COMPRESSION MOLDING OF LONG CHOPPED FIBER THERMOPLASTIC COMPOSITES

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ABSTRACT

When it comes to fabricating advanced composite structures, there is an array of fabrication processes available. However, when part complexity increases, performance is demanding and higher volume production rates are required the field begins to narrow. One such method that meets these criteria is compression molding with long chopped fiber thermoplastics. Compression molding is the process by which a charge of fiber reinforced prepreg bulk molding compound (BMC) is molded under heat and high pressures to form complex shaped parts. The BMCs under discussion are created by chopping existing unidirectional fiber reinforced thermoplastic tape into long lengths [6.4mm to 50.8mm (0.25 inch to 2.0 inch)]. These loose chips or strands are then weighed out to the exact amount required to fill the volume of a given tool, placed in a matched metal mold and heated and compressed to pressures that force the fibers to flow into the mold cavity, filling in every complex feature before cooling. Thermoplastic BMC compression molding requires a degree of mold temperature control not normally required by thermoset compression molding. TenCate/CCS uses a tooling concept called XPress to tightly control the mold temperature in zones over the surface of the part. Flat plates and a carbon fiber/thermoplastic bracket with complex features has been molded using this process. Structural test coupons have been molded and tested for stiffness and strength characterization. State-of-the-art design and analysis routines are now available to aid in the design of parts using these BMC materials.

1. INTRODUCTION

Compression molding of long, discontinuous fiber, thermoplastic composites had been around since the 1990's [1] where fiberglass and polypropylene found some application in the automotive industry. For years prior to this, thermoset based sheet molding compounds (SMC) had been and still are used. The aerospace industry has been using SMCs for years to fabricate covers and other secondary structures. BMC differs from SMC in that the BMC raw material consists of chopped flakes, chips or lengths of prepreg fibers rather than a continuous sheet of material made from continuous or discontinuous fibers. Carbon fiber is well suited for the aerospace industry due to its high strength and stiffness. Carbon fiber thermoset BMCs are currently being used on aircraft structures, for example, a V-22 Osprey access door [2] (Figure 1).

Thermoplastic BMCs are being recognized as a replacement to thermoset SMCs/BMCs when increased durability, inherently low flame-smoke-toxicity (FST), and faster part production times are desired. Thermoplastic BMCs require processing at higher temperatures than many thermosets. They also require a higher degree of temperature control during cool down to

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restrictive in geometric complexity. Thermoplastic compression molding allows for very long fibers, on the order of 25.4mm (1 inch) or more, to be integrated into a complex shape. Plus, BMCs offer a fiber content similar to continuous fiber laminated composites. Longer and more fibers provide a much stiffer and stronger material than the shorter/fewer fibers found in injection molding materials. Offering a complex shape with these higher mechanical properties is something that either injection molding or traditional laminated composites fabrication methods can do. For example, the helmet optical support structure shown in Figure 2 is incredibly complex.

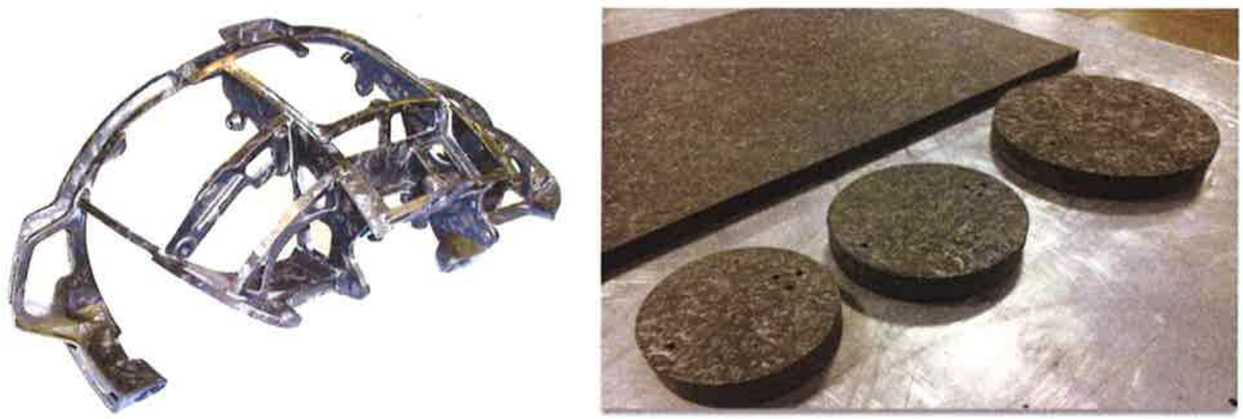

Figure 2. Helmet optical support structure and billet hard-points.

On the other end of the complexity spectrum, compression molding of simple billets, plates or pucks, up to 76 mm (3.0 inch) thick, can efficiently be used as hard-points in honeycomb panels (see Figure 2) or as raw material from which low quantity parts can be machined.

2.2 Ease of Replacing Metal Parts

The fact that very complex parts can be compression molded means that it's possible to take a part designed for metal and more easily convert it to a fiber reinforced part with little need for geometry changes. This just isn't possible with traditional laminated composite methods without also requiring a lot of post processing and machining. And, by nearly matching the metal part geometry, it may be possible to drop-in and replace the metal part without significant interface changes.

2.3 Inserts & Reinforcement Ribs

Adding inserts and reinforcement ribs is another advantage of compression molding (Figure 3). Metallic or other material inserts can be placed into the mold at the time of forming. These attachment hard points eliminate common secondary processes compared to other composite manufacturing methods. Also, by incorporating ribs into a part, which is easily done by simply adding such a feature to the tool, the bending stiffness and strength can be increased dramatically, with little if any change in part cost. It isn't all that easy to incorporate ribs into traditional laminated composite parts.

bonding and painting. All four of these polymers are excellent for higher service temperature applications ranging from 170°C to 260°C (340°F to 500°F) There are also many other BMCs more suited for industrial and automotive applications that use glass fiber reinforcements and thermoplastic engineering grade polymers like nylon. PP, PC, PE and PET.

The bulk molding compounds are in the form of chopped unidirectional prepreg tape. Figure 4 shows a typical sample of carbon fiber BMC. To produce the BMC, TenCate begins with using the Cetex® unidirectional prepreg tape for each of the polymers. The unidirectional tapes are then simply processed through a slitter and cutter that slits the BMC to the desired width and cuts it to the desired length. Fiber lengths range from 6.4mm to 50.8mm (0.25 inch to 2.0 inch). The most common length that gives a good balance between high strength and low material property standard deviation is 25.4mm (1.0 inch). Shorter fibers like 6.3mm (0.25 inch) can be used in parts that have a high degree of intricate detail so that fibers more easily migrate into the features. While the BMC fiber width can be such that the material is a perfect square, or a chip, the more common width is 3.2mm (0.125 inch).

Figure 4. Bulk molding compound.

3.1 Material Properties

Table 1 [5,6] shows the material properties of two thermoplastic BMCs compared to aluminum and titanium. In parts where the BMC can be more or less placed into all of the features in the mold, the fiber orientations for the BMC take on a near quasi-isotropic random layup. The table represents properties for this random layup. In cases where the BMC flows into features, the fibers become more aligned, especially near the edges of the mold, and properties begin to approach unidirectional values. Material properties for PEI and PEKK BMCs are currently under development at TenCate/CCS.

3.2 Material Testing

The material properties generated for Table 1 were assembled via coupon testing. Coupons were fabricated using the XPress tooling and compression process by fabricating flat plates and then machining coupons from the plate. As already discussed, the BMC is randomly applied to the

XPress. Essentially the XPress technology allows for the independent control of the temperature of the thermoplastic at up to 32 different locations within the mold. And, unlike thermoset compression molding, the temperature of the part being formed can be raised and lowered much more quickly. Figure 7 shows tooling in the press with the mechanism (left photo, white structure, top and bottom) that controls the heated zones of the tool. The right photo shows the 32 different heating zones. During the molding process each zone is monitored for temperature and is automatically adjusted to either maintain uniform temperature between zones or to add more or less heat in given zones. For example, if a part has very thick and very thin regions the heat zones can be activated to put more heat into the part where it is thicker and less where it is thinner.

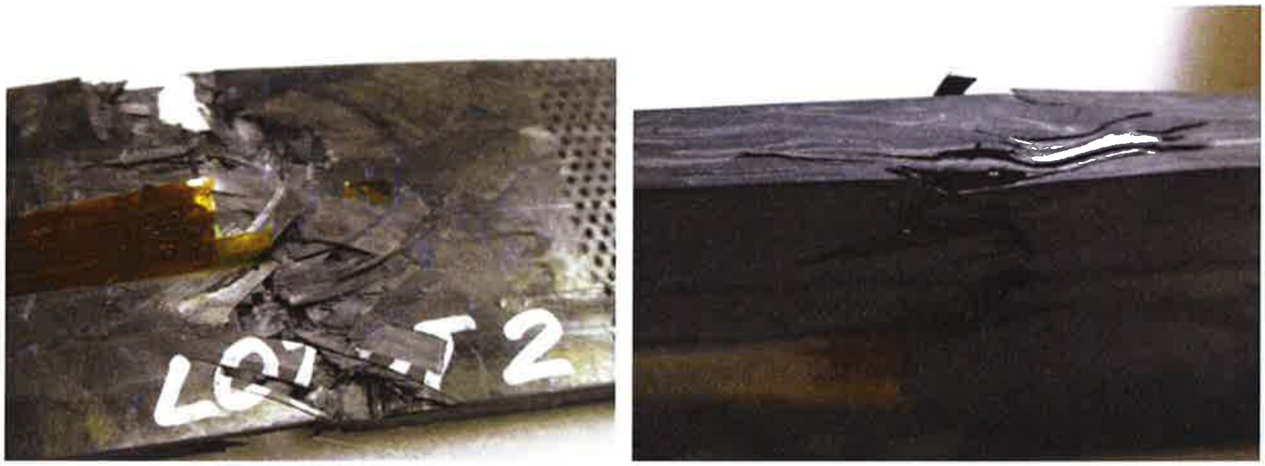

Figure 6. Tensile coupon failure modes.

Figure 7. XPress tooling setup and heating zones.

Aside from heating and cooling control, as is common to compression molding, there should be a shear edge on the tool with enough clearance to allow trapped air to transfer out but not the fiber and resin. During forming, the fiber will form a dam at the shear edge that prevents excessive bleeding of the resin out of the tool. Compared to many other thermoplastic compression are randomly "sprinkled" into the cavity. The bulk factor of the BMC is in the range of 4 to 8 times that of the consolidated part. Keep this in mind when designing the tooling so that there is enough depth to the mold to hold the compound.

Figure 9. Mold prep and BMC weight setting.

5.4 Compression Molding Cycle

The compression molding cycle is accomplished in 4 phases that transform the material from a loose chopped fiber compound to a rigid structural part (Figure 10).

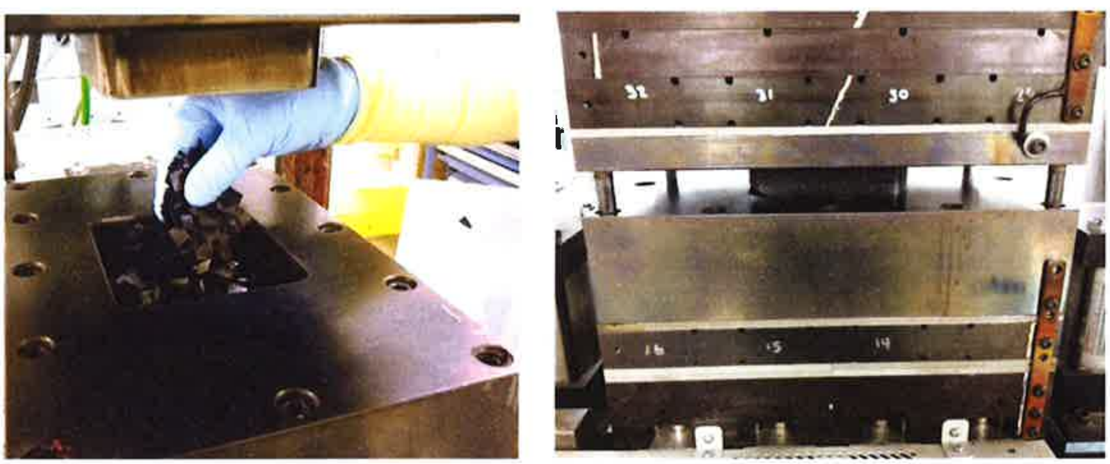

Figure 10. Apply BMC to mold cavity and close mold.

5.4.1 Heating

As the compound is added to the mold the temperature of the mold is increased to the molding temperature for the specific thermoplastic polymer per Table 2. It is advantageous to close the tool during the heat up cycle to a contact pressure of 13.8 to 20.7 bar (200-300 psi), as this allows heat to be transferred more quickly into the BMC from two sides.

leads to better creep properties and increased chemical resistance. Table 5 shows the recommended cooling cycles.

Table 5. Cooling cycle.

Thermoplastic	Cooling Cycle
PEEK	1. Hold pressure at the consolidation pressure 2. Cool part to between 5-20°C/minute. [Studies have shown [8] that rates of 0.5C/min. will produce 43% crystallinity, 5°C/min. will produce 32%, and 20°C/min. will give 25%] 3. Release pressure when part gets below the Tg of 143°C (290°F)
PPS	1. Hold pressure at the consolidation pressure 2. Cool part to between 5-20°C/minute. 3. Release pressure when part gets below the Tg of 95°C (203°F)

5.5 Demold and Deflash

The part can be removed from the tool when the temperature falls below the Tg of the polymer. There will always be a small amount of flashing that needs to be removed from the part perimeter, but note that the amount of flash is very small compared to the volume of the part. A diamond grit file is well suited to remove the flashing and any fibers (Figure 11).

Figure 11. Demolding and deflash.

6. DESIGN & ANALYSIS OPTIONS

One major question raised when it comes to applying long chopped fiber, compression molding to structures is the design and analysis of such structures. Closed form calculations on simple structures and finite element analyses for complex structures are desired when designing a part. The state-of-the art has advanced substantially recently and there are several options for aiding in the design of a structure with several analysis method options.

Difficulties encountered with designing and analyzing with these BMC materials are being alleviated with state-of-the-art, commercially available software tools.

8. REFERENCES

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