Aluminum Fasteners for Magnesium Components

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Fig. 1—KAMAX aluminum fasteners.

Lightweight designs and materials used for automotive components involve the development of innovative fastener and bolted joint designs. Use of aluminum fasteners with magnesium components is a challenge for the fastener industry and design engineers. This article discusses the technical advantages of aluminum fasteners for the joining of magnesium components, experimental results of corrosion testing and relaxation and tightening behavior.

Intensive lightweight design and the use of modern lightweight metals in the automotive industry are increasing demand for new methods for the development of fasteners and the design of bolted joints. Magnesium is the lightest metal available for the design of die-cast components. It has suitable mechanical and physical properties and is mainly used due to its good castability for thin-walled die casting parts.

Housing components, beams and stiffening components of magnesium are assembled by bolted joints. Traditionally, aluminum and steel components have been joined with high-tensile fasteners of carbon steel without any problems. However, various challenges are experienced with the combination of high-tensile steel fasteners and magnesium components.

The fundamental joint design principle is "joint failure with bolt break failure mode." This basic principle is also valid for joints with magnesium components. So steel fasteners call for higher thread engagement (longer fasteners and thicker components) and larger fastener bearing areas due to significant differences in the strength of steel and magnesium. Thus, cost and weight efficiencies are reduced significantly.

Standard surface finishes used on steel fasteners are not suitable with magnesium components due to galvanic corrosion. The large difference in thermal expansion coefficients between steel and magnesium causes considerable relaxation, leading to significant loss of clamp load when the joint is exposed to thermal cycling. These problems can be eliminated by the use of high-tensile aluminum fasteners (**Figure 1**).

Aluminum Fasteners

In the past, use of aluminum fasteners was limited to the R&D labs of OEMs and manufacturers. The application of aluminum fasteners in a production environment was doubtful. Today, product development engineers within OEMs are working intensively on this topic and the first production application of aluminum fasteners has been implemented in **BMW's** Inline 6 Cylinder Engine (NG6) (**Figure 2**). KAMAX, one of BMW's key development partners in critical fastener applications, has supported this development process and presently supplies aluminum fasteners (M6-M12) for over 15 unique joints on this engine.

A large number of capability studies have proven that the selection of a suitable aluminum alloy, with the proper heat treatment, is of great importance. For joining magnesium components in a corrosive environment and under thermal loading (e.g., engine and transmission components) Al 6056 is currently the best choice. Properly heat treated, this alloy achieves a high tensile strength and good galvanic corrosion properties in contact with magnesium. Therefore, the critical challenges in joining magnesium parts have been overcome. Mechanical properties of these fasteners are very stable for thermal loading up to 150°C (300°F). Short temperature peaks to 180°C (350°F) are also noncritical for joint behavior.

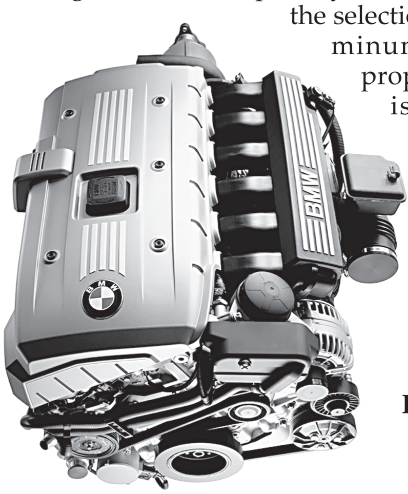

Fig. 2—BMW NG6 engine (courtesy BMW AG).

Contact Corrosion

Due to the difference in electrochemical properties of steel versus magnesium, galvanic corrosion is a big threat for joining magnesium components with steel fasteners in a corrosive environment (**Figure 3**). Typical surface coatings for galvanic isolation are not effective. Electroplated zinc and zinc alloys in combination with isolating sealers show improved corrosion resistance in lab tests. But effectiveness of these coatings is limited to porosity and surface damage caused during handling and assembly.

Fig. 3—Test results of galvanic corrosion; steel (left), aluminum (middle) and plastic (right) bolts on magnesium alloy AZ91 (after 288 hr. salt spray test).

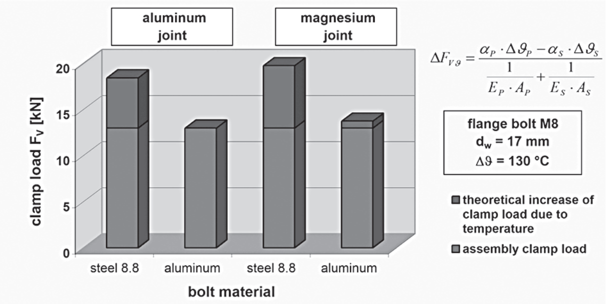

Fig. 4—Additional clamp load due to the thermal load caused by different thermal expansion coefficients (theoretical calculation).

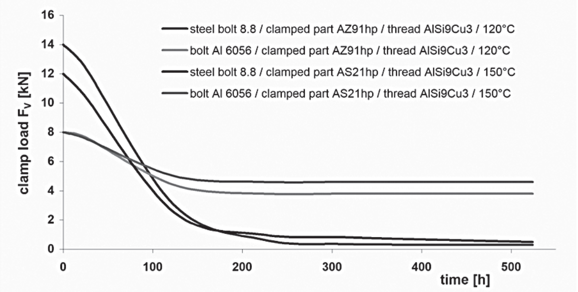

Fig. 5—Comparison of clamp load measured after thermal loading of bolted joint of magnesium parts.

Fasteners made of 6000 series aluminum alloys with copper content under 1% show improved galvanic corrosion resistance, with usual die casting magnesium alloys (AZ91 hp). They need no extra corrosion-resistant coatings and tightening behavior can be controlled by simple lubricants. Corrosion resistance is unchanged over the full service life of the joint.

Relaxation

Thermal cycles can lead to significant loss of clamp load in bolted joints due to relaxation. Loss of clamp is caused by relaxation of the joint due to the creep behavior of the magnesium itself and the huge difference of the thermal expansion coefficient. Typically the thermal expansion coefficient of magnesium is more than twice that of heat-treated steel.

Demands for higher output and compact automotive components packaging have led to higher operating temperatures on engines and components. Operating temperatures on modern powertrain units (e.g., engine and transmission) are in the range of 150°C (300°F). For magnesium components joined by a steel fastener of standard geometry (M8 flange bolt), an additional load of 7 kN (1575 lbf) is calculated for a temperature difference of 130°C (234°F). This corresponds to 50% of the assembly clamp load for this joint. Calculation of increase in tension is purely mathematical (**Figure 4**). Significant effects of relaxation due to creep are already observed during the increase in temperature. Calculated increase in clamp load is therefore not achieved completely in practical tests.

Experiments at KAMAX investigated relaxation of magnesium component joints. Test specimens were machined out of magnesium gear box housings. The results (seen in **Figure 5**) were obtained using a magnesium specimen with an OD of 17 mm (0.7") and clamp length of 14 mm (0.55"), tightened against a threaded aluminum specimen of AlSi9Cu3. The fully engaged thread length was 20 mm (0.8"). Clamp load was measured right after assembly and after 24 hours at room temperature. Residual clamp load was recorded at different time intervals of thermal loading using a special measurement of bolt length.

Higher residual clamp loads have been measured for joints with aluminum fasteners after 100 hours at elevated temps. After 200 hours, clamp load change was negligible for aluminum. With steel, loss after 200 hours was 90% and still declining after 500 hours.

Joining Magnesium Components With Aluminum Fasteners

An aluminum fastener with optimized geometry and large bearing area to accommodate the compressive yield strength of magnesium components can significantly reduce clamp load losses due to relaxation.

Aluminum fasteners are far more desirable on a dynamically loaded magnesium component joint versus a similar steel fastener, due to the difference in stiffness ratio of the joint. Minimum full thread engagement needed for aluminum fasteners is much less (1.2 to 1.5 D) than that of steel fasteners (2.5 to 3.0 D).

Lubrication is needed for proper tightening. KAMAX found synthetic wax OKS 1700 to be a good lubricant for aluminum fasteners in single and multiple tightening against magnesium and aluminum components. Coefficient of friction is constant at high temps.

It is recommended to yield the fastener with a "torque + angle" tightening strategy. Experiments have shown assembly clamp loads almost constant for up to ten tightening processes. Plastic deformability of the aluminum fastener is sufficient for multiple tightening.

Summary & Outlook

Major technical improvements can be achieved by using aluminum fasteners with magnesium components for lightweight design, particularly in temperature-loaded applications and in corrosive environments. A joint design effort, fro inception to final assembly, between design engineers and aluminum fastener manufacturers is recommended to achieve an optimized solution for bolted joints.

Use of aluminum fasteners for magnesium parts in the automotive industry is driven by a need to reduce vehicle mass. With successful production applications, demand for aluminum fasteners, especially for Powertrain applications, should increase significantly.

For more info, contact the authors.

Company Profile...

KAMAX is a leading fastener supplier to the global automotive industry. Founded in 1935 in Germany, KAMAX currently has eight manufacturing sites in Europe and North America with over 2400 highly skilled employees. KAMAX maintains its leadership through focus on customer satisfaction, technological excellence, quality control, cost control and rapid response.

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