Aluminium and steel hybrid-structured vehicles; the design of the future?

In 2004, BMW introduced the 5 Series with a front structure made from aluminium and a rear structure made from steel. The most interesting characteristic about this vehicle, from a collision repair perspective, is its construction. The front-end structure from the cowl forward is all-aluminium, while the rest of the vehicle structure is steel. The front portion of the lower rails is aluminium; the portion of the lower rails under the floor pan is steel. A rear portion of the upper rails is steel, however the rest of the upper rails are made of aluminium. The floor pan and the lower portion of the A-pillars are steel, both joined to an aluminium cowl panel.

THE first questions that come to mind are why and how. Why make only the front-end structure out of aluminium? How is aluminium and steel joined while avoiding galvanic corrosion?

The "why" can be answered by considering that an aluminium structure can be just as strong as a comparable steel structure with about one-third less weight. The aluminium front assembly allows the new 5 Series to be slightly longer, wider, and taller than previous model years but still weigh about 20 kg (44 lb) less (see Figure 1). With the front structure made of aluminium, there is almost a near equal weight distribution between the front and rear of the vehicle. Also, with the rear half made out of conventional steel, there's better repairability, necessary for a high volume production vehicle.

Figure 1 - The BMW 5 Series front structure is made from aluminium, while the area rearward of the cowl is made of steel.

When bare aluminium joins with bare steel, contact or galvanic corrosion can result. Where aluminium meets steel in the 5 Series main structure, the joints are made using adhesives and rivets, a process known as rivet-bonding. Everywhere aluminium and steel come together, the adhesive protrudes at least one millimeter outside the joints. This helps ensure that direct contact between bare steel and aluminium is completely avoided. The steel panels are also galvanized and the aluminium panels are treated with a titanium/zircon coating designed to both hinder oxidation and enhance the adhesive bonding surface. After construction, the entire vehicle is also subjected to a phosphate bath and E-coat.

Aluminium part construction used for vehicles is either stamped, extruded, or cast, and the 5 Series uses each of these in the front-end structure. The strut tower/apron assemblies are cast construction. The inner part of the lower rails (engine carriers) are extruded construction, while the outer portion is stamped. The upper cowl panel is extruded and hydroformed. The upper rails and cowl panels are stamped. The alloys are 5000 and 6000 series.

Besides the front structure, the driveshaft, suspension system, engine mounting brackets, transmission crossmember, rear subframe, and several exterior panels are also aluminium.

Repair Processes

The aluminium front section, which is available as a complete assembly, is originally assembled with coated steel self-piercing rivets and adhesive. Repairs are made using

Figure 2–The Pyrosil® (flame) kit is used to prep flanges for adhesive application.

Figure 3 - The Audi TT Space Frame is nearly 70% aluminium. (Photo courtesy of Audi of America)

coated steel blind rivets and adhesive. This is because the installation of self-piercing rivets requires a dedicated tool that isn't readily available. Also required is two-sided flange access that is not always available during repairs. The blind rivets can only be ordered from BMW, and there is a specific adhesive.

The recommended process for removing the self-piercing rivets during repairs is a unique process in itself, involving a special stud welding tool and blind rivet gun to pull the rivets out. Where access prohibits this process, the rivets can be drilled out from either side, or ground down on the backside. The stud weld pulling method begins by grinding the rivet heads to bare steel. A special stud welder is then used to weld on stainless steel studs to each rivet head. A special blind rivet gun is used to pull out the rivet. Think of the process of installing a blind rivet, how the gun pulls on the mandrel of the rivet to compress the head before cutting the mandrel off flush with the head. This is how the blind rivet gun is used with the stainless steel stud to pull out the self-piercing rivet. The high pulling force that is required to do this is why most blind rivet guns will not work. The blind rivets are installed in the resulting holes, using the same blind rivet gun. BMW holds the patent on the stud welder and rivet extractor and are only available through BMW dealers.

Preparation of the flanges for adhesive is done with a Pyrosil® (flame) kit (see Figure 2). This is the same process used on the 2004 Jaguar XJ. The flame is applied to the flange. While the flange is still warm, adhesive primer is applied. After allowing the primer to dry, adhesive is applied.

Extruded sections and cast parts, which show any sign of visible or measurable deformation, are replaced, and not straightened. This includes the front lower rails, because the inner part of the lower rails are extrusions.

There is a lower front rail service part available for partial replacement of the rail, forward of the front axle. The procedure for attaching this part to the existing rail is unique. The aluminium lower rail section is cut and fitted to the existing rail, just like any sectioning procedure. But instead of welding the section in place, it is bonded, using two insert-like "repair elements." Screws, installed in the repair elements, are turned to form a tight fit. The screws are removed after the adhesive has cured and the screw holes sealed with a PVC sealing compound.

Different approaches

Vehicle makers have been taking different approaches when using aluminium for structural parts. The 2004 BMW 5 Series is no exception with its unique aluminium/steel construction requiring specific repair procedures and equipment. Now, the all new Audi TT Coupe and Roadster are built using both aluminium and steel. Is the use of multiple construction materials the design of the future? Capitalizing on the unique properties of each material allows vehicle makers to get the best of both worlds.

Audi Space Frame Concept

The all-new 2007 Audi TT Coupe and Audi TT Roadster are both built using the Audi Space Frame (ASF)® concept. Different from traditional ASF vehicles that are made from aluminium, the ASF is made from both aluminium and steel for structural parts. The ASF® on the Audi TT Coupe (see Figure 3) is made of nearly 70% aluminium, with the remaining 30% being steel unitized construction. The use of aluminium over traditional construction materials creates a 48% weight savings and 50% higher torsional rigidity, meaning there is much less flex in the vehicle structure. The total weight of the space frame with the exterior body panels attached is approximately 277 kg (610 lb). The biggest advantage is that steel is used in areas where additional weight is desired. The steel unitized structure provides additional weight to the rear axle, creating more down force to the rear wheels and a more efficient balance between the front wheels and rear wheels. Steel is also used for the door shells and rear hatch.

The aluminium portion of the Audi TT space frame is made up of castings, extrusions, and stampings. Castings make up 22% of the Audi TT Coupe structure, and 18% of the structure of the Audi TT Roadster. Aluminium extrusions make up 16% of the structure on the Coupe and 22% on the Roadster. Steel

Figure 4 - The adhesive provides protection against galvanic corrosion where steel and aluminium are joined.

Figure 5 - The torque boxes on the Audi TT are made from cast aluminium.

and aluminium sheet stampings make up the remaining construction materials of the Audi TT space frame.

Galvanic Corrosion

Galvanic corrosion occurs when two dissimilar metals are in contact with the presence of an electrolyte. An electrolyte is a non-metallic conductor of electricity. Water and salt water are examples of electrolyte that vehicles are typically exposed to. When galvanic corrosion occurs, the more active of two metals transfers electrons to the less active metal. During galvanic corrosion between aluminium and steel, aluminium becomes the anode. The anodic metal is more active and corrodes faster than it would by itself. The anodic metal is sacrificial and corrodes to protect the other metal. The steel becomes the cathode. The cathodic metal is less active and corrodes slower than it would by itself. Steel is cathodic to aluminium. Due to both metals being used on the space frame, there are specific concerns with galvanic corrosion. During the vehicle manufacturing process, all of the connections between aluminium and steel are insulated with a nonconductive structural adhesive (see Figure 4). In addition to the adhesive, there may be another fastening method, including self-piercing rivets, clinches, or rolled hem joints. The cured adhesive also seals the flange, preventing any electrolyte from being introduced to the joint.

During collision repairs to the Audi TT, there are specific recommendations for the type of adhesive that must be used on connections between the steel and aluminium. All of the fasteners that are used have a coating on them to reduce the likelihood of galvanic corrosion.

Another concern is that steel and aluminium have different tensile strengths. When straightening a hybrid structure, the aluminium will straighten at a different rate than the steel structure. Although the Audi repair information stops short of saying do not straighten the structure, as the BMW repair information for the 5 Series does, straightening the structure may cause the adhesively sealed joints to separate. This could potentially lead to galvanic corrosion. Due to the space frame design of the Audi TT, the vehicle torque boxes are constructed of cast aluminium (see Figure 5). There is a concern of adequately anchoring the structure on the aluminium castings and straightening the structure, without causing damage to these parts. In most cases, the damaged parts will typically require removal and replacement.

Vehicle makers have continually strived to come up with methods to reduce the weight of a vehicle, yet maintain crashworthiness and handling characteristics. Although aluminium and steel hybrid-structured vehicles are not real common, vehicle makers have proven that these materials can be used together, provided that the proper corrosion-preventive measures are taken.

Conclusion

It is too soon to tell if the aluminium and steel hybrid structure will reach the mainstream of vehicle construction. When assembled together properly, both Audi and BMW seem confident that the characteristics of each material can be combined to build a solid and durable vehicle.

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