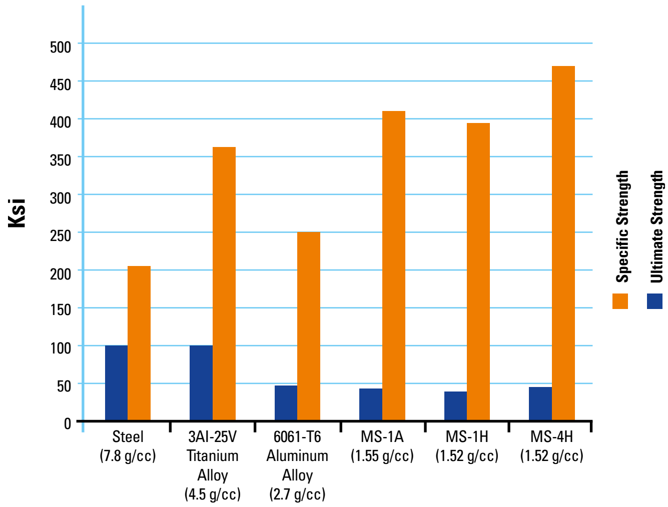
ADVANTAGES OF COMPRESSION MOLDED COMPOSITES

- 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 processsing 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

					AEROSPACE MARKET SEGMENTS					
	RESIN	DRY T_g ONSET	CURE TIME AND TEMPERATURE	KEY PRODUCT CHARACTERISTICS	AEROSTRUCTURES	SPACE AND SATELLITE	LAUNCHERS	RADOMES	AIRCRAFT INTERIORS	ENGINES/HIGH TEMP
MS-1A	Epoxy	164°C (327°F)	15-30 minutes at 138°C (280°F) followed by post cure of 1-2 hours at 177°C (350°F)	▶ Chopped fiber epoxy BMC with high modulus fiber	○	○	○			
MS-1H	Epoxy	191°C (375°F)	15-30 minutes at 138°C (280°F) followed by post cure of 1-2 hours at 177°C (350°F)	▶ Chopped fiber epoxy BMC with intermediate modulus fiber	○	○				
MS-4H	Epoxy	191°C (375°F)	15-30 minutes at 138°C (280°F) followed by post cure of 1-2 hours at 177°C (350°F)	▶ Chopped fiber epoxy BMC with high-strength (standard modulus) fiber	○	○	○		○	

BMC TORAY CETEX® THERMOPLASTIC

					AEROSPACE MARKET SEGMENTS					
	RESIN	PEAK T_g	PROCESSING TEMPERATURE	KEY PRODUCT CHARACTERISTICS	AEROSTRUCTURES	SPACE AND SATELLITE	LAUNCHERS	RADOMES	AIRCRAFT INTERIORS	ENGINES/HIGH TEMP
MC1100	PPS	90°C (194°F)	330°C (625°F)	▶ PPS based BMC with high-strength (standard modulus) fiber ▶ Fire retardant	○	○	○		○	
MC1200	PEEK	143°C (290°F)	385°C (725°F)	▶ PEEK based BMC with high-strength (standard modulus) fiber ▶ Fire retardant	○	○	○		○	
MC1322	PEKK	162°C (324°F)	380°C (715°F)	▶ PEKK based BMC with high-strength (standard modulus) fiber ▶ Excellent chemical and solvent resistance	○				○	

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

GENERAL DESIGN GUIDELINES

FEATURE	TOLERENCE
Part Weights	10g-5+ kg (0.25-12 lbs)
Dimension Tolerence	0.18 mm (± 0.007")
Features Tolerence	0.13 mm (± 0.005")
Iterative Tool Mods	0.08 mm (± 0.003")
Wall Thickness - Minimum	~1.3 mm (~ 0.05")
Draft Required	1-3°
Transition Radii	0.6-1.2 mm (0.025-0.05")

MATERIAL PROPERTIES, TORAY BMCs, (SI UNITS)

PROPERTY*	UNITS	MS-4H	MS-1H	MS-1A	MC1322**	MC1200***	MC1100	ALU	TI	301 STEEL
Fiber Type		SM carbon	IM carbon	HM carbon	SM carbon	SM carbon	SM carbon	6061-T6	6AL-4V	AMS 5518
Fiber Length	mm	25.4	12.7	25.4	25.4	25.4	25.4			
Matrix Type		Epoxy	Epoxy	Epoxy	PEKK	PEEK	PPS			
Fiber Content	by vol.	49%	49%	52%	55%	59%	59%			
Density	g/cc	1.50	1.50	1.52	1.61	1.61	1.61	2.77	4.43	7.92
Tensile Strength, F_x^t	MPa	302.0	255.8	289.6		288.9	206.8	303.4	1103.2	972.2
Tensile Modulus, E_x^t	GPa	42.7	68.9	131.0		43.4	41.4	68.9	110.3	179.3
Compression Strength, F_x^c	MPa	330.3	226.1	282.7		312.3		241.3	1061.8	420.6
Compression Modulus, E_x^c	GPa	50.3	63.4	110.3		48.3		70.3	113.1	179.3
Shear Strength, F_{xy}^s	MPa	177.9	166.9	131.0				186.2	689.5	530.9
Shear Modulus, G_{xy}^s	GPa	12.4	17.9	20.7				26.2	42.7	72.4
Flexural Strength, F_x^{flex}	MPa	750.1	439.2	461.9	541	657.8	496.4			
Flexural Modulus, E_x^{flex}	GPa	64.1	68.9	89.6	38.8	40.0	33.8			
Open-Hole Strength, F_x^{OHC}	MPa	265.4	209.6			282.0				
Compression After Impact, F_x^{CAI}	MPa	146.2	137.2							
Bolt Bearing Strength, F_x^{br}	MPa	858.4	664.0	365.4				461.9	1627.2	2013.3

* 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.
*** Laminates fabricated with 25.4mm (1") length Toray Cetex® MC1200-4A 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.

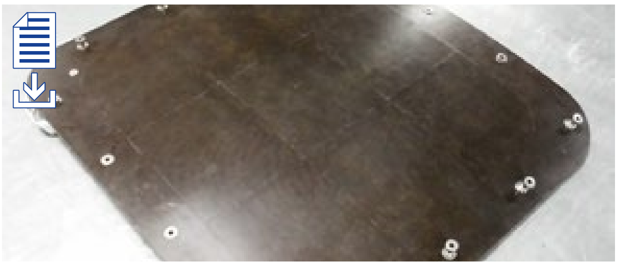
Finished ribs.

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

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

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

BMC Billet Stock
Available products for cost-effective fabrication of a thick composite structure. **www.toray**tac.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.toray**tac.com/literature (Articles section)

LOCATIONS

- Thermoplastic composites
- Thermoplastic laminates
- Thermoset composites
- Carbon-free manufacturing
- Parts manufacture
- Sales office
- ISO 9001:2015
- AS9100D

Fairfield - California, United States

Morgan Hill - California, United States

Camarillo - California, United States

Nottingham, United Kingdom

Nijverdal, The Netherlands

Toulouse, France

Guangzhou, China

Taichung, Taiwan

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For more product information such as product data sheets, case studies, or technical papers, please use the following resources:

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