



Optimizing Part Design with Thermoplastic Composite Injection Overmolding

How localized reinforcement can reduce weight and improve performance

INTRODUCTION

Continuous fiber reinforced thermoplastic (CFRTP) composites are emerging as the next generation of composite materials for highly engineered and metal replacement applications. Overmolding CFRTP composites integrates tapes or laminates into traditional thermoplastic processes, such as injection molding with long fiber reinforced thermoplastics (LFT), to create locally-reinforced components. This process combines the design flexibility and fast cycle times of traditional molding with the strength, stiffness, and lightweighting benefits that composites offer.

Successful design and optimization of an overmolded component takes into account several key

considerations. This study examines the design, fabrication, and testing process for creating and optimizing a ribbed beam hat section demonstrator part using the following methodology:

1. A topology study to determine the optimal part volume
2. Mold flow analysis to optimize the injection flow path and burn-off testing to examine long fiber orientation and retention
3. Mechanical testing to compare the performance of various part configurations

The material used in this study includes Complēt™ long glass fiber reinforced nylon 6,6 and a four-layer Polystrand™ nylon 6 and continuous glass fiber reinforced laminate.

TOPOLOGY STUDY

The objective of the topology study was to optimize the geometry of the component, including the cross-section and volume, using a three-point bending load case. This was achieved through a process of design, volume optimization, validation, and comparison.

The simulated specimen is a solid, LFT cross-section construction. This full beam has a part volume of 314 cc (Figure 1). In the volume optimization simulation, different constraints were put on the structure of the beam to reduce the volume in three scenarios and a three-point bend analysis was conducted for each. The results in Figure 2 show the part volume required to react to the bending load in each of the three test cases.

Figure 1: Volume to be Optimized

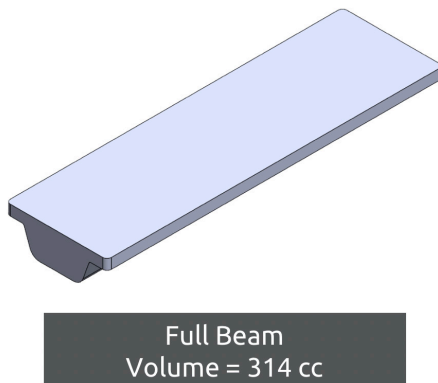
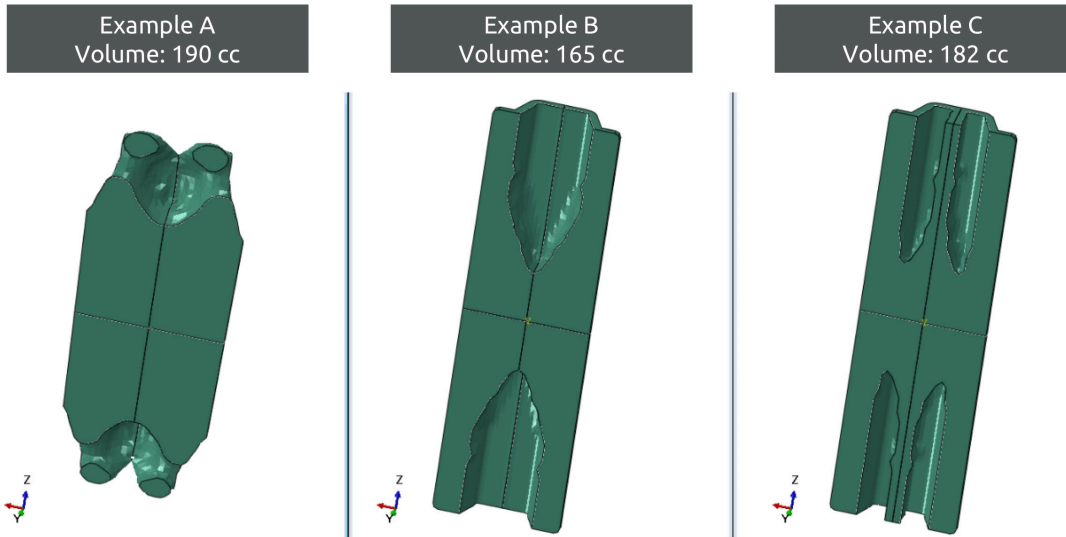


Figure 2: Part Volume Test Cases



Example A illustrates a scenario where volume is minimized without design restrictions or constraints. Material is reduced on the ends and partially along the sides of the structure, leaving a volume of 190 cc. In Example B, design parameters restricted the top and side sections of the beam from volume erosion, keeping this area of the part intact. Volume is reduced by removing material from the underside of the beam, leaving the sides of the structure to bear the bending load. A larger volume of material was removed, resulting in a total volume of 165 cc. Design restrictions in Example C left the top, sides and center line of the structure intact to enable those areas to bear the bending load, at a volume of 182 cc.

Figure 3: Reaction Force Comparison

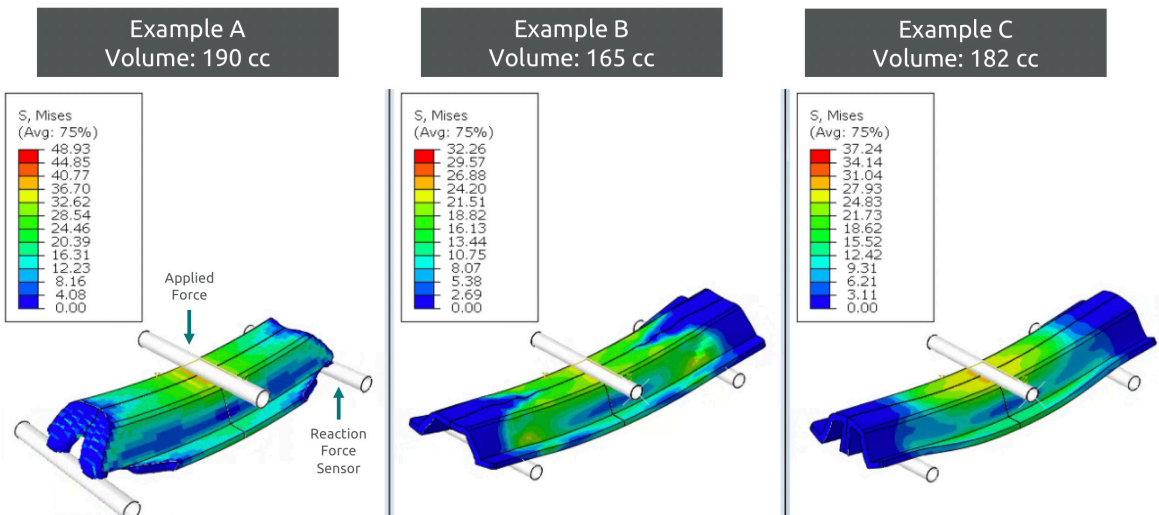


Figure 3 illustrates a comparison of simulated reaction force of the reduced-volume components. Example B in this simulation is buckling under the bending load, indicating that there is too little transverse strength or resistance to the load in the remaining geometry, specifically in the center line of the part. While Examples A and C produced part geometries that were able to meet the bending load requirements in this simulation, the resulting part geometries are not practical in terms of manufacturability. Taking these results into consideration, an LFT injection molded prototype was developed with a center ribbed structure that would withstand the bending load requirements, at a volume of 156 cc—a 64% reduction in total part volume. Test results from a physical reaction force test are illustrated in Figure 4.

Figure 4: Reaction Force – Prototype Ribbed Structure

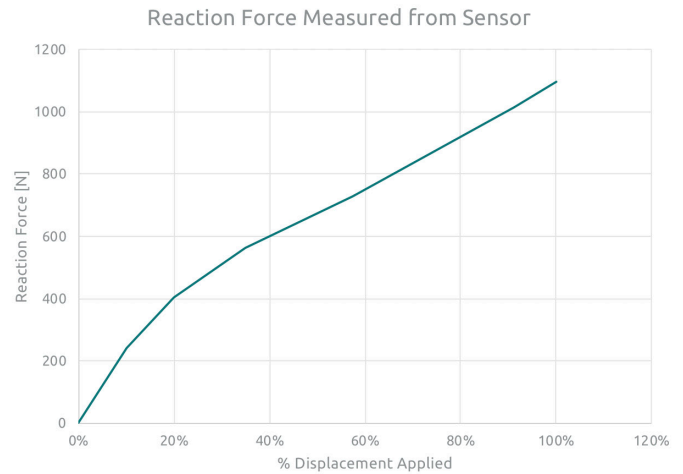
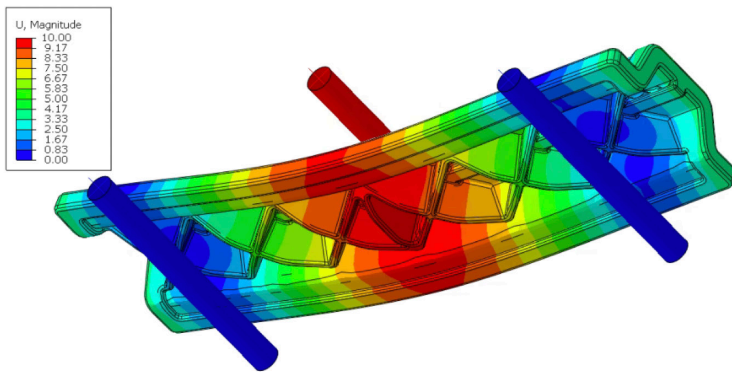


Figure 5: Volume and Reaction Force Comparison

TEST COMPONENT	VOLUME (CC)	VOLUME RATIO TO FULL BEAM SOLID STRUCTURE	MAXIMUM REACTION FORCE (N)	REACTION FORCE PER VOLUME (N/CC)
Full Beam Solid Structure	314	100%	n/a	n/a
Example A –No Constraints	190	39%	2526	13
Example B –Top and Side Constraints	165	47%	1563	9
Example C –Top, Side and Central Constraints	182	42%	1950	11
Prototype – Outside & Rib Structure	156	64%	1098	10

Figure 5 summarizes the volume and reaction force data for each of the components in the study. The last column in this table shows the ratio of the reaction force to the volume of the structure for each component. This figure is helpful in determining the optimal material configuration in this study. The lower the reaction force per volume, the more effective the use of the volume of the material in the structure.

Although the data for Example B component shows the lowest ratio and therefore appears to be the most effective, we know that the design has limitations, as previously discussed. A more robust structure such as the ribbed design in the prototype part will perform well in other load cases in addition to the three-point bend. In actual application, tests such as four-point bend and/or

torsional testing would be performed in addition to the simulations reviewed here.

MOLD FLOW ANALYSIS

Once the part volume and design have been determined through the topology study, mold flow analysis is useful in determining the optimal injection flow path to maximize the part's performance. This analysis will show flow behavior, orientation of the long glass fibers, and location of air gaps and weld lines. Resin burn off studies of the actual part are used to confirm the flow analysis. Together this information is used to optimize the mold fill process and determine where additional localized reinforcement would be most beneficial.

The images in Figure 6 depict the weld lines or knit lines in green and how the resin flows through the part. The resin enters from the left, fills the ribs and outer frame and then closes around the outer wall. This flow path affects how the glass fibers are oriented and where the weld lines are located. In Figure 7, the molded part is shown with air gaps and weld lines visible in the side wall (indicated with red markings).

Figure 6: Mold Fill

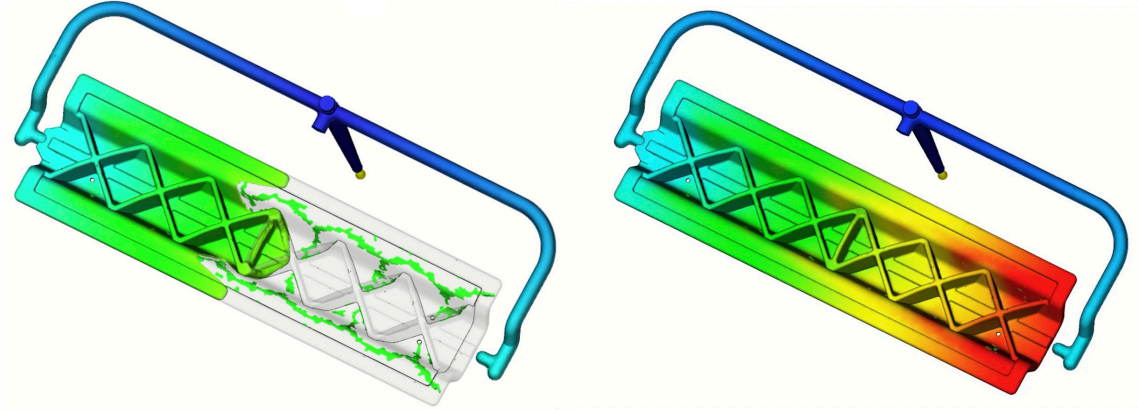


Figure 7: Air Gaps and Weld Lines



Figure 8 illustrates how the fiber orientation follows the resin flow path in the mold. The resin burn off results in Figure 9 show a correlation to the flow study, and the presence of good fiber length retention, as well as areas where the fibers are not able to cross the knit lines and intermingle.

Figure 8: Fiber Orientation

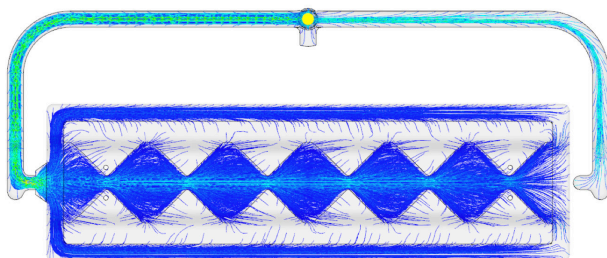
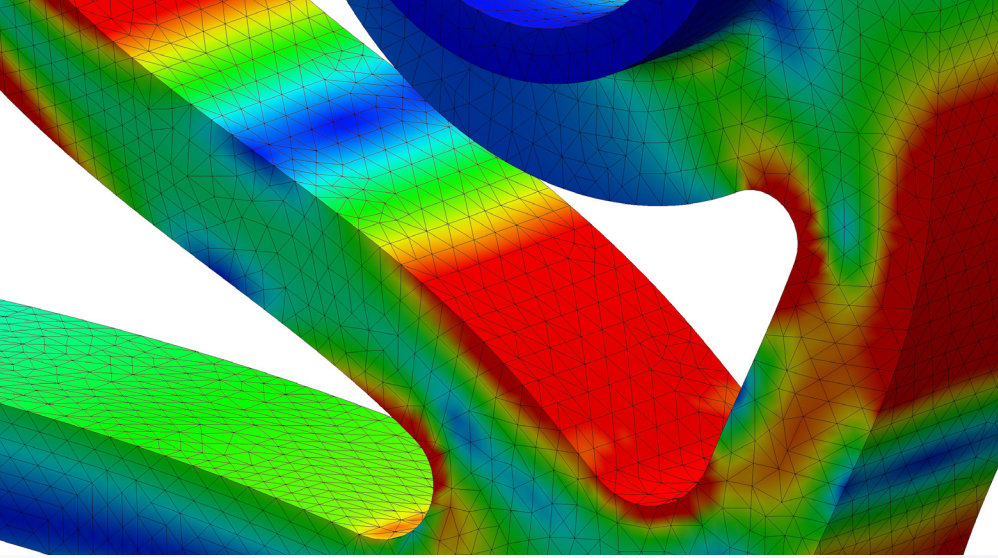


Figure 9: Resin Burn Off





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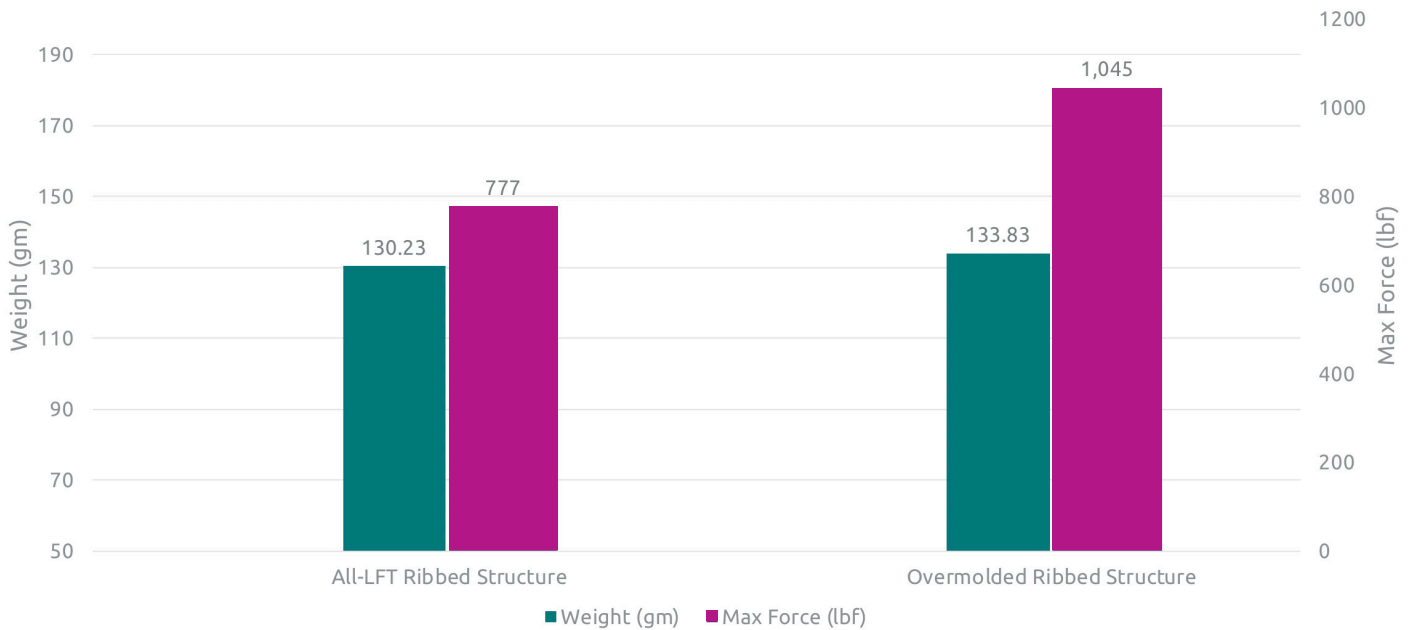
Figure 10: Injection Overmolded Ribbed Beam



CONTINUOUS FIBER REINFORCED LAMINATE FOR SELECTIVE REINFORCEMENT

The previous analysis reviewed the design of an all-LFT part, and identified areas of potential weakness in the molded design. Adding a layer of CFRTPL laminate within the injection molding process can provide additional reinforcement to the areas where weld lines and air gaps occur. In this example (Figure 10), a four-layer, $0^\circ/90^\circ/90^\circ/0^\circ$ oriented laminate was laid into the outer wall during the injection molding process. This layer of reinforcement adds localized strength to compensate for potential areas of weakness caused by weld lines and air gaps, resulting in improved mechanical properties as illustrated in Figure 11 (see page 7).

Figure 11: Performance and Weight Comparison



The key objectives in this study were to:

- a. Demonstrate the incorporation of CFRTP into a part structure via the injection overmolding process
- b. Optimize part volume and geometry to improve stiffness over alternative structures without significant weight increase

At the same thickness, and a negligible 4% increase in weight, the overmolded part achieved a significant 25% improvement in the force that the component is able to withstand compared to the LFT non-overmolded ribbed structure.

CONCLUSION

Injection overmolding with CFRTP integrates the performance benefits of continuous fiber composites with the design flexibility and fast cycle times of injection molding. This process can add value to applications that demand lightweight strength, stiffness, and impact resistance across a broad range of markets and industries.

For more information on incorporating injection overmolding with Polystrand™ CFRTP and Complēt™ LFT materials into your next project, please call **1.844.4AVIENT** or visit www.avient.com.