ADVANCED COMPOSITES ON THE FORD GT DECKLID

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Figure 1: Ford GT

Abstract

The presentation will review the engineering considerations that led the Ford GT team to the development of the industry-first one-piece carbon fiber inner panel for the rear deck engine cover and the associated manufacturing process.

While most of the structural components of the 2004 Ford GT are aluminum, the size and complexity of the rear deck, drove the team to use carbon fiber for the inner structure. Instead of using multiple stamped aluminum pieces to make the inner structure, the team decided to use carbon fiber composite technology to reduce weight, control dimensional accuracy, and for the total program cost benefit.

The paper will also discuss the manufacturing of the component, by Sparta Composites Inc. (San Diego, CA). The deck inner is made by hand lay-up of uni-directional carbon fiber/epoxy prepreg on an Invar mold for autoclave cure. In order to achieve the full-production rate of this complex panel, a number of techniques are employed, including a laser placement system, which simplifies lay-up operations.

1.0 Introduction:

The Ford GT is a unique, high-performance super car leading Ford's charge into its second century in the automotive industry (Figure 1, above). As such, the GT has some radical designs for a production vehicle, none more complex and difficult to produce than the rear decklid inner. This paper reviews the engineering considerations that lead the Ford GT team while developing the deck lid inner and associated manufacturing processes (Figure 2).

Figure 2: Decklid inner

2.0 Application

The decklid inner of the GT is a large (2 m by 1.4 m by 0.5 m) semi-structural part, in that it provides the shape/structure for the entire rear clamshell decklid of the vehicle. The inner is a functional cover for the engine compartment incorporating air intakes and water management devices, as well as wheelhouse closures with functional seals. It integrates details for wire harness mounts, rear glass, NVH padding, striker plates, lock pins, hinges and gas struts for opening and closing the decklid assembly.

3.0 Requirements

The deck lid inner as an integral part of the Ford GT is levied stringent requirements with respect to cosmetic and dimensional tolerance, weight, corrosion/temperature resistance, and cost.

3.1 Appearance

The cosmetic appearance of the inner is important, as it is highly visible with every opening of the engine compartment. Dimensional tolerances are crucial as the deck lid inner dictates the location and margin lines of the four class A outer panels hemmed to it.

3.2 Strength and Stiffness to Weight

The stiffness/strength to weight of the inner is significant for two reasons. The inner is the structural backbone of the large hinged decklid assembly. Unnecessary weight on a manually opened hinged panel of this size is unmanageable. Furthermore the size of the panel requires high stiffness for durability. Reducing weight in the rear of the vehicle improves weight distribution, further benefiting the world-class performance of the Ford GT.

3.3 Temperature and Corrosion

The Ford GT is already a classic and therefore long-term durability and functionality is vital. Corrosion and break down from temperature is not acceptable on any vehicle, especially one destined to be in showrooms for decades. The decklid inner must be able to withstand underhood temperatures in excess of 120°C without degradation of the substrate.

3.4 Cost

The Ford GT is a vehicle of world class performance and style offered at a fraction of the cost of its competition. Production for the deck lid inner must be cost effective for a 4500 unit vehicle program. Tooling costs are also significant with respect to program costs considering the limited production volume.

4.0 Design

The decklid inner, like so many other automotive composite parts, started out as a multi-piece metal assembly. Once it was determined that the shape complexity, costs, and dimensional tolerance capabilities of the multi-piece aluminum design were outside the targets for the program, the designers at Mayflower Vehicle Systems (MVS) created a 4-piece design that using an aluminum header and engine cover with composite left and right rear quarter panels (Figure 3). Once again the assembled dimensional tolerance capabilities and the cross-car stiffness/strength properties of this design strayed outside program targets. Ford/MVS engineers found the solution, a single piece composite part (Figure 4).

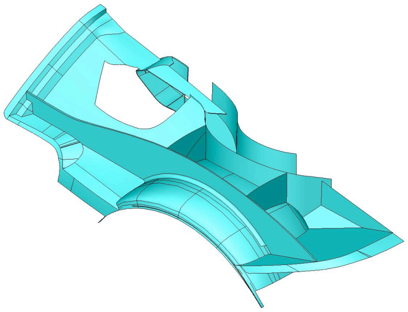

Figure 3: Early quarter-panel design concept

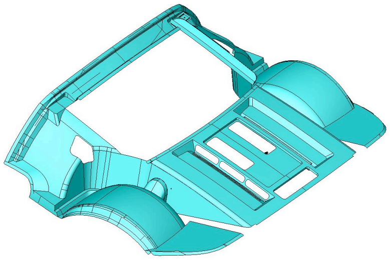

Figure 4: Early integrated design concept

5.0 Production Process Trade Studies

The program team completed an exhaustive investigation of various composite processes and materials capable of producing a composite decklid inner. The processes were investigated for part cost, tooling cost, lead-time, and part function. Processes investigated included compression molding sheet molding compound, resin transfer molding (RTM) short and long fiber reinforcements, and autoclave processing.

5.1 Compression Molding

Compression molding of sheet molding compound offered the lowest recurring part cost and the highest tooling cost. The lead-time was several months as the tooling was significantly more complex than other processes. To make a successful component using SMC, the part would need to be redesigned for manufacturability. The finished product would be considerably heavier than the other processes as the material thickness capability of the process required a panel nearly double that of other composite processes.

5.2 Resin Transfer Molding

Compared to compression molding, RTM offered lower tooling costs and shorter lead times. Lead times were still considered long, as the RTM process would take time to develop a satisfactory repeatable process for the decklid inner. The part cost was considerably higher than compression molding, requiring significantly more touch labor to produce a part. RTM also required a slightly thicker part than autoclave processing and therefore was not the lowest weight approach.

5.3 Autoclave Processing

Autoclave processing, because of single sided tooling, offered relatively short lead times and low tooling costs. The autoclave processing was also a proven, robust process, i.e., low risk, and generated the highest performance component. The part could be designed at the same thickness and contour of a metal part, at approximately 60% the weight of aluminum. Autoclave processing became truly competitive when the program team investigated lower cost unidirectional carbon fiber pre-preg. Also, the low volume of the program made the cost savings (from less redesign and low tooling costs) significant enough to offset the relatively high recurring cost. Autoclave processing commonly classified as an “expensive” process actually showed the lowest total program cost, and the highest component performance. It became an easy decision for the program team to make.

6.0 Manufacturing Trade Studies

During the program’s development, Sparta performed trade studies to determine the best approach to a number of manufacturing issues. Each study was performed for reasons specific to the decklid inner program. Variables such as material cost, production rate, labor savings, consumable costs, and scrap rate all weighed into the decisions.

6.1 Textile Form. Vs Lamination Labor Savings

Unidirectional material was selected as the baseline material. Sparta engineers estimated the time required to laminate the decklid inner using unidirectional material, and a number of different woven, stitched, and "system" (material systems designed for building body panels) materials.

The detailed contours of the deck inner were significant enough to require considerable material splicing for even the most drape-able materials. Woven, stitched, and "system" type materials showed significant labor savings (vs. unidirectional material), but the 3x-4x higher cost per pound did not offset the labor savings. Sparta engineers did conclude however, that "system" type materials would meet the need for less contoured panels, and class A surface finish applications.

6.2 Production Rate

A significant factor in the decklid inner program was the rate required to meet demands of the Ford GT build. The limited tooling budget of the Ford GT program could not afford multiple molds. The initial rate prediction by Sparta engineers on a single tool was 6 parts per 24-hour shift. This was based on a timeline that included 3 hours for lamination, and 1 hour for cure, demold, and tool prep before repeating the cycle.

As the program matured, necessary build rate increased from 6 to 9 parts per day. These rates are easily achievable in the context of typical automotive components, but for a hand laminated composite part of this complexity, 9 parts per day on a single mold is not typical. Lamination and cure performed in serial path on a single mold could not meet 9 parts per day. Sparta engineers investigated several possible paths to meet rate. Oil heating was investigated as a method of accelerating the cure (conduction vs. convection). This helped rate but would still not meet the 9 per day target. Two (2) additional molds would be necessary to meet rate using the baseline lamination approach, a cost the program was not willing to absorb. The choke point of the process was obviously the 3-hour lamination step. This manual task unfortunately did not offer much potential for improvement. The solution devised by Sparta engineering was to de-couple the lamination step from the cure step. This allowed parallel processing of lamination and cure. Lamination could take place off line on low cost lamination fixtures. The additional cost of the fixtures was acceptable as the fixtures were an order of magnitude less expensive than additional invar molds.

6.3 Miscellaneous Cost Reduction

SPARTA completed additional studies to reduce touch labor and recurring cost. The deck inners all are laminated beyond edge of part (EOP) and trimmed to the final dimension. Trimming the parts on a 5-axis router vs. using a drill fixture and hand router mask was determined to be most cost effective. The autoclave process dictated vacuum bagging the part for consolidation. Sparta engineers investigated the cost of reusable bags vs. the disposable bags. Re-usable bags proved most cost effective when factoring in the amount of labor to apply a disposable bag. Reusable bags also yield a more repeatable product.

7.0 Process Development

Along with cost trades Sparta performed several process development steps to make it possible to deliver deck inners meeting Ford GT requirements. The automotive industry dictates a different approach than typical aerospace applications where this composite technology was developed. Components are expected to be consistently high quality, repeatable, and produced at a rate much faster than typical aerospace industry standards. The higher rates also dictate more risk reduction activities, and reaction planning. If a piece of key production equipment goes down for a week, the entire Ford GT production line is stopped. To meet the high rates and low cost targets it is essential that any waste is eliminated from the production process.

7.1 Laser Projection

The complexity and size of the decklid inners dictated from the start that Sparta handle the lamination task differently than usual. The complex lamination included over 200 different patterns, making each part a complicated jigsaw puzzle. Sparta used a laser projection ply templating system from Laser Projection Technologies (LPT, Londonderry, N.H., U.S.A.) to assist technicians with solving the puzzle. Laser beams projected from above outline the current ply on the lamination fixture showing the operator where to place it. The laser projection system ensures the plies are laminated in the same orientation and sequence on every part. With over 200 plies per part, cutting the patterns from the raw material is a daunting task. Sparta used its Autometrix CNC cutting table (Grass Valley, CA, U.S.A.). The table cuts patterns from large rolls of material. The cutting table cuts patterns much more quickly and accurately than hand cutting. To save on material costs Sparta used nesting software to determine where each ply is "nested" on the table. The nesting software optimizes location of the plies determining the most efficient use of material with those shapes. With over 200 different plies on the table, sequencing them becomes an issue. Laser projection was again used to show the technician which ply to pick up and in what order.

7.2 Ply Development

To create the flat patterns cut by the CNC table and the projected 3D laser boundaries Sparta used FiberSIM^{TM} CAD-integrated design/analysis software, supplied by Vistagy Inc (Waltham Mass). FiberSIM allowed engineers to virtually laminate onto a CAD model of the mold, and simulate the manufacturing process. FiberSIM simulates fiber angles, material splices, darts, and material wrinkling (Figure 4). This information allows engineers to adjust the ply boundaries to compensate for geometry. Then FiberSIM takes the 3D boundaries developed by the engineer in 3D and flattens it for cutting on the CNC cutting table. FiberSIM also outputs the laser projection data to the Laser heads to project the 3D boundaries on the lamination fixtures. FiberSIM allowed Sparta engineers to develop ply patterns and a lamination schedule while the mold was being designed and built. This allowed initial prototypes to be delivered in much less time than would have been possible otherwise. FiberSIM has also allowed quick adjustments to patterns in areas that have not been as cooperative as the computer simulated.

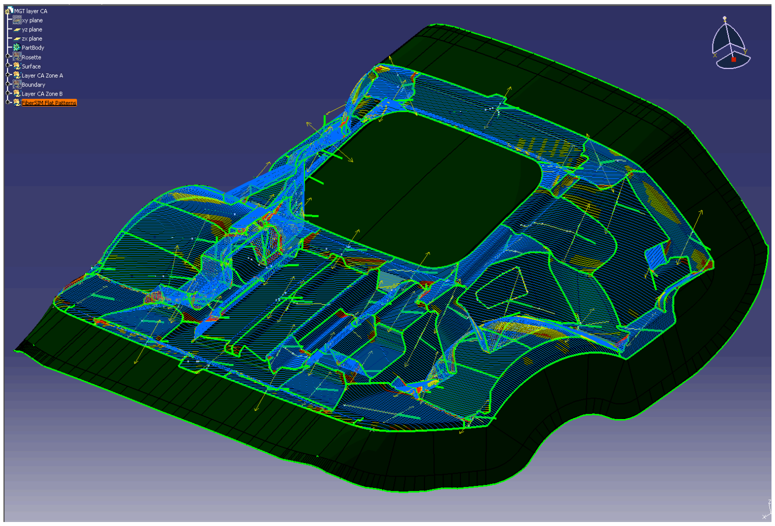

Figure 5: FiberSIM simulation of decklid inner laminate

7.3 Cure Profile Development

Extensive testing was done to develop the pressure and temperature profile used in the autoclave to cure the deck inners. Initial tests were run on flat plates with the production material. These initial tests were to check for extent of cure, and surface appearance, and improve production cure time estimates. Once the tool was complete, further testing was necessary to optimize the airflow over and under the mold. The extreme contour of the part required significant manipulation of the air stream to yield satisfactory parts with such an accelerated cure schedule. Once a production representative cure schedule was developed Sparta fabricated a number of flat panels for characterization testing at Ford Scientific Research Labs (see appendix 1).

7.4 Trimming Development

CNC trimming of the decklid inners on the 5-axis router also required process development. Sparta used a 5-axis router from Thermwood Corporation (Dale, Indiana). The continuous 5-axis cutter path was developed using Tebis^{TM} CAM software (Figure 6) from Technische Informationssysteme AG (Munich, Germany). Testing was performed to determine the ideal feeds and speeds of the router, as well as cutter characteristics. The objective of the development of the cutting process was always to trim the parts quickly and accurately while minimizing the touch labor required for deburring.

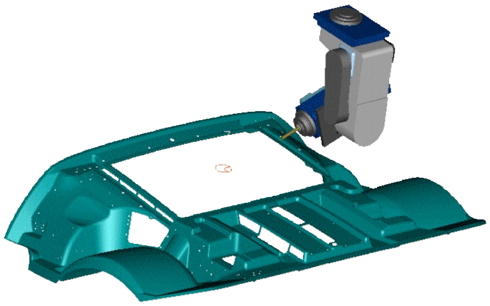

Figure 6: Tebis machine run simulation

Inspection of the deck inners was another development area. Composite components had been supplied on Ford vehicles before, but not unpainted carbon fiber as a production application. A visual acceptance criterion was developed to quantify acceptable and unacceptable conditions on the components, such as voids, surface pitting, scratches, bridging, and other appearance defects. This was accomplished collecting empirical data on acceptable parts and unacceptable parts and creating a baseline from which to accept or reject parts.

8.0 Production

Volume production takes place in Sparta Composites San Diego facility. All processes for each part are tracked and recorded on travelers that move with parts from operation to operation. SPC data on critical dimensions and any rework is recorded and monitored by Sparta QA and engineering.

8.1 Material Kitting

The first step in the production of the decklid inner is the kitting of plies to be laminated later. There are over 200 plies per part. These must be arranged in the order they are laminated so the technician is not spending time looking for the correct ply while laminating. The kits are created by cutting raw pre-preg material on SPARTA's CNC cutting table (Figure 7). The patterns have been nested in a predetermined "nest" and are cut accordingly. . A laser projection system shows the technician which order to pick up the plies (Figure 7). The plies are picked up in the reverse order of lamination so the first ply ends up on the top of the stack of plies After all of the plies have been collected in the proper sequence the kit is placed in a plastic bag sealed. The kits are either sent to the lamination station or frozen for storage.

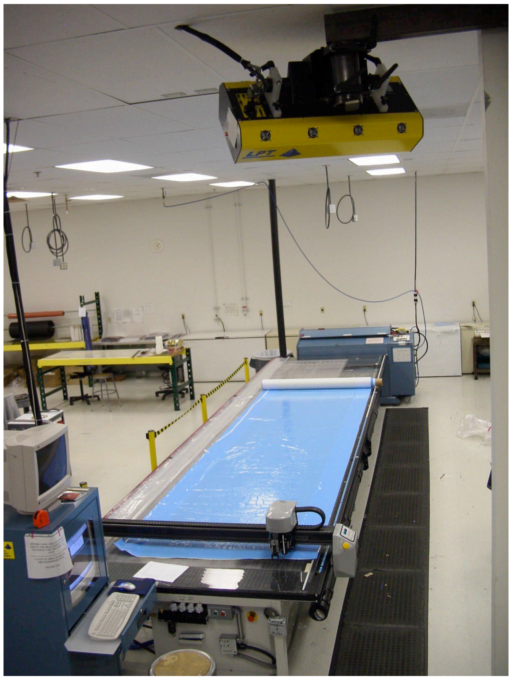

Figure 7: Autometrix CNC cutting table with LPT Inc. laser projection head above

8.2 Lamination

Plies are laminated one at a time onto the lamination fixtures. The outline of the ply to be laminated is projected onto the fixture by a laser projection system (Figure 8). At predetermined intervals the laminate is debulked, by pulling a vacuum on the fixture with the reusable vacuum bag. After debulk, the lamination proceeds as previously described. This process repeats until the entire lamination has been completed. The lamination is made up of primarily unidirectional carbon fiber prepreg. In certain areas fiberglass is applied for galvanic corrosion protection, and peel ply for bond prep.

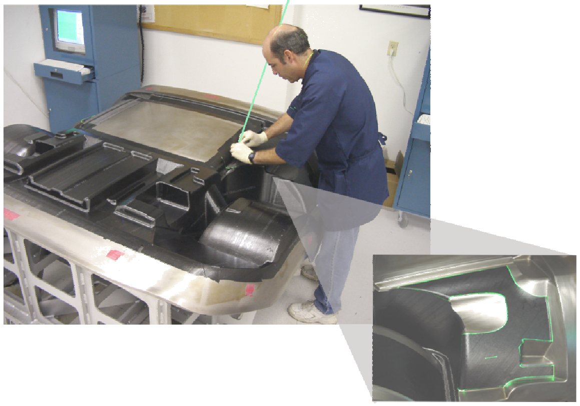

Figure 8: Lamination with laser projection

8.3 Cure

The finished laminate is placed onto the previously prepared Invar™ mold. It is then vacuum bagged, and the bag checked for leaks. Passing the vacuum check the mold is loaded into the autoclave, vacuum and thermocouple connections made (Figure 9), and the autoclave door closed. The technician enters necessary information into the cure database and starts the cure. The autoclave is PLC controlled and follows a predetermined ramp and soak of pressure and temperature. The autoclave also records temperature data read from the thermocouples attached to the mold and in the autoclave. This data is recorded and kept on file referencing the part serial number.

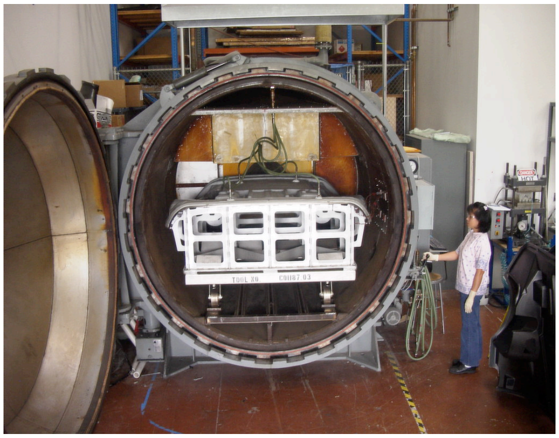

Figure 9: Mold in autoclave with vacuum connected

8.4 Demold and Mold Prep

After the cure is complete, the mold is removed from the autoclave and the part is demolded. Technicians break the flash around the perimeter of the part and pneumatic actuators “pop” the part off the mold (Figure 10). The part is visually inspected for surface appearance and placed on a rack for further processing. The mold is then prepped for the next cure. The mold is completely cleaned of any cured resin, new thermocouples are installed if necessary, and mold release is applied.

Figure 10: Removing part from mold

8.5 Trim

The molded part is taken to the router station for trimming. The part is placed on the trim fixture and vacuum applied to restrain the part (Figure 11). The machine operator starts the program and deburrs the previously trimmed part while the NC router performs the trimming operation. After trimming the operator unloads the part cleans the fixture, starts the next part and then manually deburrs the deck inner. After trimming and deburring the part is cleaned and washed for shipment (Figure 12).

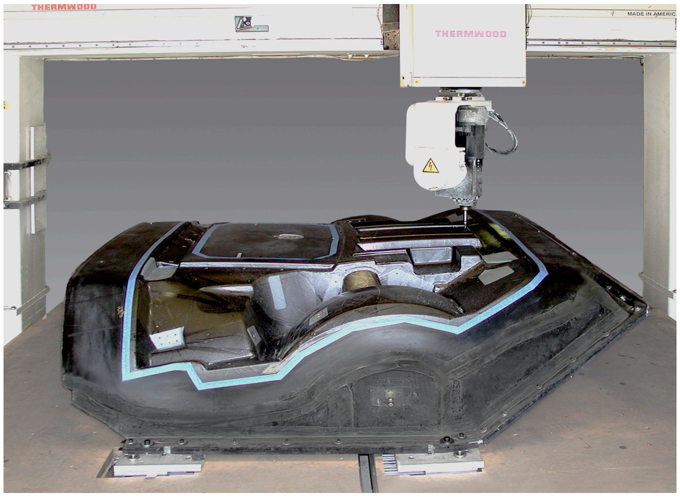

Figure 11: Deck lid inner trimmed on 5-axis router

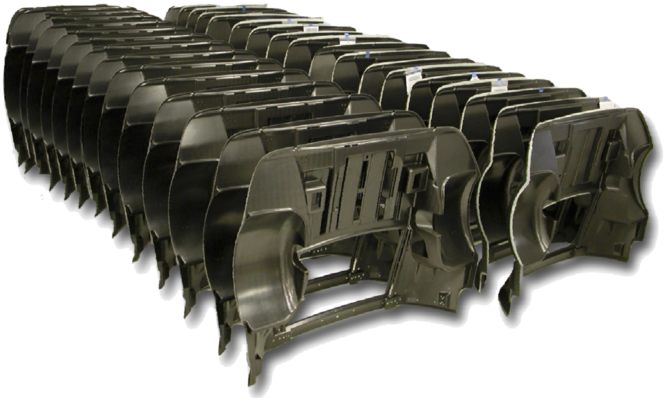

Figure 12: Decklid inners

8.6 Inspection

Completed parts are visually inspected for surface appearance, and dimensionally inspected on a check fixture. The check fixture loosely restrains the part in the "in-car" position. A portable CMM is used to verify surface and trim edge dimensional compliance. Hole location is also verified with the portable CMM and hole size is checked with go/no-go gauge pins. The finished weight is measured and recorded. Inspection data is collected in a data file and specific characteristics plotted into SPC charts for Sparta and customer review.

8.7 Packaging and Shipment

Deck lid inners are packaged in boxes of 3 inners each and shipped on dedicated trucks to the customer facility. Parts are shipped on an as needed basis.

9.0 Future Applications

The capabilities and lessons learned developing the processes to produce the deck lid inners have application in many areas. Although higher rates are achievable the described technology is not suitable for typical high volume automotive production. It is suited to niche vehicle production where lower tooling costs, and higher component performance are desirable. This technology is applicable to Class A as well as less finish critical components. Adaptations of this technology are also suitable for structural applications. Advanced composites are considered primarily for weight saving applications, but are often desirable for other reasons. Advanced composites offer part consolidation, design flexibility, engineered structural, magnetic, thermal, and electrical properties.

Appendix

Characterization Studies:

For this study static tensile testing was performed to determine the mechanical properties for Ford GT hood inner assembly. Evaluation was conducted on flat test plaques fabricated from epoxy resin carbon fiber pre-preg. Flat test plaques were processed and supplied to Ford Research Laboratory for the evaluation process using the Sparta / Toray quick cure process.

Test Specimen Preparation:

Tensile:

Tensile specimens were fabricated according to ASTM D638[1] test procedure. Straight-sided, 19.3 mm by 216 mm long blanks were cut from the plaques using a diamond-blade band saw. Next, a Tensilkut^{TM} system was used to route the specimens to the final dog-boned shape with a gage section width of 12.7 mm as specified in the D638 document. Specimens were sectioned in both a 0 and 90^{o} direction for each plaque.

Flex:

Flex specimens were fabricated according to ASTM D790[2] test procedure. Straight-sided, 127 mm by 25.4 mm long blanks were cut from two plaques using a diamond-blade band saw. Final specimen dimensions were established by wet polishing the edges of the specimens using a 400 Grit paper.

Specimen Testing:

Tensile Testing:

Tensile testing was performed in a MTS Sintech™ 30Kip test frame at a rate of 5 mm/minute. MTS Test Works 4™ software was used as the interface between the PC and test frame as well as collecting all data during testing. A 50.8mm extensometer was attached to the test specimen to determine modulus and strain to failure. A modulus was calculated over the strain range of 500-2500 ❍♏. Results from the two plaques reference tests for both 0 and 90° can be viewed in Table #1.

Table #1

Plaque 1

Specimen Dir. () = COV	Tensile Strength (Mpa)	Tensile Modulus (Gpa)	Strain to Failure %
0 Degree	718 (8.43%)	45.5 (5.71%)	1.50 (12.9%)
90 Degree	508 (1.88%)	33.1 (1.59%)	1.74 (7.47%)

Plaque #2

Specimen Dir. () = COV	Tensile Strength (Mpa)	Tensile Modulus (Gpa)	Strain to Failure %
0 Degree	724 (5.65%)	45.1 (2.80)	1.70 (9.64%)
90 Degree	518 (2.40%	30.7 (2.17%)	1.90 (4.58%)

Flex Testing:

Flex testing was performed in a MTS Sintech™ 30Kip test frame at a rate of 5 mm/minute. MTS Test Works 4™ software was used as the interface between the PC and test frame as well as collecting all data during testing. A modulus was calculated over a linear portion of the stress/strain curve. Results from the plaques tested can be viewed in Table #2.

Table #2

Plaque 1 & 2

Specimen () = COV	Flex Strength (Mpa)	Flex Modulus (Gpa)
Plaque 1	847 (3.22%)	79 (3.16%
Plaque 2	833 (2.60%)	79 (2.54%)

Characterization Discussion:

Results obtained from tensile specimen evaluation of the above plaques produced results that met stiffness targets derived from a 1.5mm thick aluminium material model. The corresponding strength and strain to failure values were sufficient to satisfy the requirements as well. Flex property results indicated values that were also sufficient for program requirements and did not cause concern for durability requirements.