COMPOSITE LIFTGATE DUCTILITY PERFORMANCE

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ABSTRACT

The FMVSS 301R Fuel System Integrity Test requirements on closures, as well as field experience, have increased demand on the liftgate performance. The energy imparted to the liftgate structure in this test configuration is difficult to absorb with inherently brittle composite materials. This report documents the load-displacement response of several reinforced composite liftgates. The liftgates were evaluated with a static test designed to simulate the deformations experienced in a rear 70% offset deformable barrier crash test.

INTRODUCTION

The system performance requirements of liftgates are affected by the new rear moving barrier test described in the revised FMVSS 301 Fuel System Integrity test [1]. While the test is configured to evaluate the rear crash performance of the fuel system, due care evaluation of the vehicle crashworthiness in this test mode is also monitored. In the new test shown in Figure 1, the tested vehicle will be impacted from the rear with a 1368 kg deformable barrier at more than 80 kph. In this test, the Barrier is aligned with the target vehicle but offset so only 70% of the rear of the target vehicle is impacted.

This impact can cause significant deformation of the rear structure of the vehicle which can result in large relative motion between rear body components. A typical pretest photo showing the sled with the aluminum honeycomb deformable barrier is shown in Figure 2[2]. Publicly available after-test photos are shown in Figures 3-4[2] and 5-6[3] for two vehicles currently available for sale in the US. These tests were performed by MGA Research Corporation in Burlington, WI for the National Highway Traffic Safety Administration (NHTSA). As shown below, relative displacements on the order of 200 mm can be observed in the lower portion of the liftgate and floor structure. Typically, the lower outboard corner of the liftgate on the unstruck side deforms very little while the striker and latch are moved forward much farther. This results in large (>200 mm) displacements in the striker and latch area relative to the rest of the liftgate.

A vehicle structure is designed to be stiff at low strains in the region of normal use. To protect the occupants in crashes, system ductility becomes important to absorb the energy imposed on the structure. The load-displacement (stress-strain) response for most composite materials is essentially linear. Current research to improve the ductility of composite structures is ongoing at GM and elsewhere with a goal of reaching a load-displacement response similar to Figure 7. This type of response is usual for metallic materials with a typical elastic-plastic material response. However, for composite materials often the inherent stress-strain response is much more linear with a brittle failure.

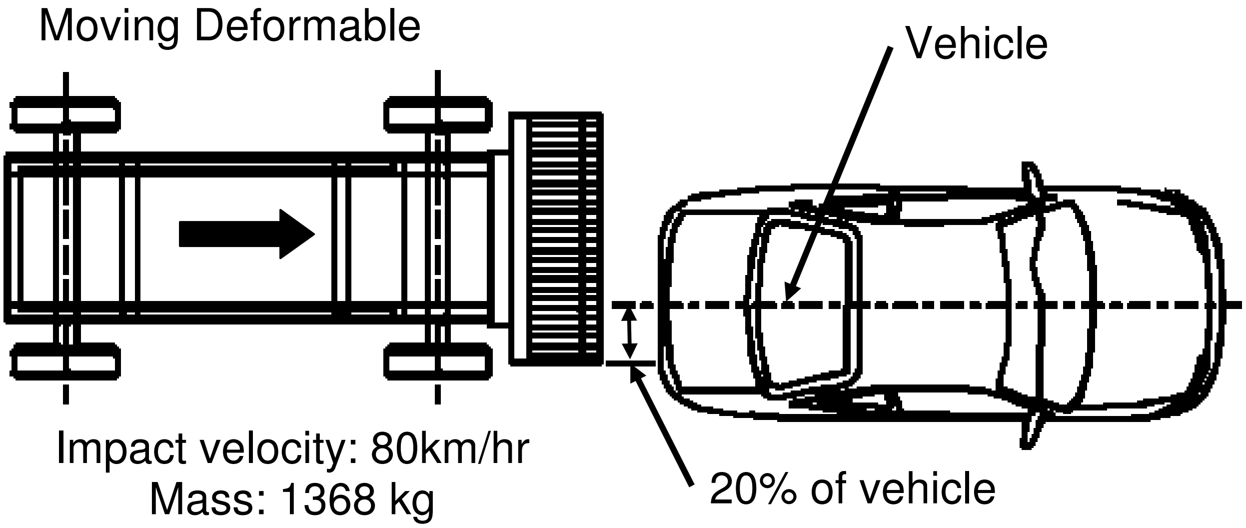

Figure 1. FMVSS 301 offset deformable barrier test configuration.

Figure 2. FMVSS 301 offset deformable barrier test configuration[2].

Figure 3. FMVSS 301 offset deformable barrier test results [2].

Figure 4. FMVSS 301 offset deformable barrier test results [2].

Figure 5. FMVSS 301 offset deformable barrier test results [3].

Figure 6. FMVSS 301 offset deformable barrier test results [3].

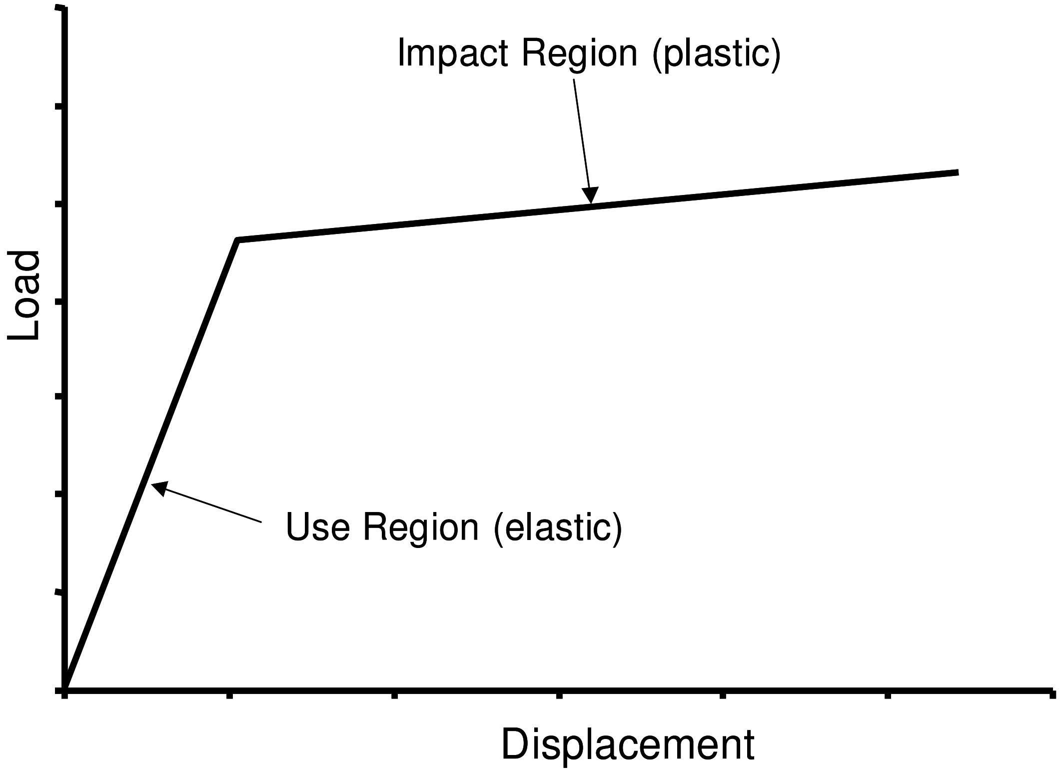

Figure 7. Desired load-displacement response of composite closures to be stiff in normal use but ductile in crash situations.

A composite version of a typical SUV liftgate was designed and built to investigate mass reduction over a typical production steel design. Rather than starting with a totally new liftgate, the development study imposed several constraints on the design. First and foremost was the assumption that the composite liftgate must directly replace an existing steel liftgate. This included using the same internal hardware and fitting the existing body opening and seal locations. For the program, mass was the major driver with a goal of reducing the liftgate-in-white mass by at least 30%.

The pieces that make up the typical production liftgate are shown in Figure 8. This liftgate shows one typical method of construction for steel liftgates. The liftgate-in-white consists of an inner and outer panel with a separate latchbox in this case due to packaging constraints for the latch. In addition, the hinge and beltline areas are reinforced with separate reinforcements for a total structural part count of 7. On this particular hinged glass design, the upper half of the outer panel is covered by three appliqués surrounding the glass on the top and sides. Only the lower half of the outer panel is a Class A cosmetic surface. Also note that due to steel formability constraints, almost 30% of the area of the lower cosmetic panel must be covered by a separate injection molded license plate appliqué.

Finite element analysis on modified versions of the liftgate was used to drive the design of the liftgate panels. In those analyses, a mathematical approximation known as isogrids[4-6] was used to model the stiffness enhancement resulting from using ribs to locally stiffen the panels. Given the design clues provided by the original series of finite element analyses, a Unigraphics CAD model was built and a detailed finite element model created for further analysis. After confirmation simulations on the detailed model were run, the aluminum injection and compression molds were built.

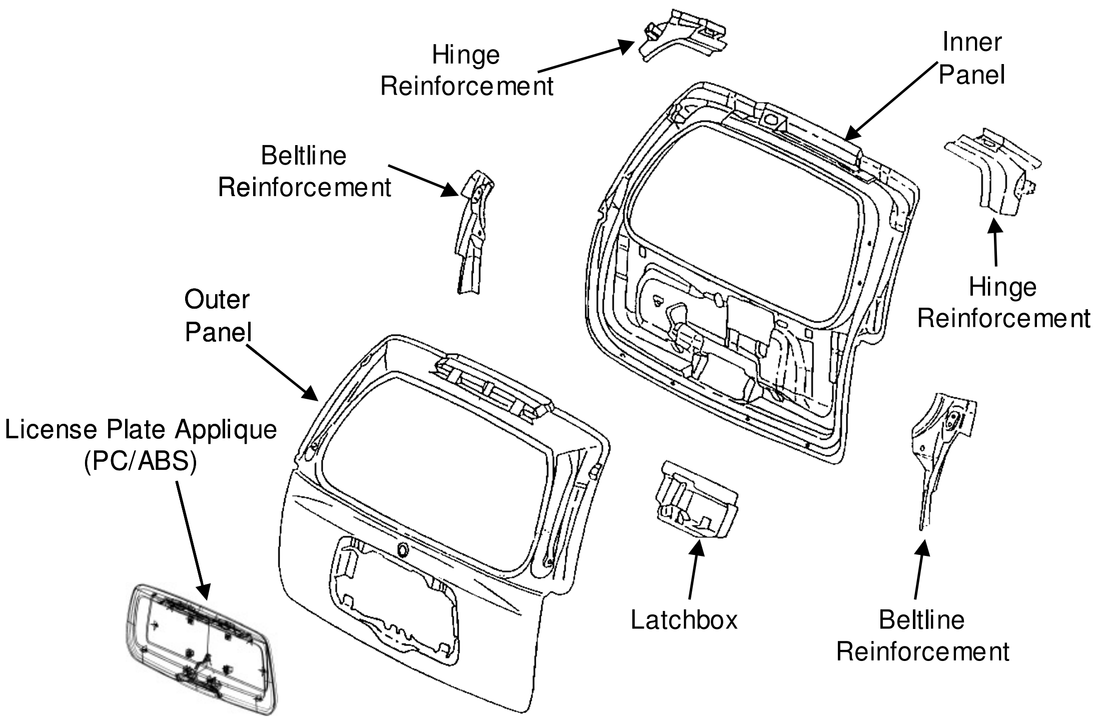

Figure 8. Typical steel liftgate panels and reinforcements.

As shown in Figure 9, the composite liftgate consists of three pieces. The inner panel and the upper portion of the outer panel were compression molded from long glass filled polypropylene. Materials molded in the inner panel tool have included glass mat thermoplastic (GMT), precompounded and in-line compounded direct long fiber thermoplastic (DLFT) materials. As discussed below, various materials have been overmolded in the latch region to reinforce the structure and improve system ductility.

The hinge and beltline reinforcements included in the steel design were replaced with ribbed reinforcement areas of the inner panel. The upper outer panel was a uniform thickness shell. Finally, the lower portion of the liftgate was covered with an injection molded TPO panel with the license plate pocket integrated into the panel.

As shown in Figures 3-6, the FMVSS 301 test results in very large displacements in the rear of the vehicle. In the vicinity of the unstruck lower corner of the liftgate and the entire region above the beltline, there are usually minimal displacements. However, the situation is very different on the struck side and in the center of the vehicle. Displacements of the striker greater than 200 mm have been observed.

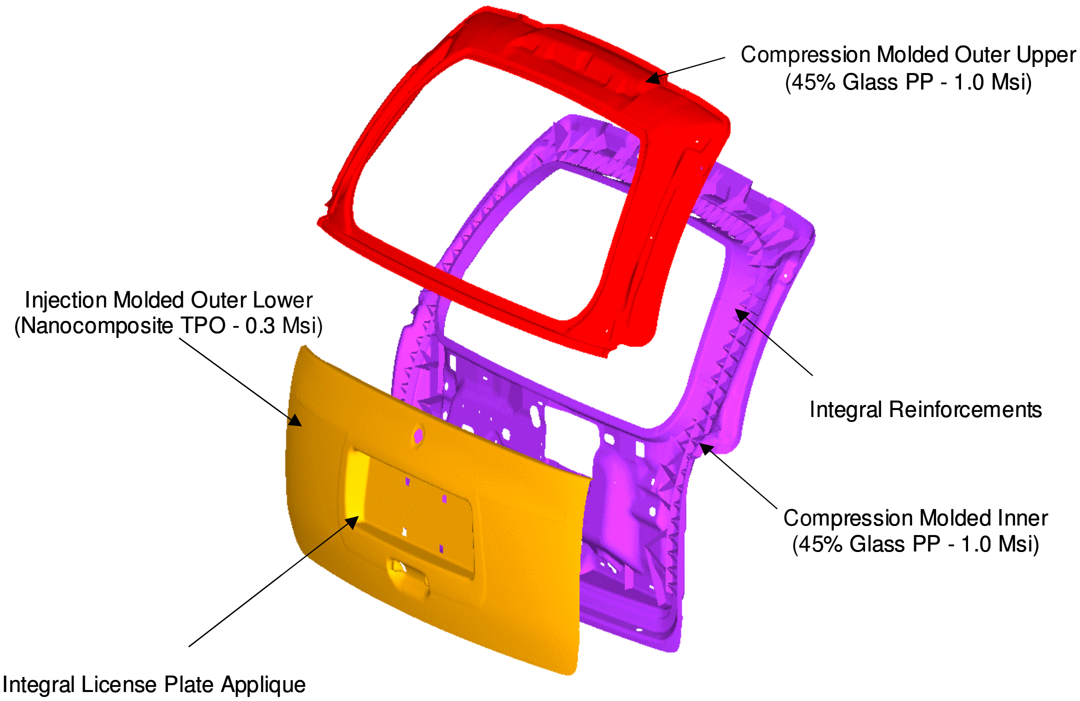

Figure 9. Composite technology demonstration liftgate panels and reinforcements.

The test shown in Figure 10 was constructed for development purposes to simulate the dynamic deformation of the liftgate in the 301 test configuration . This testing has been performed in several different but similar setups. The liftgate sample was suspended by bolting the body side hinges to a crossbar. The liftgate was then positioned in an approximately closed position with the latchbox bottom surface parallel to the bedplate. Two stanchions were then placed against the bottom edge of the liftgate inner panel to constrain the liftgate from moving forward. A fixtured striker fully latched to the liftgate was used to apply a forward displacement to the latch. Displacements were recorded using the LVDT transducer integrated into the hydraulic actuator. Forces were measured using a load cell attached between the hydraulic ram and the striker. The actuator was stroked forward in car 250 mm of displacement, held and then returned to zero. Testing rates were quasi-static at speeds of 1-2 mm/s.

RESULTS AND DISCUSSION

The unreinforced liftgate inner panel, shown in Figure 11, displayed the behavior one might expect for an inherently brittle material. In this case, the panel cracked where the latchbox blends into the inner panel. Even though the inner panel was molded in one piece, this was still a high stress area driven by the geometry of the part and the boundary conditions. After the first crack appeared as shown in Figure 11b, the latchbox separated from the inner panel as the crack propagated.

One way to maintain the connection between the latch and the structure is to use a tether. To test this philosophy, a tether system was designed to connect the latch to the liftgate structure. As shown in Figure 12a, this system consisted of a folded steel strap that was attached under the latch on one end and to the inner panel structure on the other end. A backing plate on the opposite side of the inner panel was used to anchor the strap (Figure 12b). In the test, the initial phase was virtually the same as the previous test without the tether. After the latchbox separated, the strap unfolds with very little force until it draws taut. After the tether tightens, the inner panel is reloaded and deforms until fracture.

After testing the unreinforced inner panels, the four reinforced inner panels shown in Figure 13 were tested. In the case of the “GMT – GMTEX” panel, a patch of Quadrant’s GMTEX [7] material was laid into the mold over the latchbox and then covered with the rest of the GMT charge (50 mm random chopped fiber). Both materials were heated at the same time in the conveyor oven and molded at Continental Structural Plastics in Petoskey, Michigan. The GMTEX material used was a sandwich of commingled glass-PP fabric (Twintex) with a core of the 50 mm chop material. The fabric skins had four times as many fibers in the cross car direction as the vertical direction.

Three different reinforcements were molded with direct compounded DLFT material as the base material at the Decoma Product & Process Development Center in Concord, Ontario. In the case of the “DLFT - CURV” panel, the over molded reinforcement was CURV™, a fabric woven from oriented polypropylene fibers [8]. The 1.5 mm thick CURV material was preheated in a convection oven at 160℃ until pliable. While having no glass fiber reinforcement, the oriented PP gives this material a unique combination of modulus and ductility. The “DLFT - Twintex” panel was molded with a patch of preheated Twintex plain weave, 44 oz/yd2 (1492 g/m2) commingled 60% glass/PP fabric. Finally, the “DLFT - Hardwire” panel was molded with a patch of unidirectional Hardwire® in the latch region[9]. Hardwire® is twisted steel wires laminated to a plastic mesh. In this case , the wire patch was preformed in the latch area by closing the mold on the patch, opening the mold and laying in the extruded charge to over mold the wire patch.

Several pictures of the “DLFT - Twintex” panel are shown in Figure 14. View A shows the initial state while view B shows the first visible crack appearance, well away from the latch area. There was also some distortion and bending of the latchbox in the fracture location of the previous unreinforced liftgate testing. As the displacement continued to the final value of 270 mm in view D, the unreinforced portion of the panel is broken virtually in half, but the latchbox areas of the structure still supports load due to the reinforcement patch. The “GMT - GMTEX” panel is shown from various angles while at maximum displacement in Figure 15. As before, the reinforcement allows the panel to support load all the way out to maximum stroke on the actuator.

The response of the “DLFT - CURV” inner panel are shown in Figure 16. View A was taken shortly after the lower flange of the panel fractured while views B-D were taken when the actuator was at maximum displacement. Clearly the ductility of the CURV material prevented the cracks in the panel from propagating in the latchbox region, preventing the complete separation of the latchbox that was observed previously in the unreinforced liftgates.

Results for the “DLFT - Hardwire” panel load displacement test are shown in Figure 17. While similar in many ways to the Twintex reinforced panel, the DLFT – Hardwire reinforcement was more effective in stopping propagation of the initial latchbox crack. In Figure 17b, we see a crack, similar in many ways to the start of the unreinforced liftgates brittle failure. However, the crack cannot propagate through the wire reinforcement. This allows the liftgate to continue to support load all the way out to the maximum displacement of 266 mm, even though the unreinforced portion of the panel is cracked completely in half. Close-up views of the latch area with the reinforcement are shown in Figure 18. Clearly, the latchbox begins to fracture brittlely in Figure 18b. But the wire reinforcement prevents the cracks from propagating and causing latchbox separation from the panel.

The load-displacement curves for the composite inner panels are shown in Figure 19. The unreinforced “DLFT” panel shows a typical response for a chopped fiber panel with reasonable initial stiffness but a brittle response with failure at 20-25 mm and minimal load carrying capability after initial fracture. The “DLFT – CURV” panel had both the lowest initial stiffness and the lowest peak force. This is not surprising given that half of the material in the latch box area was replaced with the unfilled CURV material. While CURV is not as stiff as the glass filled polypropylene that it displaced, its ductility allows the material to stop cracks and improve the system ductility. The “DLFT - Twintex”, “DLFT - Hardwire” and “GMT - GMTEX” panels all had very similar initial stiffness. The Hardwire reinforced panel started to crack at a load very similar to the unreinforced systems, but the reinforcement stopped the crack propagation and allowed the panel to reach almost 5kN maximum load. The Twintex and GMTEX reinforced panels had very similar properties with the GMTEX panel having the highest ultimate strength. The response of these reinforced panels was extremely encouraging and might contribute to the ductility response and resulting crash performance of the entire liftgate.

The elastic-plastic system behavior shown in Figure 7 is an idealized response that may not be feasible or required in actual crash situations. Prototype and production composite liftgates need to be tested in rear crash tests to evaluate their performance. While the magnitude of displacements of the latch area appear to be consistent across many vehicle manufacturers and vehicle types, the load requirements are less clear. However, the forces acting on a liftgate during a crash from the inside are very difficult to estimate. While static component tests are very useful from development purposes, the must be supplemented with full vehicle crash tests.

Figure 10. Experimental setup at the GM Body Test Lab for measuring the load-displacement response of a liftgate when the striker is pulled forward (in-car direction).

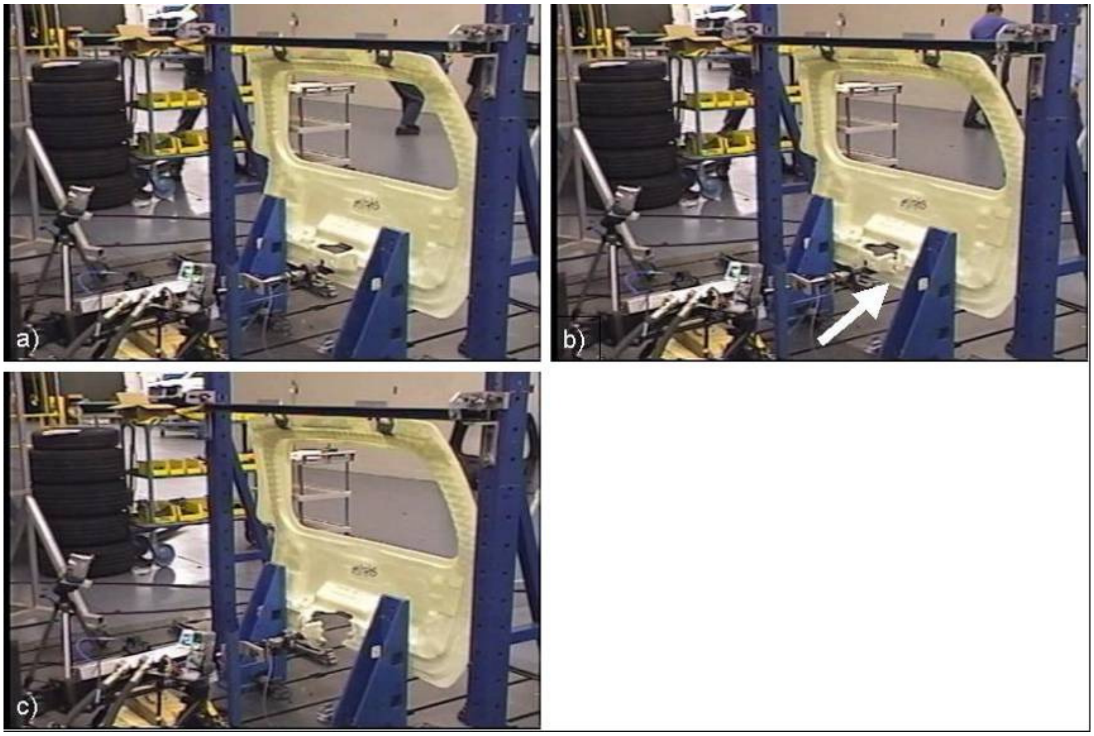

Figure 11. DLFT composite liftgate inner panel load displacement test showing a) initial state, b) first crack appearance, c) latchbox separation on left side.

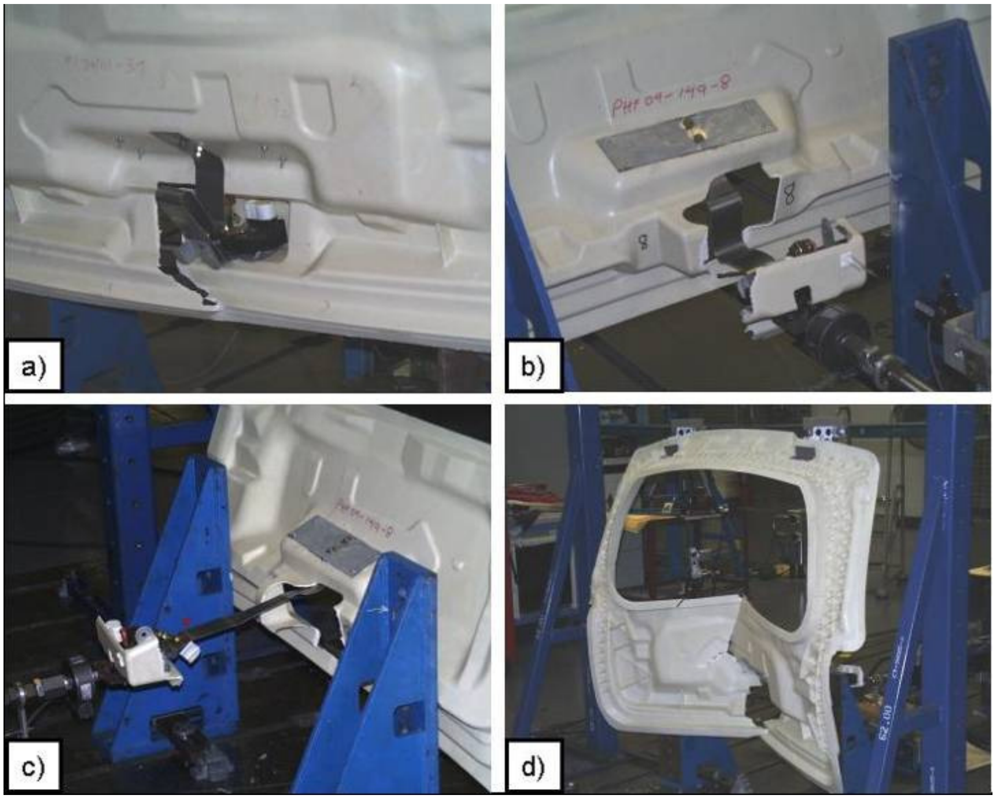

Figure 12. DLFT composite liftgate inner panel with a steel strap reinforcement showing a) latchbox cracking on left side, b) latchbox separation, c) extension of the steel tether and d) buckling of the panel.

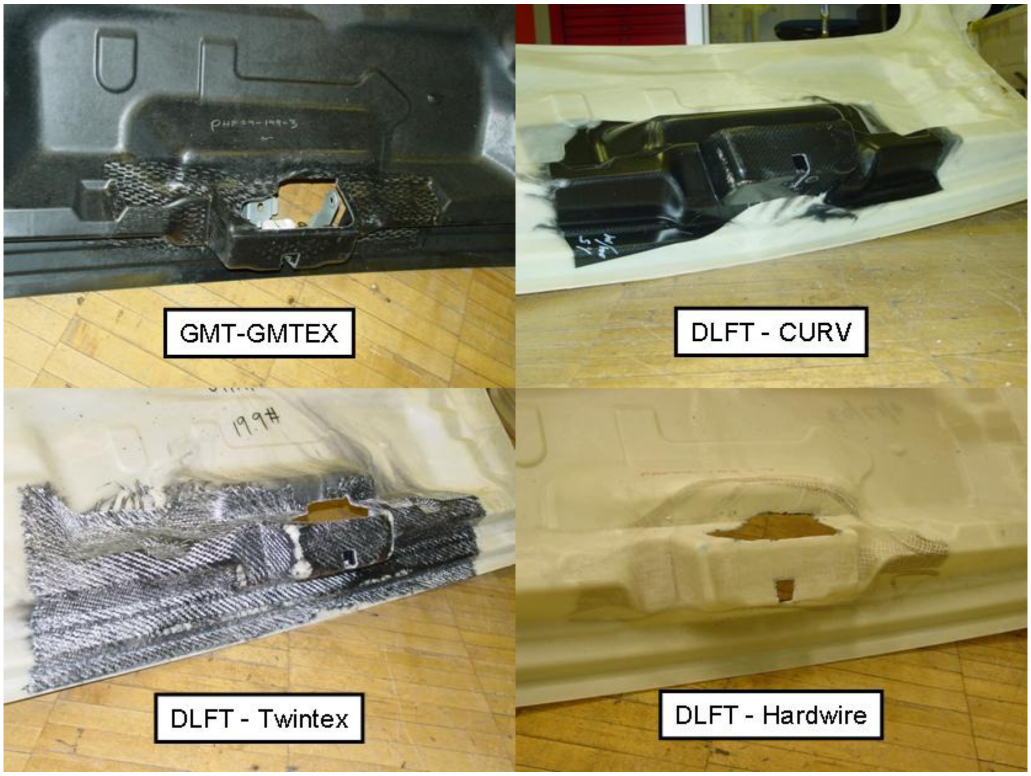

Figure 13. Reinforced polypropylene composite liftgate inner panels before test.

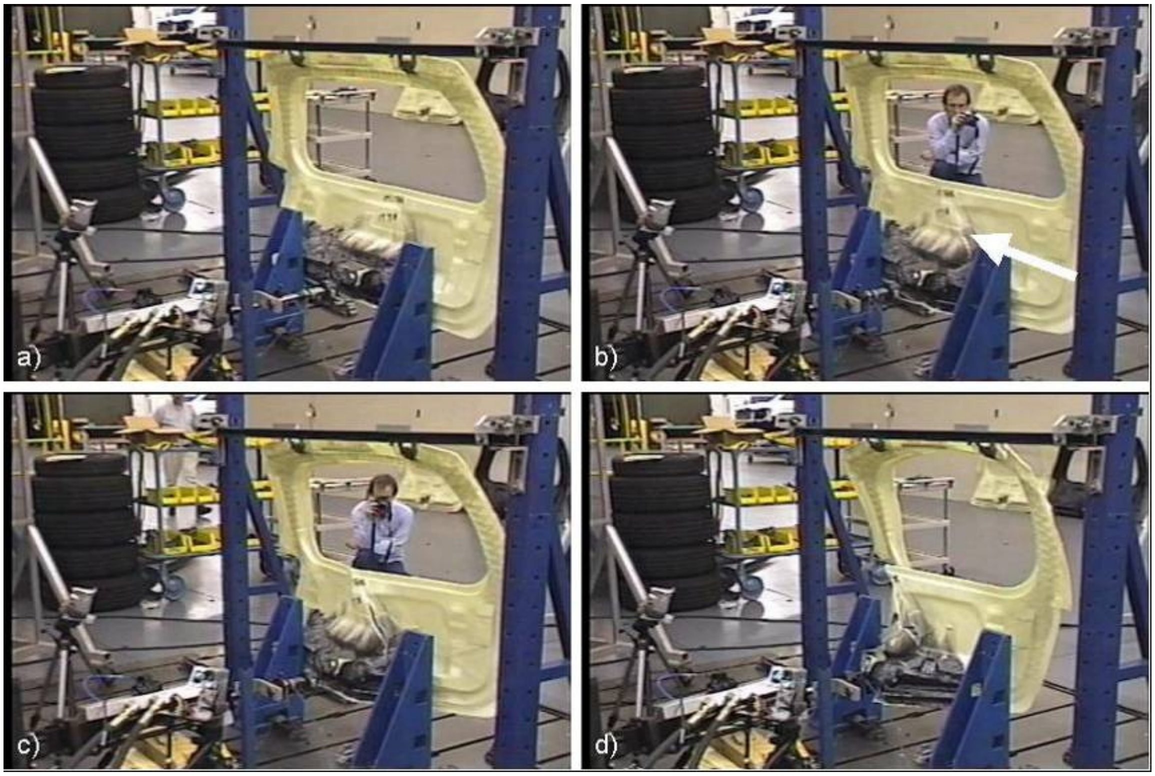

Figure 14. Twintex reinforced DLFT inner panel load displacement test showing a) initial state, b) first crack appearance, c) complete cracking of the unreinforced portion and d) maximum displacement of 270 mm.

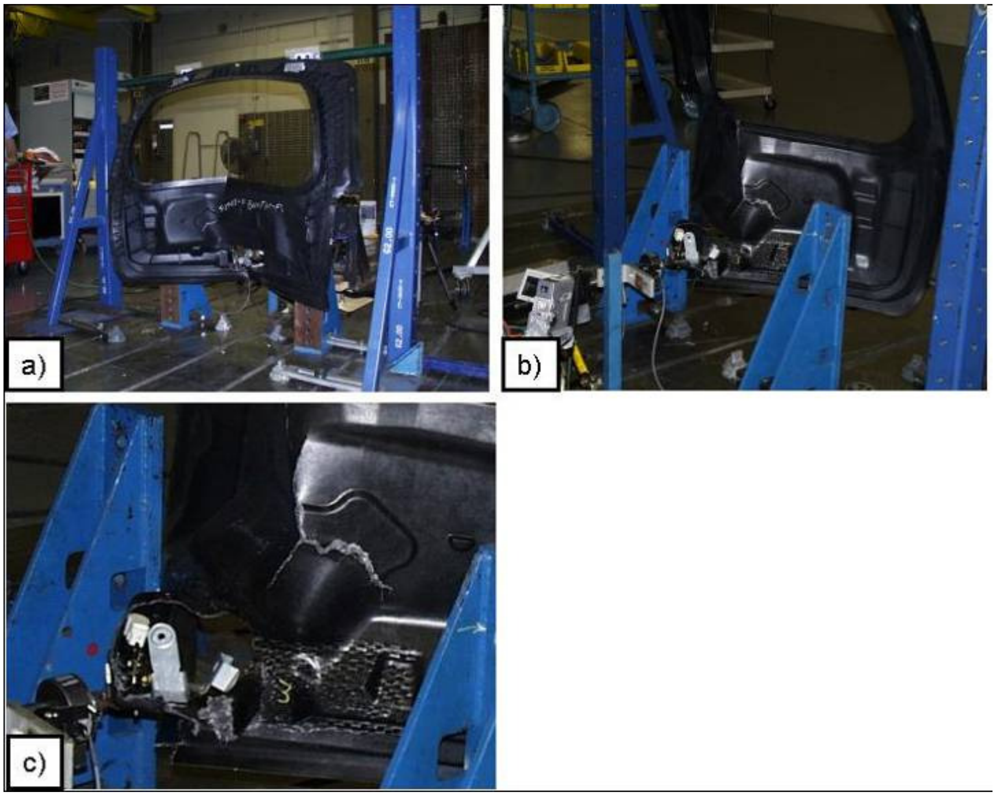

Figure 15. Various views of the GMTEX reinforced GMT inner panel while still under load at maximum displacement of 264 mm.

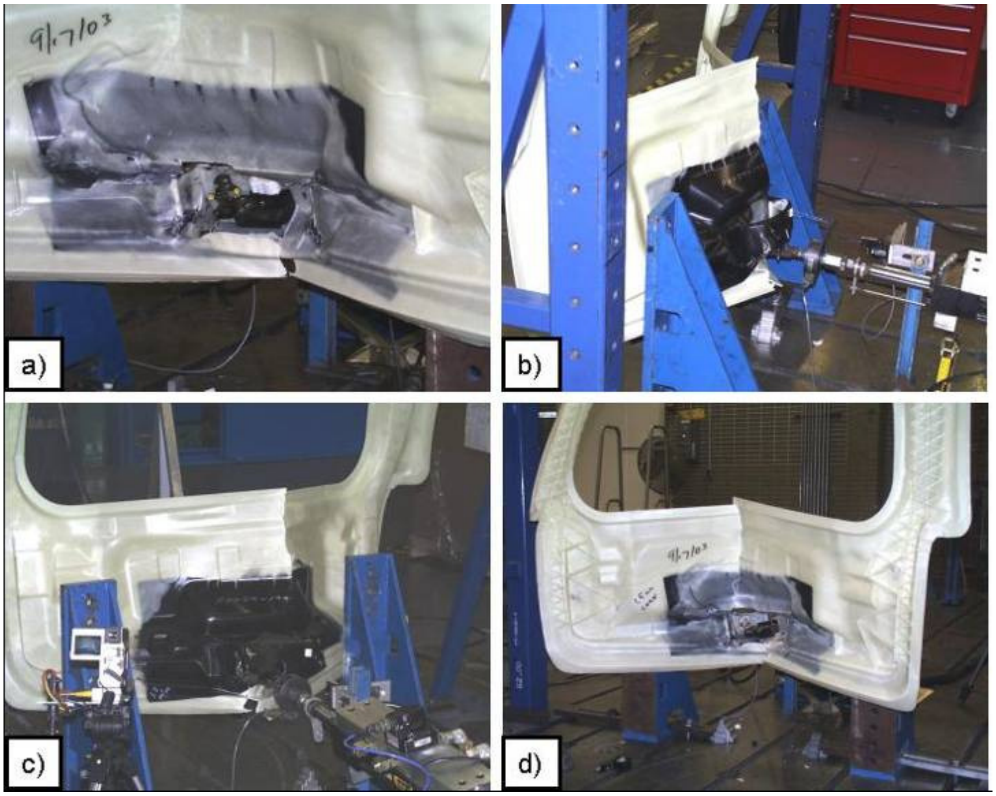

Figure 16. Various views of the CURV reinforced DLFT liftgate inner panel while under load.

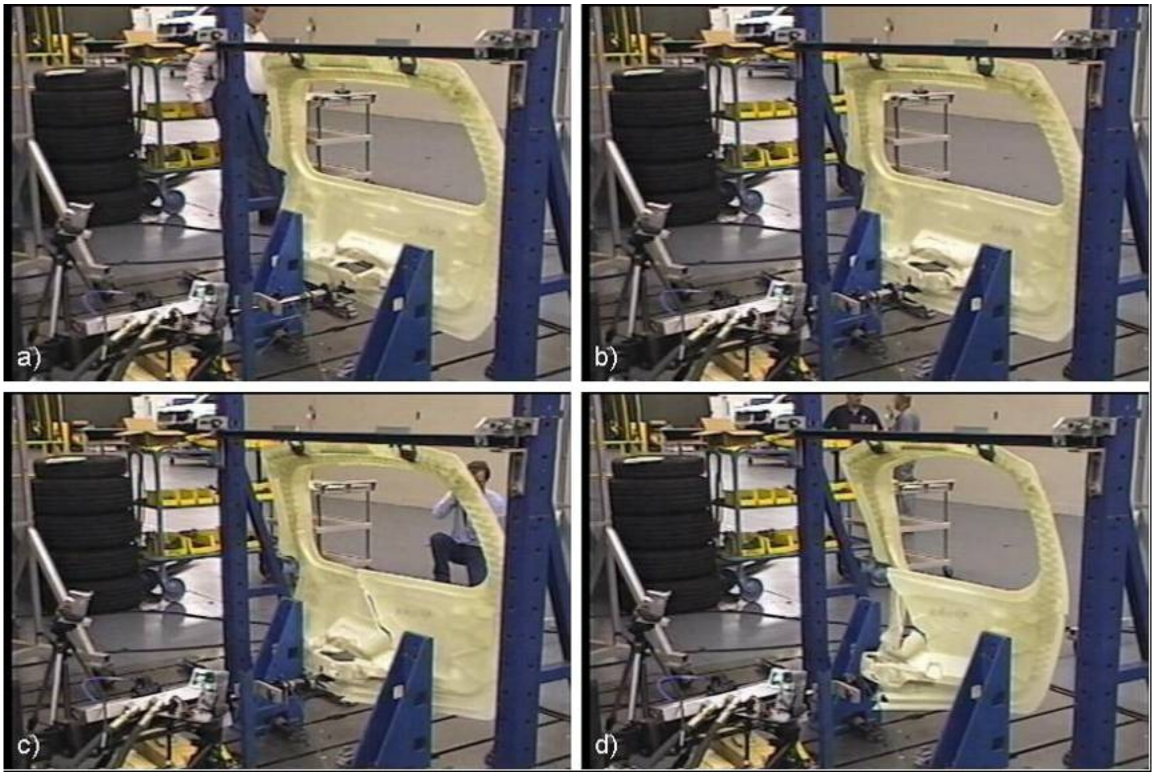

Figure 17. Hardwire reinforced DLFT inner panel load displacement test showing a) initial state, b) first crack appearance, c) complete cracking of the unreinforced portion and d) maximum displacement of 266 mm.

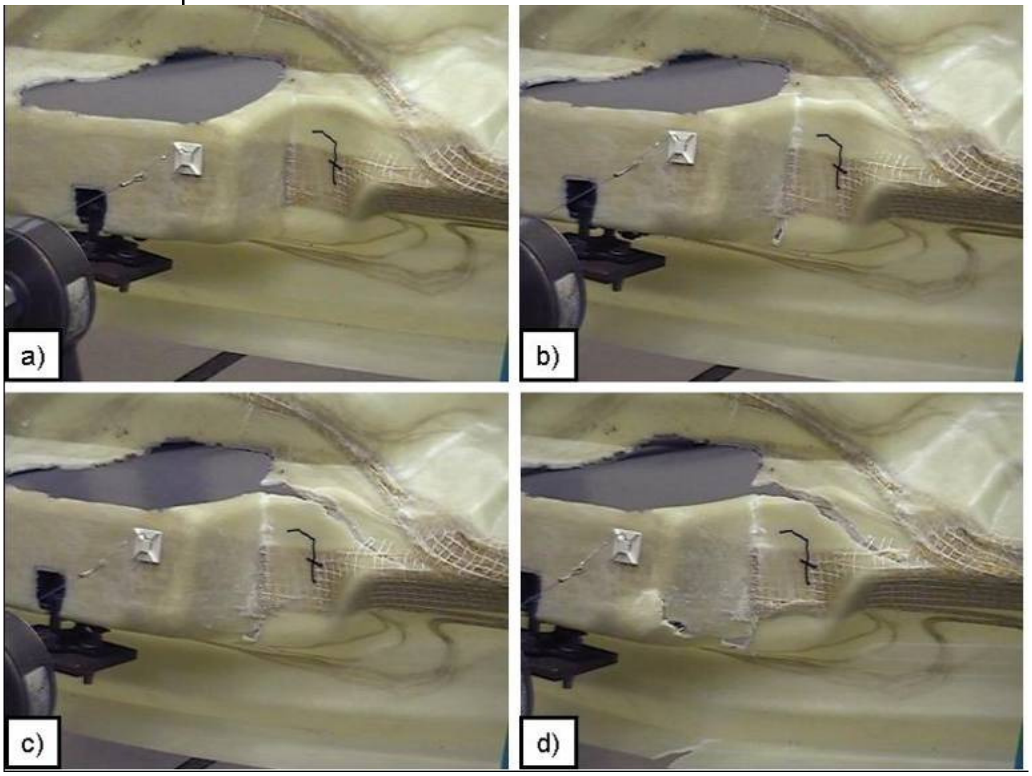

Figure 18. Hardwire reinforced DLFT inner panel load displacement test showing a) initial state, b) first crack appearance, c) major crack blunting and d) continued cracking.

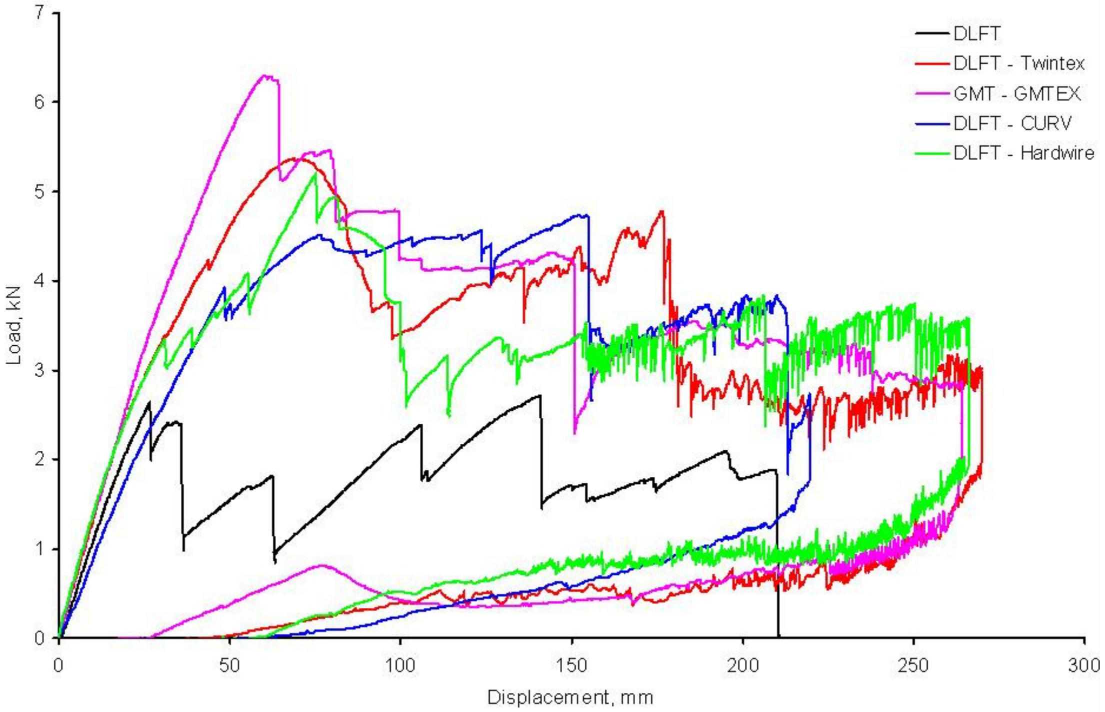

Figure 19. Load displacement curves for the five different inner panels tested.

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