

Structural Evaluation of an Experimental Aluminum/Magnesium Decklid

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ABSTRACT

Experimental decklids for the Cadillac STS sedan were made with Al AA5083 sheet outer panels and Mg AZ31B sheet inner panels using regular-production forming processes and hardware. Joining and coating processes were developed to accommodate the unique properties of Mg. Assembled decklids were evaluated for dimensional accuracy, slam durability, and impact response. The assemblies performed very well in these tests. Explicit and implicit finite element simulations of decklids were conducted, and showed that the Al/Mg decklids have good stiffness and strength characteristics. These results suggest the feasibility of using Mg sheet closure panels from a structural perspective.

INTRODUCTION

Magnesium is the lightest (i.e., lowest density) of the common engineering metals, and therefore its alloys are potentially attractive for structural use in cars and trucks in order to reduce mass. Historically, Mg alloys have been used for this purpose in transportation industries, especially since the late 1930s [1]. In addition to mass reduction, the potential benefits of using Mg alloys include increased part consolidation, improved machinability, and reduced noise and vibration. Numerous parts have been designed or prototyped in Mg for carmakers worldwide [2, 3, 4, 5], and some have gone into high-volume production, including GM's diecast IP beam for vans [6] and Ford's diecast radiator support for pickups [7]. The IP beam has since been replaced with a steel structure, but the radiator support continues to be diecast. Recently, there has been renewed interest in automotive use of Mg alloys for the purposes of mass reduction and part consolidation [8].

Automotive applications of Mg alloys are almost exclusively in the form of die castings. This is in part due to the poor room-temperature formability of rolled Mg alloy sheet [9]. However, with the development of hot gas blow forming processes, such as superplastic forming (SPF) [10] and quick plastic forming (QPF) [11], complex shapes may be formed from wrought sheet or tubing, albeit with longer forming times compared to stamping. These techniques enable forming of experimental panels of various Mg alloy sheets (the most common of which is AZ31B) for the purpose of engineering evaluation, and potentially for regular production.

Our previous work [12] reported on the forming of experimental decklid inner panels for the Cadillac STS (Figure 1) using the QPF process and AZ31B Mg alloy sheet blanks instead of the regular production AA5083 SPF-grade Al sheet blanks. It showed that Mg inners can be formed with some modifications to the existing bill of process. Specifically, the initial gas pressurization rate during forming was decreased, and the overall forming cycle time was increased, in order to avoid panel splitting.

The purpose of the current work is engineering evaluation of the structural behavior of experimental decklids. These are similar to regular production decklids except that they have Mg sheet inner panels rather than Al. Also, some of the coating and joining practices were changed to accommodate the Mg. The stiffness and strength of the decklids were computed numerically, and the dimensional integrity, slam durability, and impact response were determined empirically.



Figure 1. Photograph of a Cadillac STS V-series high-performance luxury sedan.

EXPERIMENTAL

BUILDING ALUMINUM/MAGNESIUM DECKLIDS

Building of experimental decklids having Al sheet outer panels and Mg sheet inner panels differed from the regular production process for building Al/Al decklids because of the different properties of the Mg. Specifically, the poorer corrosion resistance and the lower room-temperature ductility of the Mg required different strategies for corrosion protection and joining.

Both the experimental Mg inner panels and the regular production Al outer panels were formed using GM's QPF hot gas blow forming process [11]. Panels were then acid washed to remove the boron nitride forming lubricant, then die trimmed and pierced. A representative cleaned and trimmed/pierced inner panel is shown in Figure 2. The inner panels were drilled in the reinforcement regions to accommodate break-stem rivets, conversion coated using oxyfluoro compounds of Ti, Zr, and Si, with organic polymers, then ecoated. These coatings were chosen to protect the inner panel from corrosion both during exposure to the acidic phosphate bath in the paint shop, and during exposure to road salt and water in service.

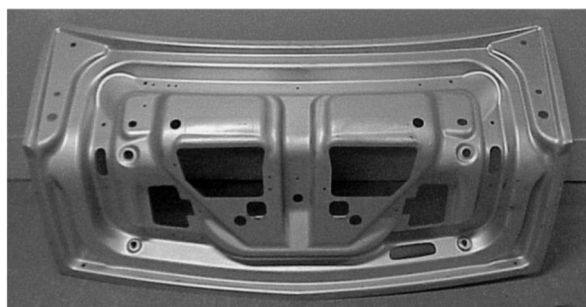


Figure 2. Photograph of an experimental Mg sheet metal inner panel for the Cadillac STS decklid.

Regular production of decklids uses clinching to attach the Al reinforcements shown in Figure 3 to the Al inner panels.

However, because clinching trials with Mg sheet revealed a propensity for cracking of the clinch button, aluminum break-stem rivets and a one-part, high-performance, heat-curing epoxy adhesive were chosen instead to attach the aluminum reinforcements to the coated magnesium inners, as shown in Figure 4. Outer panels were then joined to the inner sub-assemblies using the regular-production process and materials, including die hemming, epoxy-modified acrylic hem adhesive, and anti-flutter mastic. These decklids were then phosphated, ecoated, after-hem sealed, primed, and painted. Regular production hinges and general assembly (GA) parts were installed to prepare for slam durability testing and drop tower impact testing.

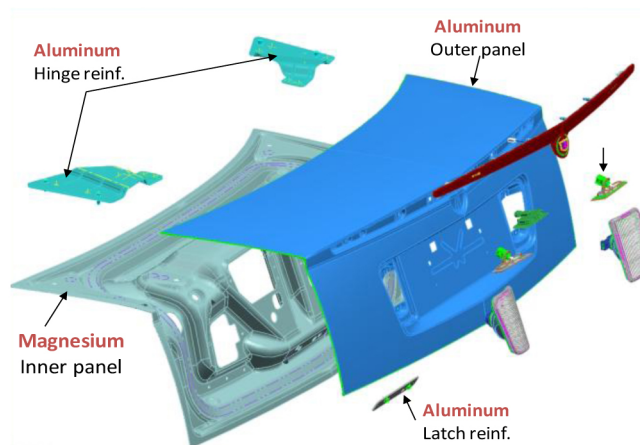


Figure 3. Exploded-view illustration of an experimental decklid.

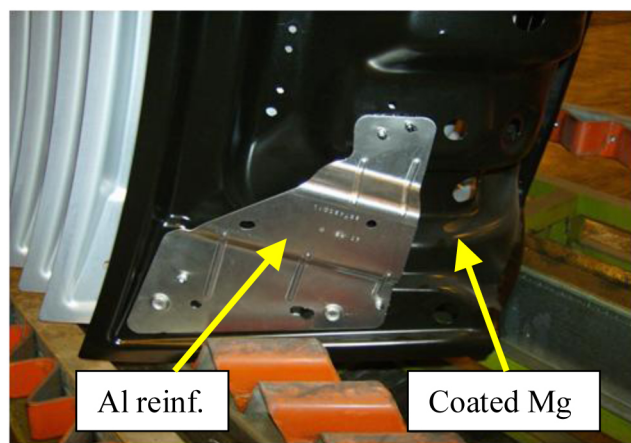


Figure 4. Photograph showing portion of a black ecoated Mg decklid inner panel with a bare Al hinge reinforcement attached. The expanded tails of four Al break-stem rivets used to attach the reinforcement are also visible.

STIFFNESS SIMULATION

Finite element (FE) simulations were conducted to investigate the response of both Al and Mg decklids to different static (implicit FE) and dynamic (explicit FE) load cases. The two materials used for the inner panel were Al AA6061-T4 and Mg AZ31-O. (Properties of the AA6061 alloy were chosen for use in this work because they are close to those of hot-blow-formed AA5083, and were available in the database at the time, whereas those for AA5083 were not.) The aluminum alloy was considered as the baseline material and the performance of the decklid with the Mg inner panel was compared to the performance of its Al counterpart. Mechanical properties of both materials used in the FE simulations are shown in [Table 1](#) and [Figure 5](#).

Table 1. Mechanical Properties of materials used for the decklid inner panel.

	AA6061-T4	Mg AZ31-O
Density (kg/mm ³)	2.71x10 ⁻⁶	1.81x10 ⁻⁶
Young's Modulus (GPa)	70	45
Poisson's Ratio	0.33	0.35
Yield Strength (MPa)	131	164

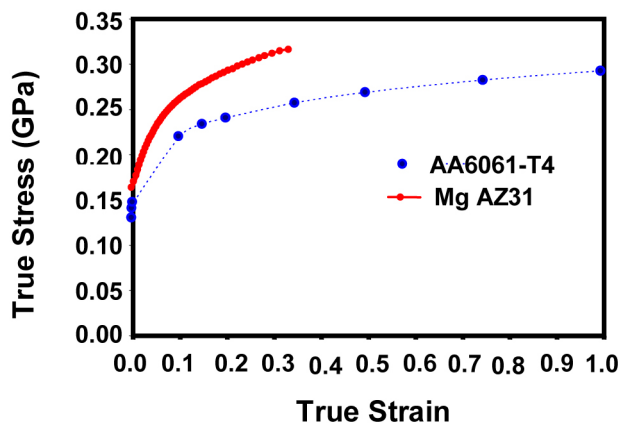


Figure 5. True Stress-True Strain Curves for AA6061-T4 and Mg AZ31.

A FE model of the decklid addressed the decklid in a closed position together with the hinge mechanisms. Five load cases - lateral deflection, torsional stiffness, lost motion stiffness and the sitting strength at the decklid side and center - were defined in the model. In the lateral deflection load case, the load is applied on the decklid inner hem at the edge of the waterfall for the purpose of measuring the maximum cross-car deflection. In the torsional stiffness load case, the load is applied at the lower left corner of the decklid along the vertical direction. In the lost motion stiffness load case, the loads are simultaneously applied at both decklid hinge bolts,

and the vertical deflection is then computed at the load points. In the sitting strength load case, the loads are distributed at selected points within a certain area of the outer panel surface at the decklid side and center to simulate a person sitting on a decklid. For each load case, the deflection at the load application point was measured from the simulation and the corresponding stiffness was computed where appropriate. The stresses in the decklid were examined for the sitting strength load case and compared against the yield strength of the materials used. To calculate the stresses in the decklid or hinges resulting from load applied to the leading edge of an open decklid, a model with the hinges rotated such that the decklid is in its lower open position was used. A decklid model without the hinges was used to calculate the decklid corner stiffness and the beavertail stiffness. In the corner stiffness load case, a distributed load is applied to the front corner of the decklid and the vertical deflection is measured at the center of the load application area. In the beavertail stiffness load case, a distributed load is applied to the center of the decklid outer panel bottom edge and the fore-aft deflection is measured at the inner panel forward of the load application area. In addition to the linear static stiffness analyses, a natural frequency analysis was also performed. This required modeling of the decklid seal, bumpers and hinge set screws in addition to the parts already contained in the stiffness models.

All models with the baseline Al alloy inner panel contained local thinning information, i.e. the local thickness variation caused by the forming process, for both the inner and outer panels. This information was obtained from prior FE simulations of the panel forming process. The inner panel thickness values predicted from the high temperature forming simulation ranged from 0.76 mm to 1.82 mm. There was no local thinning information available for the Mg inner panel; therefore, all static load cases as well as the natural frequency analysis were performed assuming uniform thickness of the inner panel. Several different uniform thickness values of the Mg AZ31 inner panel, including 1.6 mm, were evaluated.

The decklid slam and overtravel dynamic load case was also investigated. For this load case a more detailed model than that used in the static load cases was used. This model contained the decklid, hinges and latch mechanism as well as the rear bumper, shelf, rear closing panel and parts of the rear rails, rear floor and side rings. The overslam simulations of the decklid were performed for two different values of uniform inner panel thickness, i.e. 1.6 mm and 0.8 mm.

DIMENSIONAL ACCURACY

The dimensional integrity of the Mg decklid inner panel was evaluated at different assembly and process stages. At each stage, the Mg panel was measured to understand the manufacturing capability of the Mg sheet material. These stages included a bare Mg decklid inner, an ecoated Mg