

Aluminum Vehicle Body Construction and Enabling Manufacturing Technologies

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ABSTRACT

Aluminum materials are very attractive for lightweight applications. Aluminum usage in automotive vehicles has increased over time as manufacturers search for affordable weight reduction applications and high-performing, low-investment construction methods. Further application of aluminum is likely with the discussion of increased tailpipe emission requirements and increased fuel economy regulations. Currently, the Audi A8, Audi R8, Ferrari F430, Lamborghini Gallardo and Jaguar XJ8 are aluminum intensive vehicles that are in production. In this paper, manufacturing methods in forming and joining technologies for body construction is discussed. Various forming technologies for body in white construction and body closures are discussed as well as joining technologies for body closures and body structures. Application of materials and processes in the current automotive applications as well as economic analysis for spaceframe and unibody body construction is discussed.

INTRODUCTION

The use of aluminum in automotive components has increased significantly for the past few years [1]. The main advantage of aluminum over steel is that its density is three times lower than that of steel. Other advantages of using aluminum materials are that it has inherently good corrosion properties and is highly recyclable.

An aluminum structure has several advantages over steel for automotive applications primarily due to its light weight. High torsional stiffness with reduced mass, which benefits NVH and vehicle dynamics, can be attained with thoughtful design. Aluminum has greater "specific energy absorption" than steel, meaning that equivalent energy management performance can be achieved with less weight than with traditional steel construction [2]. Automotive manufacturers, both current and past, are using aluminum materials for spaceframes and other large-scale structural applications. The Plymouth Prowler, Audi A8, Audi A2, Audi R8, BMW Z8, Ford's - Th!nk Neighbor, Ford GT and Honda's NSX, are

just a few aluminum intensive vehicles that are currently, or were until recently, in production. Although, the unibody steel body represents the most common automotive body structure construction, aluminum can be used in a variety of designs, including unibody body, spaceframe and hybrid body architectures. Hybrid architectures, consisting of a combination of aluminum product forms including stampings, extrusions (straight, bent and hydroformed) and castings, are becoming more common. The Ford GT (Figure 1) represents the first Ford Motor Company hybrid aluminum spaceframe (Figure 2-3). The frame is comprised of castings, extrusions, stampings, and flat and roll-bonded panels. Castings are used at the suspension attachment locations as well as at the interface of the rear bulkhead and central tunnel. Numerous extrusions with varying cross sectional properties, several of which are bent through a variety of forming processes, connect the castings and complete the structure. In this paper, various forming and joining technologies that are being developed for aluminum body structures are discussed.

BODY CONSTRUCTION

Typical vehicle body construction consists of three major types of architectures. They are unibody, spaceframe and body-on-frame architecture. In unibody or monocoque body construction, extensive stampings are used and the most common joining method is resistance spot welding for steel vehicles and mechanical fasteners with adhesive for aluminum intensive vehicles. The current best example of a unibody aluminum intensive vehicle is the Jaguar XJ8 (Figure 4). The second architecture is spaceframe architecture, where numerous extrusions and or bent tubes, castings and stamped parts are joined by a variety of joining techniques. The current aluminum spaceframe intensive vehicles are Ford GT (Figure 2), Audi A2 (Figure 5), Audi R8 (Figure 5), Audi A8, Ferrari Modena, BMW Z8 (Figure 7) and Chevrolet Corvette (Figure 8). The Renault Espace (Figure 9) is an example of a steel spaceframe structure. The third type of body construction is body on frame where a multipiece stamped body is connected to a chassis frame. This

type of architecture can be seen on SUVs (Ford Explorer, GMC Envoy, Dodge Durango), large sedans (Lincoln Town Car) and light and medium duty trucks (Ford F-150, F-250, GMC Silverado, Dodge Ram) which are primarily steel intensive architectures. As of today, there is no body on frame aluminum intensive vehicles.



Figure 1: Ford GT

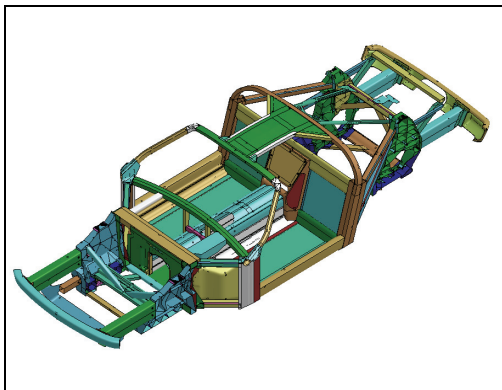


Figure 2: Ford GT Gas Metal Arc Welded Spaceframe

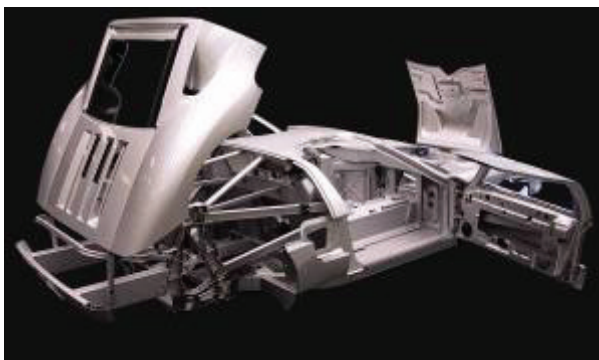


Figure 3: Ford GT Body in White (Spaceframe and Aluminum Stamped panels)



Figure 4: Jaguar XJ8-unibody body architecture



Figure 5: Audi A2 is using many hydroform parts in its aluminum space frame structure (Courtesy of Audi)



Figure 6: Spaceframe Architecture of Audi R-8 [3] (Courtesy of Audi)



Figure 7: BMW Z8 spaceframe (Courtesy of BMW)



Figure 8: Chevrolet Corvette Spaceframe [4] (Courtesy of GM)



Figure 8: Renault Espace (Courtesy of Renault)

ALUMINUM MATERIALS FOR BODY CONSTRUCTION AND CLOSURE PANELS

Aluminum alloys are available in different forms for different applications. Aluminum alloys are selected for their suitability for a specific manufacturing process. These specific aluminum grades are used for extrusions, sheet, and casting applications. For vehicle spaceframe applications, a combination of aluminum extrusions, castings and aluminum sheets are commonly used. Table 1 shows the application of aluminum alloy grade and manufacturing process and body structural application. For structural members, typically 6061 and 6063 aluminum extrusion grades are used. Typical aluminum alloys that are used in structural castings are A356-T6, C446, C448-T6 and Silafont 36-T6. The chemical composition and mechanical properties of aluminum grades for automotive applications are shown in Table 2.

Aluminum Grade	Manufacturing process	Automotive Application
AA 6061, AA6063	Extrusion	bumpers, front and rear crash cans, rockers, hinge pillar, a-pillar, and roof bows
AA 5754	Sheet	For structural reinforcements, door inner, hood inner, liftgate inner, cowl panel, rocker, b-pillar, torque boxes, brackets
AA 6061	Sheet	Door outers, hood outers, roof panel outer, lift gate outer, body side
A356	Sand permanent mold and castings	Shock towers, nodes for joining extrusions, b-pillar reinforcements, hinge pillar, and control arms
C446, C448, Silafont-36	Die castings	Shock towers, b-pillar reinforcements, hinge pillar, brackets, nodes, midgate

Table 1: Aluminum grades and processes for automotive body structural applications

Aluminum Grade	Yield Strength (0.2% Offset) (MPa)	Ultimate Tensile Strength (MPa)	Elongation in 50 mm (%)	Ultimate Shear Strength (MPa)	Modulus of Elasticity (GPa)
AA 6061-T6 [5]	320	360	11	215	69
AA 6063-T6 [6]	215	240	12	150	69
AA 5754-O [5]	115	220	22	160	70
A356-T6 [6]	165	234	3.5	74	27
Silafont-36 [5]	243	293	8.6	NA	NA

Table 2: Mechanical properties of various aluminum grades

MANUFACTURING PROCESSES FOR ALUMINUM BODY STRUCTURE ARCHITECTURES

STAMPINGS

The stamping process is a conventional forming process to form a desired shape by inserting an aluminum blank in a die and press force will form the part in the die. This process is no different than conventional steel stampings. However, a typical challenge in aluminum stamping is the springback issue. Often, springback is compensated for in the stamping dies. Lately, robust CAE tools have been developed to predict the springback compensation during the product development stage. Another issue is die wear in aluminum stamping processes. Dies wear out faster using aluminum sheets than with mild steel due to the abrasive nature of the material due to higher silicon content in the aluminum alloys. Typical aluminum grades for body structural and body closure applications are AA 5754 and AA 6111 respectively. However, in warm and Superplastic forming processes, 5083 grade is widely used.

EXTRUSIONS:

The extrusion process is a relatively inexpensive manufacturing process to produce a uniform cross section and long structural members with a minimal tooling cost. However, the geometries are restricted to two dimensions (2D) only. In order to get a 3D shape into an extruded section, combinations of processes such as stretch bending, rotary draw bending and hydroforming processes are employed. Typical aluminum extrusions that were used in the Ford GT vehicle are shown in Figure 10. Aluminum grades 6060, 6061, 6260 and 6063 are widely used in aluminum spaceframe construction. Several aluminum extrusions that were used in other automotive applications are shown in Figures 11-12.



Figure 10: Ford GT Spaceframe extrusions



Figure 11: Ford GT spaceframe extrusion cross-sections

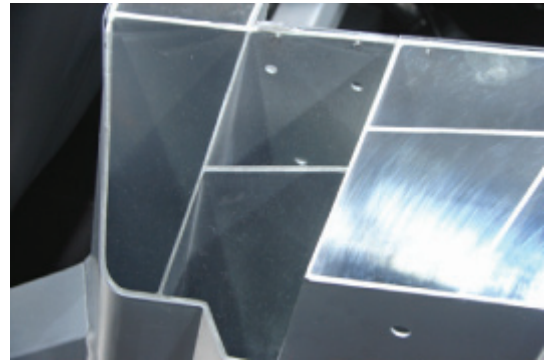


Figure 12: Complex Extrusion in Audi R8 spaceframe architecture (Courtesy of Audi)

CASTINGS

Aluminum castings are generally used in aluminum body construction where the structure needs to meet higher local loading and durability requirements. The casting process enables part integration in the body structure design. Typical aluminum alloys used for casting processes are A356, C446, C448 and Silafont-36 grades. A typical cast surface is not a class A surface and hence, castings are limited to structural applications only. Three types of casting processes are used in the industry. One is sand casting where higher wall thickness is not objectionable and desired. This is a lower investment process. Second one is permanent mold casting process; this is a process between sand and die casting process. Ford GT used permanent mold casting for suspension castings as shown in Figure 13. The die-casting process is very similar to plastic injection molding where a molten aluminum metal is injected into the die at a high pressure and the metal forms to the mold shape. Die-casting process can give wall thickness of as low as 2.0 mm and typical applications of die-casting process are B-pillars (Figure 14), shock towers (Figure 15) and complex bracket reinforcements.